AIR TECHNICAL INT
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(Title Unclassified)
REFERENCE BOOK OF A MECHANICAL ENGINEER
IN 6 VOLUMES
(Spravochnik Mashinostroitelya, V Shesti Tomakh)

by

E. A. Satel'

Moscow, Vol. 5, 1956

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chapter I
(Technology of Casting)

DEPARTMENT OF THE AIR FORCE

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CHAPTER I

TECHNOLOGY OF CASTING

Mold Materials.

Mold materials are used for making temporary molds in the foundry industry.

Mold materials are characterized by their thermophysical properties (thermal conductivity, specific heat) and by their plasticity, strength, pliability, permeability to gas, and thermochemical stability.

We distinguish raw molding materials, mold and core mixes, and auxiliary mold materials.

Raw Molding Materials.

In most cases natural mixtures of sand and clay are used as the raw materials for molds. Natural materials containing up to 50% of clay are classified as molding sands, and those containing more than 50% of clay as molding loams. Sometimes special mold materials are also used.

Mold sands are characterized by their content of clay, the size and uniformity of the granules composing them, their chemical composition, permeability to gas, and their strength.

Sands are divided into the following classes (by GOST 2138-51) according to their clay content:

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Sands	Clay content in % by weight
Quartz (K)	up to 2
Lean (T)	2-10
Semi-fat (P)	10-20
Fat (Zh)	20-30
Soapy (OZh)	30-50

Clay (the clay component) is defined as particles up to 0.022 mm in diameter.

Quartz sands are divided into groups by grain size. Grain size is determined by screening a sample of sand washed free of clay through 11 standard screens (No. 6, 12, 20, 30, 40, 50, 70, 100, 150, 200, 270). The grains passing all the screens go into the pan (fraction No. 270). The largest sieve (No. 6) has square openings 3.36 mm on a side, while the finest (No. 270) has openings 0.055 mm on a side. Not less than 70% by weight of all the grains of sand must remain on three adjoining screens, and the number of the extremes of these three screens serves to denote the sand group. For example, the grains of K 50/100 sand are concentrated mainly on screens No. 50, 70, and 100.

Quartz sands are divided into four grades by chemical composition. The first grade contains not less than 97% SiO_2 and not more than 0.5% (K_2O + Na_2O), 1% (C_2O + MgO), 0.75% Fe_2O_3.

Sulfide sulfur is not allowed. The second grade contains not less than 96% SiO_2 and not more than 1.5% (K_2O + Na_2O + CaO + MgO), 1.5% Fe_2O_3, 0.025% S (as sulfide). The third grade contains not less than 94% SiO_2 and not more than 2% (K_2O + Na_2O + CaO + MgO), 1.5% Fe_2O_3, 0.025% S (as sulfide). The fourth grade contains not less than 90% SiO_2, and the remaining impurities are not mentioned in the standard. Every quartz mold sand meeting the requirements of GOST 2138-51 is designated by the letter K, the number of the grade and the symbol of the group, for example 1K 50/100; 4K-100/140. ~~For each mark of sand a lower limit of gas permeability is prescribed. For the finest sands (K-270/140) it is 25 units, for the coarse sands (K-20/40), it~~

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is 800 units.

The strength of quartz sands is not specified by standard. The minerological composition is not specified; checking it is optional; undesirable impurities are feldspar and mica.

Quartz sands are used in core mixtures for casting all alloys, and are used in mold mixtures primarily for making steel and large iron castings. The coarse sands are used for large castings, the fine sands for small castings. 1K sands can be recommended for steel casting, 2K and 3K for large and small iron castings respectively, and 4K for casting nonferrous alloys.

Lean sands like quartz sand are divided into groups according to grain structure. Their chemical composition and strength is not prescribed by standard and they are not divided into grades. The lower limit of gas permeability varies according to their coarseness from 15 units for T 270/200 to 450 units for T 30/50. In cases where excess clay content has no ill effects on the properties of the mold or core mixtures, they are used instead of quartz sands.

Semi-fat, fat, and soapy sands are characterized by their grain structure and strength. Their chemical composition and gas permeability are not prescribed by standard. They are not divided into grades. The lowest value for the compressive strength under optimum moisture conditions and standard compression varies for semi-fat sands from 0.2 kg/cm^2 (P 30/50) to 0.4 kg/cm^2 (P 200/270; for fat sands from 0.45 kg/cm^2 (for Zh 40/70) to 0.4 kg/cm^2 (for Zh 200/-270); for soapy sands from 0.6 kg/cm^2 (for OZh 50/100) to 0.75 kg/cm^2 for (OZh 200/-270).

Semi-fat sands are used in the composition of mold mixtures and sometimes of core mixtures for iron and nonferrous casting to give these mixtures the necessary strength. Fat and soapy sands are used for the same purposes in making large iron castings. In steel foundries, fat and soapy sands are seldom used, since the clay they contain usually has inadequate thermochemical stability.

Molding loams contain not less than 50% of clayey substances (particles not

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more than 0.022 mm in diameter).

According to GOST 3226-49, loams are divided into molding bentonite loams (B) and ordinary molding loams (F).

Bentonite loams include loams consisting mainly of crystals of montmorillonite ($Al_2O_3 \cdot 4SiO_2 \cdot H_2O + nH_2O$). Montmorillonite not only holds water on the crystal surface but is distinguished by the capacity to absorb water inside the crystalline lattice. This is responsible for the considerable swelling of bentonite loams in water, and for their high binding action. 1% of bentonite replaces up to 3% of ordinary loam in the composition of a moist mold mixture. It is advisable to use bentonite for making molds for green sand casting.

For making dry molds(with mixtures in which other binding additives are not simultaneously introduced), bentonite is unsuitable.

Bentonites of marks B-I and B-II are distinguished, for which the colloidal content is respectively not less than 95% for B-I and not less than 90% for B-II. The compressive strength of sand bentonite specimens is not less than 0.3 kg/cm^2 for B-I and 0.2-0.3 kg/cm^2 for B-II. Ordinary molding loams (F) consists mainly of crystals of kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) or of related minerals, which do not exhibit intracrystalline wetting. These loams swell in water owing to surface hydration, but to a lesser extent than bentonite loams.

Ordinary mold loams are classified according to their degree of leanness, according to their binding power, and according to their thermochemical stability.

According to degree of leanness, we distinguish fat loams (FZh) with a leanness factor $K = SiO_2/Al_2O_3 < 2.65$, and lean loams (FO) with $K = SiO_2/Al_2O_3 > 2.65$ (where SiO_2 and Al_2O_3 are expressed in percent by weight, by chemical analysis). FZh loams are used in making molds for casting in the moist state, and FO clays are used for molds to be cast after drying. The unsuitability of fat loams for dry molds is due to their great shrinkage and the danger of forming cracks on the surface of the molds during heating in the drier, and especially during the subsequent

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cooling.

Ordinary molding loams are divided according to their binding power into the groups given in Table 1.

Table 1

Classification of Ordinary Mold Loams According to Binding Power.

		Compressive Strength of Sand-Loam Specimens in kg/cm^2	
Symbol	Name of Loam	In Moist State*	In Dry State, Not Less Than**
M	Low binding	0.15-0.3	1.0
S	Medium binding	0.3-0.5	1.0
P	Strong binding	0.3-0.5	2.0
V	High strength	> 0.5	2.0

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* According to GOST 3594-47, specimens tested in the moist condition are prepared from a mixture containing 90 parts by weight of K 50/100 sand, 10 parts by weight of the test loam, and 3 parts by weight of water.

** Specimens to be dried are prepared from a mixture of K 50/100 sand, 95 parts by weight, test loam 5 parts by weight, water 6 parts by weight. Drying at 180-200°C for 1½ hrs.

Ordinary mold loams are divided into three sorts according to thermochemical stability (Table 2).

Table 2

Classification of Ordinary Mold Loams by Thermochemical Stability.

			Content of harmful impurities in % not more than		
Grade	Thermochemical stability	Fire resistance in °C not less than	Sulfide sulfur	CaO + MgO	K_2O + Na_2O
1	High	1580	0.2	2	3
2	Medium	1350	0.3	3	Not Limited to this
3	Low	Not Limited			

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Loams of the first sort are used in pouring steel castings, of the second sort in pouring iron castings, while loams of the third sort are suitable for casting alloys of copper, aluminum, and magnesium.

Mold loam is marked by the letters F, Zh or O indicating the degree of leanness, the number of the grade, and a letter characterizing the binding power of the loam, for example FO1C, FZh2B.

The strength of sand-loam mixtures increases irregularly on heating. A sharp increase in strength is observed on removal of the hygroscopic and hydrate water (evaporation). A further increase in strength takes place when the loam gives up its water of crystallization (bentonite loams at 120-200°C, ordinary loams at 350-600°C). The following period of increase in strength is in the temperature range of decomposition of the argillaceous substances (750-850°C).

On cooling, the strength of dried molds and cores decreases. The reduction in strength is slight if only the hydroscopic and hydration water was removed in drying, but it is great if the water of crystallization was also removed from the loam in drying. In this case the reduction in the strength of the surface layers of the molds or cores is greatest, and they crumble strongly. The reduction in strength is sharper, the less lean the loam, and the more intense the cooling of the molds and cores after drying. For this reason the drying must be conducted at temperatures that do not cause the elimination of the water of crystallization, and the dried molds and cores must not be cooled too rapidly. It is advisable to knock out the dry molds and cores only after cooling.

The loam may be added to the mold or core mixtures in the dry ground state or in the form of a water suspension prepared in advance. In the latter case the best hydration of the loam is reached, but in using green mold materials, the additional water contained in the suspension may make the mixtures too moist.

Special Mold Materials.

In order to obtain castings with a fine-grained metal structure and good me-

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chanical properties, mold materials with elevated thermal conductivity are used in foundry practice. The use of such materials likewise allows considerable reduction in scale and improves the surface of the casting. In making castings of chrome and chrome-nickel steel, as well as large castings of carbon steel, ground chromomagnesite or chrome iron ore (residue on screens No. 200, 270 and in bottom pan amounting to 30-40% by weight of whole sample) is used instead of ordinary molding sands. Moist chromomagnesite, if stored for a long time out of doors, must be heated before use to at least 700°C.

Chrome iron ore must contain not less than 32% of Cr_2O_3 and not more than 1% of CaO. Before use it must be ground, and if there is a marked amount of carbonate ("boiling" under HCl test) it must be roasted at 700°C.

For a more detailed discussion of these materials, see Volume 6, Chapter VIII.

Binding Materials (binders) are introduced into the composition of dry-core mixtures, and less often, of mold mixtures, to give them high strength. Organic and inorganic binders are distinguished. The organic binding materials are distinguished by their power to burn and decompose at high temperatures, and in this connection to give the cores high pliability.

Binders are added to mold (facing) mixtures mainly to obtain a firm, noncrumbling surface layer of the mold. In the USSR methods have been developed, allowing us, when such a layer is employed, to use green molds with a bound (dried) surface instead of dry molds. Shell molds are also used, consisting only of a strong thin layer duplicating the outlines of the pattern. Binders are added to the composition of core mixtures, taking into consideration the peculiarities of the cores for which these mixtures are intended.

Classification of Cores (Bibl.20).

Class I - Cores of intricate configuration with very thin cross sections, strongly washed by the metal, having only few narrow core prints, forming in castings important difficultly accessible and unmachined inner cavities.

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Class II - Cores of intricate configuration which have a compact or even massive part but also have thin fins, bosses or joints, having more extensive core prints than cores of Class I, and forming unmachined inner cavities of vital importance in the castings.

Class III - Center cores of medium complexity not having particularly thin parts, forming unmachined cavities in the castings, whose surfaces must be very clean. The cores rest on massive core prints.

Class IV - Cores that are not of complex configuration, which form machined inner cavities in the castings: cores forming unmachined cavities, where no special requirements are made for the quality of the surface of such cavity, and also outside-dimension cores of medium and low complexity.

Class V - Massive cores forming large inner cavities in a heavy casting.

Classification of Binding Materials (Bibl.20).

The classification of binding materials is based on two main criteria (cf. Table 3):

a) the nature of the material (organic or inorganic, nonaqueous binding materials).

b) character of hardening (irreversible, intermediate, reversible).

The non-aqueous materials include materials insoluble in water, and not wetted by it (for instance oils); and aqueous materials which are soluble in water or wetted by water (for example, sulfite-alcohol vinasse). The irreversibly hardening materials include those which as a result of a single heating during core drying, undergo irreversible chemical changes leading to the formation of a strong film.

The reversibly hardening materials include substances which under repeated heated and cooling still maintain their principal initial properties. Rosin, for example, melts in the core drier, coating the sand grains, and again hardens on cooling. It is well known that cores made with rosin are plastic at 160-200°C and acquire strength only after solidifying.

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The materials of intermediate character of hardening include those of complex composition, containing both reversibly and irreversibly hardening materials.

The characteristic of the binding action of various binders is their specific strength, i.e., the magnitude of the total strength imparted by a binding material to a dry specimen of the mixture, divided by the percentage of this binding agent used in the mixture.

In calculating the specific strength only the quantity of the binding material itself, without the solvent, is taken into account. This calculation uses the following formula

$$R_{spec} = \frac{R_t \times 100}{p(100 - v)}$$

where R_{spec} = specific strength in $\frac{kG/cm^2}{1\%}$; R_t = tensile strength of dry specimens, in kg/cm^2; p = percent of binding material used in mixture; v = content of solvent in binding material, in % by weight.

The evaluation of binding materials by their nature and by the specific strength allows their classification by the scheme given in Table 3.

Binding materials in one and the same group have related properties, and therefore impart closely related technological properties to the core mixtures (Table 4).

Binding materials in one and the same group can replace each other.

Field of Application of Binding Materials and Their Composition and Properties.

Group A-1 - The binding materials of this group are used in making Class I and II cores.

Vegetablesoils used in the food industry should not be consumed in core making.

The binding materials in group A-1 have the following composition and properties.

Binder P - oxidized Baku petrolatum, dissolved in white spirit.

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Addition of 10-12% of polyvinyl lacquer (TU MKhP 1267-44) to binder P allows the core drying temperature to be lowered and increases the dry strength.

Table 3

Classification of Binding Materials

Group of materials and specific strength	Class A		Class B		Class C	
	Organic nonaqueous materials		Organic aqueous materials		Inorganic aqueous materials	
	Character of hardening	Name of binding material	Character of hardening	Name of binding material	Character of hardening	Name of binding material
of first group $R_{spec} > 5 \frac{\text{kG/cm}^2}{1\%}$	Irreversible	A-1 linseed oil, boiled oil, P; powdered bakelite 4 GU(v)	Irreversible	B-1, MF-17; M; MSB		V-1, water glass
of second group $R_{spec} = 3 + 5 \frac{\text{kG/cm}^2}{1\%}$	Intermediate	A-2, 4GU (p), GTF, ZIS, SLK, BK	Intermediate	B-2, SP, SB, KV, Dextrin, Pectin mucilage	Irreversible	V-2
of third group $R_{spec} < 3 \frac{\text{kG/cm}^2}{1\%}$	Reversible	A-3, wood pitch, KT, Rosin	Reversible	B-3, Molasses, sulfite-alcohol vinasse	Reversible	V-3, Cement, Molding loam

The properties of binder P are also improved by adding 20% of tall oil. In this case the binder is called PT (petrolatum-tall oil).

Its properties (according to GOST 5506-54) are as follows: appearance and color; uniform oily liquid of light brown to dark brown color; viscosity at 50°C,

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conventional (Engler) 2.7-4.0°; specific gravity γ_4^{20} = 0.820-0.880; saponification value ≥ 57; tensile strength of dry specimens not less than 8 kg/cm^2.

Table 4

Basic Technological Properties of Core Mixtures

	Class			Class			Class		
Technological indices	A	B	C	A	B	C	A	B	C
	1st group			2nd group			3rd group		
	$R_{spec} > 5 \frac{kG/cm^2}{1\%}$			$R_{spec} = 3 + 5 \frac{kG/cm^2}{1\%}$			$R_{spec} < 3 \frac{kG/cm^2}{1\%}$		
Strength of green mixtures	l	l	h	l	h*	-	mod*	h*	h*
Fluidity of mixture	ex	ex	mod	mod	g	-	mod	mod	l
Pliability	w	ex	ex	sl	c	-	w	c	**
Strength of dry cores	h	h	h	av	av	-	mod	mod	mod
Same after adding loam to mixture	mod	mod	mod	mod	in	-	dim	mod	-
Hygroscopicity of cores	sl	sl	mod	sl	c	-	sl	c	***
Core drying temperature	h	av	h	h	l	-	h****	l	l

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* Under condition of simultaneous introduction of loam into mixture.

** In cement mixtures, excellent; in loam mixtures, weak.

*** In sand-loam mixtures, considerable. In sand-cement mixtures, the moisture, owing to the formation of hydrated compounds, helps to strengthen the mixture.

**** Rosin, as a reversibly hardening material, requires a low drying temperature.

Notation: l low; ex excellent; w weak; h high; dim diminishes; sl slight; g good; av average; mod moderate; c considerable; in increases.

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Composition of Technological Sample

1K 50/100 quartz sand	100	parts by weight
Binder P	2	parts by weight
Water	2.5-3.0	parts by weight

The specimens are dried for 1 hr 30 min, at 220-240°C.

Bakelite powder is a ground mixture of phenolformaldehyde resin with urotropine. Its properties (according to GOST 3552-47) are as follows: tensile strength not less than 130 kg/cm^2; in screening, not more than 2% remains on sieve with mesh side 0.095 mm (mark A); not more than 2% on seive with mesh side 0.63 mm (mark B); on storage in hermetically sealed container, must not lose free flowing quality or form lumps within one month from day of shipment from suppliers factory. The method of making control specimens and testing them differs from that usually employed in the foundry industry and are described in detail in the above mentioned GOST.

Powdered bakelite is used in making shell molds. For this purpose, 6 to 8 parts by weight of powdered bakelite is added to every 100 parts by weight of fine dry quartz sand. (See below for further details on shell molds).

Group A-2 - The binding materials of this group are used in making Class II and III cores. In isolated cases they are also suitable for Class I cores.

GTP binder is the heavy fraction of generator shale tar which is a byproduct of thermal refining of Estonian shales. This binder must satisfy the following specifications (by GOST 5339-50): appearance and color, uniform oily liquid dark brown to black in color, specific gravity 1.10-1.03; (Engler) viscosity at 50°C, 10 to 20°; content of mechanical impurities not over 2.5%; sulfur not over 1.5%; water not over 3.5%; reaction of aqueous extract, neutral; tensile strength of dry specimens not less than 5.6 kg/cm^2.

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Composition of Technological Sample

K 50/100 sand	96.1	parts by weight
GTF binder	1.95	parts by weight
Water	1.95	parts by weight

The specimens are dried for 1 hr 30 min, at 180-200°C.

ZIS Binder. ZIS-2 and ZIS-3 binders have found practical use. They consist of a mixture of Estonian shale tar (GTF) and petroleum bitumen, both dissolved in white spirit.

The following is the percentage composition of these binders:

ZIS-2	
Petroleum bitumen No.4	40
GTF binder	25
White spirit	35
ZIS-3	
Petroleum bitumen No.4	25
GTF binder	55
White spirit	20

Properties: appearance, black liquid; specific gravity 0.950-0.965; content of solvent 19-24%; tensile strength of dry specimens > 15 kg/cm^2.

Composition of Technological Sample in %

K 70/100 quartz sand	93.5
Marshallite	4.0
ZIS-3 binder	2.5

The specimens are dried at 250°C for 1 hr 45 min.

A characteristic feature is the use of ZIS binder in the composition of mixtures not containing water. In anhydrous mixtures, ZIS binder develops considerably

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greater strength than in mixtures of the usual type.

SLK Binder. SLK binder contains 50% of GTF binder and 50% of polyvinyl-alcohol lacquer.

Properties: specific gravity 0.98-0.99; viscosity at 50°C, 2.5-3.3; acid value 9.0-9.5; tensile strength of dry specimens not less than 7.0 kg/cm^2.

Composition of Technological Sample in %

K 70/100 quartz sand	98.0
SLK binder	2.0

The specimens are dried at 180-200°C for 1 hour.

BK Binder. Emulsion of sulfite-alcohol-vinasse and polyvinyl alcohol. For stabilization, shale tar (GTF binder) is added.

Composition of Binder in %

Sulfite-alcohol vinasse	73-75
Vinyl alcohol	15-17
FTF binder	8-12

Properties: appearance, uniform liquid of light brown color; specific gravity at 20°C 1.15-1.16; viscosity, determined at 20°C on BZ-4 apparatus 1.5-2 min; tensile strength of dry specimens over 12 kg/cm^2.

Composition of Technological Sample

K 50/100 quartz sand	100	parts by weight
BK binder	5.0	parts by weight
Water	1	part by weight

Drying temperature for the specimens: 200-220°C, drying time 1 hour.

Group A-3 - Binding materials of this group are used in preparing Class III and IV cores and also in the composition of facing mixtures for molds on surface drying.

Wood pitch is the residual product after distilling off the oils from the tars

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obtained on the low-temperature carbonization of wood. It is delivered in lumps. It is used in powder form and is ground at the foundries themselves.

Properties: softening temperatures 80-110°C; moisture not over 3%; tensile strength of dry specimens not less than 3 kg/cm^2.

Composition of Technological Sample

K 50/100 quartz sand	97	parts by weight
Ground pitch	3	parts by weight
Water	3	parts by weight

Samples dried at 220-240°C for 1 hour.

KT binder is a suspension of peat pitch in an aqueous solution of sulfite-alcohol vinasse in the presence of loam.

Composition: peat pitch 50-55%, sulfite-alcohol vinasse (sp. gr. 1.27-1.3) 28-30%, molding loam 15-22%.

Properties (by GOST 5270-50): appearance, uniform hard mass of dark color; on dilution with water in any proportion it should form a uniform suspension; on the surface of the binder a film of thickness up to 2 mm is allowed; tensile strength of dry specimens not less than 9 kg/cm^2.

Composition of Technological Sample

K 50/100 quartz sand	100	parts by weight
KT binder	6	parts by weight
Water	3	parts by weight

Specimens dried for 1 hour at 220-230°C.

Group B-1 - Binding materials of this group are used in making Class I and II cores, and to some extent also Class III. In the USSR, urea-formaldehyde (carbamide) thermo setting resins are used to prepare cores. Three binding materials based on them have been developed, the MF-17, MSB and M binders (Bibl.28), (74).

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MF-17 binder is a condensation product of urea and formaldehyde in presence of a plasticizer.

Properties (by TU MKhP 2538-51): appearance, uniform viscous mass, white to light brown in color; dry matter not less than 65%; (pH) 6.5-8; on mixing two parts by weight of the resin with one part by weight of water, the resin must not coagulate; viscosity of resin on FE-36 apparatus and with nozzle diameter of 5 mm, should be within range of 20-150° Engler at instant of preparation. After 4 months of storage the viscosity must not exceed 600° Engler.

Composition of Technological Sample

K 50/100 quartz sand	100	parts by weight
MF-17 binder	2.5	parts by weight

Before charging into crusher mill 25% by weight of a 10% oxalic acid solution is added as a catalyst. The specimens are dried for 10 minutes at 200-220°C. The tensile strength of dry specimens is not less than 25 kg/cm^2.

MSB binder is a condensation product of the urea and formaldehyde. In the presence of sulfite-alcohol vinasse and a plasticizer.

Properties (TUM 538-54): (pH) 7-8; viscosity by VZ-4 instrument 15-60 sec; specific gravity 1.18-1.22; free formaldehyde not over 1.5%.

Tensile strength of dry specimens over 15 kg/cm^2.

Composition of Technological Sample

K 50/100 quartz sand	100 parts by weight
MSB binder	2.5 parts by weight
10% oxalic acid solution	0.6 part by weight

The specimens are dried for 10 min at 80-200°C.

Mixtures with the MF-17 and MSB binders are distinguished by rapid drying, and they are therefore called rapid-drying binders.

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M Binder. Properties: specific gravity at 20°C, 1.15-1.20; viscosity on FE-36V instrument from 4 to 10°; (pH) 7.2-7.8; tensile strength of dry specimens not less than 10 kg/cm^2.

Composition of Technological Sample

K 50/100 quartz sand	97	parts by weight
M binder	3	parts by weight

The specimens are dried for 1 hour at 160-170°C.

Groups B-2 and B-3 - The binding materials of these groups are used mainly in combination with binding materials of Class A in making Class II and III cores. They are used as the main binders in combination with loam in making Class IV and V cores, and sometimes for Class II cores as well.

In addition SP, SB and KV binders are used in the composition of facing sands for surface dried molds.

KV binder is obtained by evaporating down acid water, not detarred, of wood gas generator stations.

Properties (TU MBDP217-52): specific gravity at 20°C, 1.22-1.25; dry matter not less than 65%; insoluble tar not more than 13%; ash not over 5%; tensile strength of dry specimens not less than 7 kg/cm^2.

Composition of Technological Sample

K 50/100 quartz sand	100	parts by weight
Detarred KV binder	4	parts by weight

The specimens are dried for 1 hour at 130-140°C.

SB and SP binders are emulsions of the following composition:

SP: sulfite-alcohol vinasse (specific gravity 1.25-1.27), 95%; oxidise petrolatum (P binder without addition of catalyst), 5%.

SB Binder. Sulfite-alcohol vinasse (specific gravity 1.22-1.23) 80%; GTF bind-

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or 20%.

Properties: appearance, viscous uniform liquid of dark color (formation of film on surface of liquid, which film on mixing must dissolve in general mass of liquid, is allowable); tensile strength of dry specimens, not less than 5 kg/cm^2 for SP and not less than 10 kg/cm^2 for SB.

Composition of Technological Sample

K 50/100 quartz sand	100	parts by weight
SP or SB binder	5.6	parts by weight
Water	1	part by weight

The specimens are dried for 1 hour at 200-220°C.

Dextrine is obtained by heating starch with dilute acids. Potatoes or corn, which are food products, are used as raw materials for the manufacture of starch. The use of dextrin as a binding material for cores must therefore be restricted as much as possible. Dextrin is white, yellow, or straw-colored.

White dextrin dissolves in water to the extent of more than 61.5% of the entire sample, straw-colored dextrin 93.5%, and yellow dextrin 95%.

The strength imparted to a dry specimen by white dextrin is about 25% lower than that obtained by using yellow or straw-colored dextrin.

The following specifications are recommended:

Indexes	White dextrin	Straw-colored or yellow dextrin
Percentage of moisture not more than	10	10
Ash, in % of dry matter, not more than	1	1
Solubility at 17.5°C in percent of dry matter, not less than	60	92

Pectin mucilage has properties closely resembling the best grades of dextrin,

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and is therefore a substitute of equal value for dextrin.

According to specifications (No.7954) liquid pectin mucilage contains not less than 48% dry matter, and the powdered mucilage not less than 88%. The latter is usually evaluated by the tensile strength of specimens (not less than 10 kg/cm^2).

Composition of Technological Sample

K 50/100 quartz sand	100	parts by weight
Pectin mucilage	2.5	parts by weight
Water	4	parts by weight

The specimens are dried at 160-180°C for 1 hour.

Sulfite-alcohol vinasse: Sulfite liquor, a by-product of cellulose production, may be processed by fermentation of the sugars it contains, yielding alcohol. The residue from this process is sulfite-alcohol vinasse. It is delivered in three forms: LKBZh, foundry concentrates of liquid vinasse; LKBT, foundry concentrates of solid vinasse; and KBP, concentrates of powdered vinasse. The specifications are given in Table 5.

Composition of Technological Sample

Dry KK 50/100 quartz sand	97	parts by weight
Molding loam	3	parts by weight
Sulfite-alcohol vinasse (sp. gr. 1.275)	5	parts by weight
Water	1	parts by weight

The specimens are dried for 1 hour at 160-180°C.

Group V-1. The binding material of this group (water glass) is used in the composition of facing sands for molds and in making III and IV class cores.

Water glass consists of block silicate dissolved in water.

The most important for foundry work is the modulus $M = \frac{SiO_2\%}{Na_2O\%} = 1.032$ the

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recommended range of which is from 2.1 to 2.3, and the specific gravity, of which the recommended range is 1.48-1.52. For self-drying molds, the modulus ranges from 2.7-2.8.

Table 5

Specifications for Sulfite-Alcohol Vinasse

Indexes	GOST 6632-53 LKBZh	GOST 6632-53 LKBT	GOST 6003-51 KBP
Appearance	Thick liquid	Mass	Powder
Color	Dark brown	Dark brown	Light brown
Specific gravity not less than (γ_4^{20})	1.275	not prescribed	not prescribed
Dry matter, in %, not less than	50	76	87
Substances insoluble in water, %, not less than	0.55	0.75	-
Ash in % of total dry matter, not less than	-	-	20
Reducing substances in % by weight of dry matter, not more than	-	-	10
Active acidity, pH, in range	5-7	5-7	-
Tensile strength of dry specimens in kg/cm^2, not less than	4	4	-

1 to 1.5% of a 10-20% caustic soda solution is added to the water glass in the composition of rapid drying mixtures (Bibl.28). Water glass is delivered by GOST 962-41 or 4419-48. The specifications by GOST 962-41 are given in Table 6.

Group V-3. Cement is used in the composition of facing sands for molds. Loam is used in the composition of molding mixtures and core mixtures. The loam is used as the principal binding material in making Class V cores.

Cement. Portland cement of mark 400 or higher (GOST 970-41) is used in

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foundry work. The figure indicating the mark of a cement shows the compressive strength in kg/cm^2 of specimens 98 days after preparation.

Table 6

Specifications for Water Glass (by GOST 962-41)

No.	Index	Form of water glass		
		Soda	Soda-sulfate	Sulfate
1.	Chemical composition, 1%			
	a) silica (anhydride of silicic acid) SiO_2	32-34.5	28-32	28-32
	b) Iron oxides and aluminum oxide ($Fe_2O_3 + Al_2O_3$) not more than	0.25	0.4	0.5
	c) Calcium oxide (CaO) not more than	0.2	0.3	0.35
	d) Sulfuric anhydride (SO_3) not more than	0.18	1	1.5
	e) Sodium Oxide (Na_2O)	11-13.5	10-12	10-12
	f) Water (H_2O) not more than	57	60	60
2.	Modulus	2.6-3	2.56-3	2.56-3
3.	Specific gravity	1.5-1.55	1.43-1.5	1.43-1.5

A characteristic feature of cement is its ability, after mixing with water, to solidify in air. For this reason molds made of sand-cement mixtures, after making, and before pouring, are left in air at a temperature not lower than 12-15°C for 24-72 hours.

The artificial carbonization of sand-cement molds shortens the process of hardening to 10-12 hours.

Molding Loam. The properties and specifications are given above.

Molding Mixtures.

In casting into green molds, foundries with a mechanized mold material de-

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partment mostly use only a single molding mix.

In casting in dry or drying molds, and also in foundries where the process of making and transporting the mixtures is not mechanized, facing and backing sands are usually used, the former serving to form the layer of the mold in contact with the casting metal; and the second for making the rest of the mold.

Tables 6-8 give the typical compositions of molding sands, worked out by the authors, for cast iron-steel and nonferrous foundry work.

The quantity of loam or, as the case may be, of loamy (T, P, Zh, OZh) and quartz sands added to the mix, varies considerably according to the loam content of the burned (floor) sand. For this reason it must be determined from a calculation of the total loam content of the mixture, as shown in the tables.

As a rule, green molds are used for casting cast-iron and steel articles weighing up to 500 kg. Heavier articles are cast into green molds only where the configuration is simple and the function is not of vital importance.

Casting in partly dried molds is done mainly as a substitute for casting in dry molds. It is done instead of casting in green molds only on those cases where there is danger of getting a defective casting due to dirt, washes, and other defects due to the molds.

As a result of the fuel economy and shortening the drying time, casting in partially dried molds is more economical than casting in dry molds.

Casting of cast iron in partially dried molds is still limited to castings up to 3-5 tons in weight.

Steel casting in partially dried molds with water glass has given a good account of itself with castings up to 40 tons. To avoid scabbing with heavy carbon steel castings, it is expedient to use chrome iron ore or chromomagnesite for the molds instead of sand. Chromomagnesite should likewise be used for castings of various weights of special steels (for instance, chromium-nickel steel).

To eliminate the danger of cracking owing to parts of the mold preventing the

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Table 7

Typical Compositions of Molding Sands for Iron Founding

a		b			c							d					
																ss	
e	f	g	h	i	j	h	i	k	l	m	n	o	p	q	r	s	t	u
								v										
To 20 20 [illegible]–[illegible] [illegible]–[illegible] [illegible]–1000 [illegible]–1000	To 10 over 10 to 25 over 25 To 40 over 40	4–5 5–6 6–7 7–8 8–12 10–15	[illegible]	0,5 0,5 0,7 0,8–1 1–1,2 1,2–1,5	20–25 25–30 30–35 35–40 40–50 40–60	75–[illegible] 70–75 65–70 [illegible] [illegible] [illegible]	2–3 2–3 3–4 4–5 [illegible] [illegible]	— — — — — —	— — — — — —	— — — — — —	— — — — — —	— — — — — —	[illegible]	[illegible] 9–11 10–12	[illegible] 4,3–5 4,5–5,5	[illegible] 50–80 60–100	0,3–0,5 0,3–0,5 0,3–0,5 0,3–0,5 0,4–0,6 0,45–0,7	— — — — — —
								w										
To 1000 1000–5000 —	— — —	— — —	— — —	— — —	40–60 45–65 70–80	40–60 35–55 20–30	— — —	0–3 0–3 2–4	— — —	— — —	— — —	— — —	[illegible]	12–14 12–16 14–16	6–7 6–8 7–9	60–80 80–100 120–150	0,5–0,7 0,6–0,8 0,7–0,8	0,8–1,2 1–1,5 1,2–2
								x										
To 3000 3000	— —	— —	— —	— —	80–100 80–100	0–10 0–30	— —	0–2,0	1,5–3,0	0–2,0	5–7	0,5–1,5	80/100 [illegible]	3–7	3–5 4–6	≥80 ≥80	0,15–0,2 0,15–0,2	≥12 ≥3
								y										
To 1000	—	—	—	—	50–100	0–50	5–8	—	—	—	5–7	0,5–1	80/100	3–7	3–5	80	0,15–0,2	—

a) Characteristic of castings; b) Composition of all-purpose molding sand, parts by weight; c) Composition of facing sand, parts by weight; d) Characteristic of sand (single and facing); e) Weight in kg; f) Wall thickness in mm; g) Fresh sand; h) Floor sand; i) Coal (PZh) (Semibituminous); j) Fresh materials; k) Sawdust; l) Group A-3 binders; m) Sulfite-alcohol vinasse, sp.gr.1.27-1.28; n) Water glass, sp.gr. 1.48-1.50; o) NaOH, 10% solution; p) Grain composition; q) Loam %; r) Moisture, %; s) Gas permeability in wet condition; ss) Strength in kg/cm^2; t) Green specimens, compressive strength; u) Dry specimens, tensile strength; v) Green molds; w) Dry molds; x) Molds with dried surface; y) Self-drying molds; z) up to; aa) over.

1) The fresh materials, i.e., sand and loam, are taken in quantities corresponding to the calculation of the total loam content of the mixture, given in the corresponding column. In sands for green molds the use of argillaceous sands (P, Zh) is recommended, for dry molds, with castings up to 5 tons, argillaceous sands (P, Zh, OZh) or loam, and for castings heavier than 5 tons, or when using self-drying molds or molds with dried surface, quartz sand and loam.

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Table 8

Typical Compositions of Molding Sands for Steel Casting.

a		b										c				d	
e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v
								w									
To [illegible]	—	[illegible]–[illegible]	[illegible]–75	—	—	—	—	—	—	—	—	[illegible]/[illegible] [illegible]/[illegible]	10–12	4–5	70	0,4–0,6	—
								x									
To [illegible]	To [illegible]	[illegible]–[illegible]	10–[illegible]	—	—	—	0–1	—	—	—	—	70/[illegible] [illegible]/100	12–15	6–8	[illegible]	0,5–0,7	1,0
To [illegible]	> [illegible]	[illegible]–[illegible]	—	[illegible]–[illegible]	—	—	—	—	—	—	—	[illegible]/[illegible] 70/[illegible] [illegible]/100	7–12	6–8	[illegible]	0,5–0,8	1,5
> [illegible]	To [illegible]	[illegible]–[illegible]	—	[illegible]–[illegible]	—	—	—	—	—	—	—	[illegible]/100	7–12	6–8	[illegible]	0,6–0,8	1,5
								y									
To [illegible]	—	[illegible]–70	[illegible]–[illegible]	—	—	—	—	—	5–7	0,5–1,5	—	[illegible]/100 100/[illegible]	4–6	3,5–5	[illegible]	0,3–0,35	[illegible]
To [illegible] [illegible]–[illegible]	To [illegible]	[illegible]–70 [illegible]–100	[illegible]–70 6–[illegible]	— —	— —	— —	— —	3 —	— 5–7	— 0,5–1,5	— —	[illegible]/[illegible] 100/[illegible]	8–10 4–6	4–5 3–5	[illegible] [illegible]	0,25–0,4 0,[illegible]–0,35	3 [illegible]
> [illegible]	To [illegible]	100	—	—	—	—	—	—	5–7	0,5–1,5	—	70/40 [illegible]/100	4–6	3–5	100	0,[illegible]–0,35	[illegible]
> [illegible] > [illegible] > [illegible]	> [illegible] > [illegible] > [illegible]	— — —	— — —	— — —	100 — —	— 100 170	1,5–2,5 4–6 —	— — —	— — 6–7	— — 1–1,5		} *	— — —	6–7 1,5–5,5 4,5–5,5	— — —	0,5–0,6 0,3–0,35 0,15–0,2	1,5 10,0 20
								aa									
To [illegible]	—	[illegible]–1[illegible]	To [illegible]	—	—	—	—	—	5–7	0,5–1,5	—	[illegible]/100 100/[illegible]	3–7	3–5	[illegible]	0,15–0,3	—
		[illegible]–[illegible]	—	—	—	—	—	—	—	—	10–15	40/70 [illegible]/140	—	5,3–6,[illegible]	[illegible]	0,1–0,15	5,0**

* Checked by residue on lower sieves 200 + 270 + pan 30-40%.

** On compression 24 hours after preparation.

a) Characteristics of castings; b) Composition of facing sand, parts by weight; c) Characteristics of sand; d) Strength in kg/cm^2; e) Weight in kg; f) Wall thickness in mm; g) Fresh materials (quartz sand and loam); h) Floor sand; i) Marshallite; j) Chrome iron ore; k) Chromomagnesite; l) Sulfite-alcohol vinasse, sp.gr. 1.27-1.28; m) SB binder; n) Water glass; o) NaOH, 10% solution; p) Cement; q) Grain composition; r) Loam, %; s) Moisture, %; t) Gas permeability, not less than; u) Green specimens, compressive strength; v) Tensile strength of dry specimens, not less than; w) Green molds; x) Dry molds; y) Molds with dried surface; z) up to; aa) Self-drying molds.

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Table 9

Typical Compositions of Molding Sands for Nonferrous Casting.

	a					b				c	
	d	e	f	g	h	i	j	k	l	m	n
o	[illegible]	[illegible]	— —	1.0–1.5 —	— —	70(14[illegible]) 100/200 70(140)	8–12 10–13	4.5–5.2 [illegible]	[illegible]	[illegible]	— [illegible]
p	[illegible]	[illegible]	— 0.5	— —	— —	100/200 100/250	8–10 8–12	4–5 [illegible]	>25 [illegible]	[illegible]	— [illegible]
q	[illegible] —	[illegible] —	—	—	8–10 —	100(20) —	8–12 —	5–6 —	>25 —	0.3–0.6 —	—

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a) Composition of sand in parts by weight; b) Characteristics of sand; c) Strength in kg/cm^2; d) Fresh materials; e) Floor sand; f) Sulfite-alcohol vinasse; g) Mazut; h) Fluoride supplement; i) Grain composition; j) Loam, %; k) Moisture, %; l) Gas permeability in wet condition; m) Green specimens, compressive strength; n) Dry specimens, tensile strength; o) Bronze castings; p) Aluminum castings; q) Magnesium castings.

Note: Over fraction-line, data for casting into green molds, under fraction-line, for casting in dry molds.

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metal from shrinking, sawdust is added to the composition of the facing sand.

For casting magnesium alloys, a fluoride additive (a mixture of a fluoride and a boride) is used in the molding sand.

When backing sand is reused, 3 to 10% of fresh sand is added to it.

Core Mixtures.

Tables 10-13 give typical compositions of core sands developed by the present authors. The compositions of sands with M binder have been developed by B.A.Arbuzov.

In making cores from sands containing water glass, the lower limit of moisture indicated in Table 13 should be maintained to facilitate core removal.

In Tables 10-12 the loam content is given allowing for the quantity of argillaceous component contained in the quartz sand. The quantities of binding materials are indicated calculated on the base content (without the solvent content).

To avoid gas holes in steel castings, MF-17 binder should be used for castings with a wall thickness over 35 mm, and MSB binder for castings with a wall thickness over 10 mm thickness. For iron castings and castings of copper alloys, no limitation is prescribed.

Auxiliary Molding Materials.

Anti-scabbing means. Measures to eliminate scabbing are as follows:

a) addition of coal or other organic additives to the molding sands, in order to produce a reducing atmosphere in the mold (in casting iron and bronze);

b) introduction of an anti-scabbing coating on the surface of the mold in the form of parting powder, paint or rub-mixes;

c) use of sand compositions which give an easily removable crust of the scab, under which a clean casting surface is found.

Anti-scabbing mold coatings may consist of reducing substances, preventing oxidation of the castings (in casting iron, bronze, and magnesium alloys) or of inert materials which do not interact with the oxides of the cast metal (in casting steel

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Table 10

Typical Compositions of Core Sands for Cast-Iron Casting.

	a								b							
	c				d									e		
f	g	h	i	j	k			o	p	q	r	s	t	u	v	w
					l	m	n									
I	—	[illegible]	—	—	1–1,5	—	—	—	—	[illegible]/130	1–2	130	2–3	0,05–0,06	6	[illegible]
II		97	3	—	—	1,5–2	—	2–4	—	[illegible]/100	3–5	100	3–4	0,06–0,10	5	[illegible]
III	—	[illegible]–97	3–4*	—	—	—	2–4	2,5–3,5	—	[illegible]/100	3–6	100	3,0–4,5	0,10–0,20	4	[illegible]
IV	6–[illegible]	—		[illegible]–[illegible]**	—	—	To 3	1,5–3	To 3,0	[illegible]/130 70/63	6–10	70	4,0–5,5	0,20–0,40	2	[illegible]
V	[illegible]–[illegible]	—	—	[illegible]–[illegible]	—	—	—	To 3	[illegible] 3,0	70/100 70/40	10–14	70	5–6	0,40–0,70	1	[illegible]

a) Composition of sand; b) Characteristics of sand; c) Granular part of sand, in % by weight; d) Binding materials, % of weight of granular part of sand; e) Strength in kg/cm^2; f) Core class; g) Floor sand; h) Quartz sand; i) Loam; j) Argillaceous sand; k) Nonaqueous materials (in % of binder base); l) Group 1 A-1; m) Group 2 A-2; n) Group 3 A-3 or SP and SB; o) Sulfito-alcohol vinasse (sp.gr.1.27); p) Sawdust; q) Grain composition; r) Loam, %; s) Gas permeability in wet condition; t) Moisture; u) Green specimens, compressive strength; v) Tensile strength of dry specimens, not less than; w) Drying temperature, °C.

* Or argillaceous sand, calculated.

** Or quartz sand and clay, calculated.

Table 11

Typical Compositions of Core Sands for Steel Casting.

f	a								b							
	c				d									e		
					k											
	g	h	i	j	l	m	n	o	p	q	r	s	t	u	v	w
I	—	[illegible]	—	—	1,3–1,4	—	—	—	—	[illegible]	1–2	[illegible]	2–3	0,05–0,08	7	[illegible]
II	—	[illegible]	[illegible]	—	—	1,5–2	—	2,0–4	—	[illegible]	2–5	[illegible]	3–4	0,08–0,1	5	[illegible]
III	—	[illegible]	[illegible]	—	—	—	2–4	[illegible]	—	[illegible]	3–6	[illegible]	3–4,5	0,1–0,2	4	[illegible]
IV	[illegible]	[illegible]	[illegible]	—	—	—	To 2	[illegible]	To 3	[illegible]	8–10	70	4–5,5	0,2–0,4	2	[illegible]
V	[illegible]	[illegible]	[illegible]	—	—	—	—	[illegible]	3	[illegible]	10–14	70	5–7	0,4–0,7	1,5	[illegible]
VI	—	[illegible]	[illegible]	[illegible]	—	—	—	—	3	—	8–12	[illegible]	6–8	0,8	1,5	[illegible]

a) Composition of sand; b) Characteristics of sand; c) Granular part of sand, in % by weight; d) Binding materials, % of weight of granular part of sand; e) Strength in kg/cm^2; f) Core class; g) Floor sand; h) Quartz sand; i) Loam; j) Marshallite; k) Nonaqueous materials (in % of binder base); l) Group 1 A-1; m) Group 2 A-2; n) Group 3 A-3 or SP and SB; o) Sulfite-alcohol vinasse (sp.gr.1.27); p) Sawdust in % by weight of granular part of sand; q) Grain composition; r) Loam in %; s) Gas permeability in wet condition (not less than); t) Moisture in %; u) Compressive strength of green specimens; v) Tensile strength of dry specimens (not less than); w) Drying temperature, °C

Table 12

Typical Compositions of Core Sands for Nonferrous Casting.

f	a									b						
	c				d					p	q	r	s	e		v
	g	k			l			m	n					t	u	
		h	i	j	A-1	A-2	A-3 o									
w																
I	—	100	—	—	1,2—1,5	—	—	—	—	50/100 70/140	To 2	120	2—3	0,03—0,06	7—10	200—230
II	—	97	3	—	—	1,5—2	—	2—4	—	50/100 100/50	3—5	90	3—4	0,06—0,1	5—7	210—220
III	—	96—97	3—4	—	—	—	2—4	2,5—3,5	—	—	3—6	90	3—4,5	0,1—0,16	3,5—6,0	220—240
IV	0—40	—	—	60—100	—	—	To 3	2—3	—	50/100	5—9	70	4—5,5	0,15—0,25	2—3	160—180
V	20—60	—	—	40—80	—	—	—	To 3	—	50/100 70/140	7-10	60	5—6	0,2—0,35	0,8—1,5	160—180
x																
I	—	100	—	—	0,6—1,2	—	—	—	*	50/100 70/140	To 2	120	2—3	0,03—0,06	3—6	200—230
II	—	90	—	10	—	1—1,5	—	1,5—3	*	50/100 70/140	2—4	90	3—4	0,06—0,1	4—7	200—220
III	—	80—85	—	15—20	—	—	1,5—2,5	2—3	*	50/100 70/140	3—5	90	3—4	0,1—0,16	3,5—6	220—240
IV	0—30	30—60	—	40—50	—	—	—	1,5—3	*	50/100 70/140	5—8	70	4—5	0,15—0,25	2—3	160—180

* In casting magnesium alloys, 0.25-0.5% boric acid and 0.25-1.0% flowers of sulfur are added to the composition of the sands.

a) Composition of sand; b) Characteristics of sand; c) Granular part of sand, in % by weight; d) Binding materials, % of weight of granular part of sand; e) Strength in kg/cm^2; f) Core class; g) Floor sand or core face; h) Gas permeability in wet condition; i) Loam; j) Argillaceous sand; k) Fresh materials; l) Nonaqueous materials (in % of binder base); m) Sulfite-alcohol vinasse (sp.gr.1.27); n) Special additives; o) Group A-3 or SP and SB; p) Grain composition; q) Loam, %; r) Gas permeability, not less than; s) Moisture, %; t) Green specimens, compressive strength; u) Tensile strength of dry specimens; v) Drying temperature, °C; w) For copper alloys; x) For aluminum and magnesium alloys.

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Table 13

Typical Compositions of Rapid-Drying Core Sands.

c	a											b						
	d				e						r	s	t	u	v	f		g
	h	i	j	k	l	m	n	o	p	q						w	x	
y																		
I	—	100	—	—	2,0–2,5*	—	—	—	—	—	—	50/100	7₀ 2	120	0,5–1,5	0,08–0,0[illegible]	16	1[illegible]0–220
II	—	95,0–97,0	—	1,0–2,0	2,0–2,5	—	—	—	1,5–2,5	—	0,25–0,50	50/100	1,0–5,0	100	1,5–2,5	0,08–0,12	14	1[illegible]0–220
III A-IV	0–20	78,0–98,0	—	0–4	2,5–3,5	—	—	—	2,5–3,0	—	0,25–0,50	50/100	4,0–6,0	70	2,5–3,5	0,12–0,20	12	200–220
III A-IV	0–20	70,0–90,0	—	0–6	—	—	5,0–7,0	0,5–1,0	—	—	0,25–0,50	50/100	3,0–7,0	70	3,0–4,0	0,15–0,20	12	200–220
z																		
I	—	100	—	—	—	1,0–1,5	—	—	—	0,2–0,5	—	70/100	7₀ 2	100	[illegible]	0,04–0,0[illegible]	7	[illegible]
II A-III	—	90–95	5,0–10,0	—	—	[illegible]	—	—	—	2,0–3,0	—	50/100–70/100	[illegible]	70	[illegible]	0,05–0,10	6	[illegible]

* 10% oxalic acid solution, equal in quantity to 25% the weight of the binder is added.

** In casting magnesium alloys, 0.25–0.5% of boric acid and 0.25–1% of flowers of sulfur are added.

a) Composition of sand; b) Characteristics of sand; c) Core class; d) Granular part of sand, in % by weight; e) Binding materials, % of weight of granular part of sand; f) Strength in kg/cm^2; g) Drying temperature, °C; h) Floor sand; i) Quartz sand; j) Semi-oily sand; k) Loam; l) MF-17 or MSB; m) M; n) Water glass, sp.gr.1.48-1.52; o) Caustic soda, 10% in solution; p) Sulfite-alcohol vinasse (sp.gr.1.27); q) Pectin glue, by weight 1.20-1.25; r) Mazut; s) Grain composition; t) Argillaceous mixture in %; u) Gas permeability, not less than; v) Moisture, %; w) Green specimens, in compressive strength; x) Tensile strength of dry specimens, not less than; y) For cast iron, steel and copper alloys; z) For aluminum and magnesium alloys.

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POOR ORIGINAL

and aluminum alloys). In either case, the mold coating must form a dense crust preventing the penetration of the crust into the interior of the mold.

The addition of carbonaceous anti-scabbing agents to the composition of molding sands is practiced in casting iron and copper alloys. In casting steel, this method is of limited use, owing to the danger of carbonization of the casting surface. In casting magnesium alloys, fluorides and borides are added to the molding sands, and boric anhydride and sulfur to the core sand.

In casting copper alloys, the carbon in the composition of the sand may be replaced by mazut. To obtain an easily removable crust, sands containing water glass or cement are used.

Parting powders (coal, preferably semibituminous, graphite, or cement) are used to cover green molds. They are mainly employed in casting iron (cement is also used in casting various alloys).

Mold coatings. Table 14 gives the compositions of mold coatings.

Before use, the paste is diluted with water to the specific gravity indicated in the table.

No mold wash is used on molds of rapid-drying sand with water glass or steel casting, nor for bronze casting (except for phosphor bronzes). It is obligatory to use a mold wash on molds for iron casting. Composition: amorphous (black) graphite, 30.0-33.5 parts by weight; flake (silvery) graphite, 25.0-28.0 parts by weight; bentonite, 3.5 parts by weight; sulfite-alcohol vinasse (sp.gr.1.30), 10.0 parts by weight; water, 28.0 parts by weight. The paste so obtained is diluted in water to specific gravity 1.25-1.30. No mold wash is applied to molds and cores made of chromomagnesite sands.

To increase the density of the metal at individual points of iron castings, or to obtain a local whitening, a mold wash containing up to 5% of tellurite powder may be used.

Rub mixes are used on cores that form inner cavities with a very clean surface

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in castings. They are used mainly in iron founding.

Restoration (Regeneration) of Molding Materials.

The repeated use of spent core sands considerably reduces the consumption of fresh sands.

Table 14

Typical Mold Coating Compositions.

b	a									m	n	o
	c	d	e	f	g	h	i	j				
								k	l			
ЧБ-1	60	—	—	—	—	—	3,5	3,5	—	33	1,35—1,4	p
ЧБ-2	58,5	—	—	—	—	—	3,5	—	10	28	1,35—1,4	
ЧБ-3	58,5	—	—	—	—	—	3,5	—	10	28	1,35—1,4	
КМ4	17	—	—	17	—	31,5	3,5	—	10	21	—	q
КМ4У	9	—	—	17	9	31,5	3,5	—	10	20	—	r
ST-1	—	70,5	—	—	—	—	3	1,5	—	25	1,4—1,5	s
ST-2	—	70	—	—	—	—	3	—	10	17	1,4—1,5	t
ST-3	—	70	—	—	—	—	3	—	10	17	1,4—1,5	u
T8	—	—	61	—	—	—	4	—	—	35	1,25—1,3	v
T6	30	—	31	—	—	—	3	—	3	33	1,35—1,4	w

a) Composition of paste, parts by weight; b) Symbol; c) Amorphous graphite; d) Quartz dust; e) Talc; f) Coke; g) Forge charcoal; h) Marshallite; i) Bentonite; j) Binders; k) Group B-2; l) Group B-3; m) Water; n) Specific gravity of coating before use; o) Castings for which used; p) Small, medium and heavy iron castings; q) Medium iron castings; r) Small iron castings; s) Steel castings; t) Steel castings; u) Steel castings; v) Bronze castings; w) Aluminum castings.

Spent core sands may be reworked with the object of restoring (regenerating) the original composition and properties, or may be used without restoration of the composition, for joint introduction with fresh sand.

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Reworking sands to restore (regenerate) their composition and properties. Spent sands may be regenerated by air separation, electro separation, hydro separation, and also by the use of special vibration apparatus.

Air separation is effected by the scheme rollers - magnetic separator - screen - disintegrator - air separator.

Electro separation is effected by the following scheme: crusher rollers or mills - magnetic separator - screen - electro separator. The yield of suitable sands after separation is as high as 90%. The consumption of electric power is 2.0-2.5 KWH per ton of floor sand.

Hydroseparation. In modern mechanized foundries, the castings are cleaned hydraulically and by the sand-hydraulic method, with which the hydroseparation of spent molding sands can be conveniently combined.

In this case hydroseparation may be effected by various schemes, analogous to the existing schemes of wet concentration of minerals.

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CASTING-BOXES AND PATTERNS

Casting Boxes

Casting boxes must be as light as possible, sufficiently strong, rigid, exact, interchangeable, and also convenient in operation.

Standard casting box dimensions. Pursuant to GOST to 2133-43, the standard dimensions of casting boxes are regulated by the normal size interval in length (diameter), width and height. The size intervals of standard casting boxes is given below. For large series and mass casting work, the manufacture of special casting boxes with different dimensions is allowed. The sizes of removable flasks are 400 x 250, 400 x 300, 450 x 250, 450 x 300 mm, with a height ranging from 75 to 150 mm.

Size Interval of Casting Boxes in mm

Length (diameter) of casting	Size Interval	Width of casting boxes	Size Interval	Height of casting boxes	Size interval
300-500	50	250-400	50	50-200	25
500-1200	100	400-1000	100	50-200	25
1200-2400	200	1000-1200	200	over 200	50
2500-3000	250	1250-3000	250		
3000-5000	500	> 3000	500		

The structural elements of integral-casting boxes should, it is recommended, follow GOST 2529-44.

Materials for casting boxes. Depending on the dimensions and conditions of utilization, casting boxes are made of gray cast iron, cast steel, rolled steel, aluminum alloys, or lumber. From gray cast iron of marks SCh 15-32 and SCh 18-36, cast and built-up casting boxes of any dimensions are made. The disadvantages of cast iron casting boxes are their great weight and their liability to breakage from

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blows during core extraction. Integrally cast steel casting boxes are considerably more expensive than cast iron boxes and give good results in large series and mass production. They are from 20 to 25% lighter than cast iron casting boxes and are several times more durable. Steel of any mark according to GOST 977-53 is suitable for cast casting boxes; welded steel casting boxes are seldom used, since a special profile of the rolled product is required.

In machine casting, hand casting boxes of aluminum alloys have given a good account of themselves. It is expedient to make permanent casting boxes out of wood (spruce, pine) only for loam casting and in case of urgent need.

Removable flasks for cast molding are made of oak, beech or larch wood. In this case the connecting frame is made of metal.

Storage of casting boxes. Casting boxes are stored in special casting box warehouses located next to the foundries and equipped with cranes.

Casting Patterns and Pattern Equipment

A pattern set may include the pattern itself, which reflects mainly the external outlines of the object being cast; core boxes, reflecting the inner outlines of the object being cast (cavities, openings, depressions); molding and core patterns, which entirely or partly replace the patterns or core boxes; the molding board and other plates necessary for use of the pattern on the molding machine; patterns and conductors for control and assembly of molds and cores.

Table 15 gives a classification of patterns.

Characteristics of wooden patterns by classes of strength. Class 1 patterns, which are the most important, serve for manual and machine molding with prolonged use. The operating parts of the pattern, or the whole pattern, as well as the boxes, are made of high grade hardwood; the thin parts, of aluminum. The wood is used after careful veneering. All non-moving joints are made with glue and wood screws.

The removable parts in hand molding patterns are installed on metal wedges

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Table 15 Classification of Patterns

Group	Hand molding patterns	Machine molding patterns
By materials	Metal - thin-walled, decorative (sic) curvilinear for series production;	Metal, for large series and mass production;
	combination wooden and metal parts for series production	combination - metal patterns with wooden boxes for large series production
	wooden, for individual and series production	wooden, for small series production
	plaster, wax, skeleton-loam and others for individual castings	plaster and cement for series production
By size	Large, over 1500 mm medium, from 500 to 1500 mm small, up to 500 mm	Large, over 500 mm medium, from 150 to 500 mm small, up to 150 mm
By character of mold	Nondemountable simple nondemountable for molding with recess or "counterfeits"; demountable and with removable parts	Nondemountable one-sided; nondemountable two-sided with "block" demountable, two-sided
By construction	Full - on entire outline of casting Incomplete, with patterns and pieces for large casting;	Massive metal, for small castings; hollow metal, for medium and large castings;
	Skeletons, outline, for loam patterns;	integrally-cast pattern plates
	mold and core strickles broaching and grinding	
By complexity	Intricate-curvilinear outline with a large number of core boxes	Intricate-hollow, large with hand finishing or machine finishing, and with a large number of core boxes;
	medium complexity - simple outline with large number of core boxes;	medium complexity - small, hand and machine finishing, with boxes;
	simple - rectilinear outline with simple boxes	simple - machined for the most part on universal machines

"dovetails". The parts of the patterns and boxes subject to impacts are bound with metal. The bases of the patterns are attached by bolts. Core boxes are made so they can be shaken out entirely, or built up, but cannot be taken apart. Patterns of thin and weak construction are attached to wooden molding boards. In patterns and boxes, the fillets along the parting must be notched in. Demountable

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connections are made on strong pins of metal or hardwood. Class I patterns can stand hundreds and even thousands of mold strippings. The surface of the pattern is carefully finished and is coated with varnish not less than 3 times.

The letter and figure markers must be metal.

Class II patterns, used periodically, are employed for handmolding. These patterns are made of the usual woods (pine, alder, linden) with veneering and use of nails and screws. The pattern is usually all wood, without metal binding and bolt tie bolts. The removable parts are made of wooden wedges. The individual parts are attached by glue and screws without notching. The fillets are likewise glued on without notching in. The boxes are removable. For thin patterns, wooden panels under the models ("counterfeits") are made, and the patterns are made without demountable joints. The surface of the pattern is well finished and is coated with varnish not less than 2 or 3 times. Class II patterns can withstand tnes of mold strippings.

Class III patterns, used a single time, are employed for hand molding. They are made of inexpensive species and grades of wood. Whole patterns are not infrequently replaced by incomplete, skeleton and outline patterns. The removable parts are installed on pegs. The core boxes are made as small as possible, and are made in the simplest structure. Such patterns may be painted once. Class III models are good only for a few castings.

For wooden patterns lumber (boards and beams) of evergreens - pine, larch, spruce - and deciduous species, birch, beech, maple, alder, linden, etc. are used. Pine is suitable for medium and large patterns of any class, especially in binding bases (plates, boxes, frames). Larch is heavier and stronger than pine, and it is expedient to use it instead of pine in Class I patterns. Spruce is suitable for unimportant parts of Class II and III patterns. Birch is suitable for small patterns and parts, especially if it is finished on the lathe. A birch facing is used for wearing parts on class I patterns made of pine. Beech is expediently

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used for small class I patterns and for facing medium class I patterns. Maple shows a good resistance to wear in machine patterns. It is expedient to use alder in small and medium class I and II patterns with an intricate complex outline and which are notched in by chisel. Linden has an analogous function for class III patterns.

The quality of evergreen lumber should correspond to selected grades 1 and 2 by GOST 3008-45, that of hard decidious species, to grades 1 and 2 by GOST 2695-44. Alder and linden should be grade 1. For small machine patterns it is expedient to use improved pressboard, delta and balinite. The moisture in pattern wood must be between 10 and 12%. Pattern wood of high moisture content is unsuitable for the work, since the form and dimensions of the pattern change on drying.

The consumption of wood for patterns depends on the amount of use they get, which corresponds to the degree of series production of the casting. With an individual repair, or experimental casting, the patterns do not perform long service, and the consumption of wood runs up to 0.1 m3 per ton of casting. In small series production the consumption of wood runs up to 0.05 m^3, while in series production it is not over 0.02 m^3 per ton of casting.

Alloys for metal patterns. For thin-walled manual and machine patterns gray cast iron of mark SCh 15-32 by GOST 1412-54 is used. The chemical composition of the cast iron, (in %), is as follows: carbon, 3.5-3.8; silicon 2.4-2.6; manganese 0.7-0.9; phosphorus 0.3-0.6; sulfur, up to 0.1. For high patterns for machine molding, subject to strong wear, the aluminum-copper alloy mark AL-12, by GOST 2685-53, is recommended. The melting point of this alloy is 640°C, its specific gravity is 2.9, and its shrinkage 1.2%. For manual and machine patterns of all sizes, Al-13 alloy by GOST 2685-53 is suitable. Melting point 630°C, sp.gr. 2.8, shrinkage 1%. For casting patterns in accordance with the workpiece, a nonshrinking and low melting pattern alloy composed of 45% lead and 55% bismuth, is used.

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Accuracy of patternmaking. In accordance with the class of accuracy of the castings, wooden patterns are made in three classes of accuracy with maximum deviations from the dimensions according to table 16. For metal patterns the accuracy of manufacture must not be less than that of class I.

Table 16

	Class of accuracy of pattern		
	I	II	III
Measured dimension on pattern, in mm	Type of production		
	large series	series	individual
	Maximum deviations in mm (±)		
Up to 50	0.2	0.3	0.5
50-100	0.3	0.4	0.5
100-200	0.4	0.5	0.8
200-300	0.5	0.8	1
300-500	0.6	0.8	1
500-800	0.8	1	1.5
800-1200	1	1	1.5
1200-1800	1	1.5	2
1800-2600	1	2	3
Over 2600	1.5	2	3

Painting of wooden patterns. A red color is recommended as the basic color for painting wooden pattern sets by GOST 2413-44, for patterns used for casting ferrous alloys, and yellow for patterns and for casting nonferrous alloys.

The individual parts and surfaces of the pattern must be painted as follows: The surfaces of the castings to be machined, black round spots on a background of red or yellow; core markers, solid black paint; points of installation of removable parts, bordered with black band; strength ribs to be machined in the mold or core,

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by black oblique bands; risers, inlets for laboratory tests are separated from the main body of the casting by a black band.

The pattern markers. Patterns and every individual or removable part of a pattern set must have the following markers: number of detail to which pattern belongs, on all parts of the set, serial number of model set with letter K on all parts of set; number of core boxes in set, with letter Ya on pattern; number of core box according to sequence of insertion of given core in mold with letter Ya on core box; number of removable or insertable parts in pattern or core box with letters OV respectively on pattern or on box.

Example of marking of a pattern of a detail B341013 of first set, with one box and two removable parts: for model - B341013 - K1-Yal-OV2; for box - B341013 - - K1-Yal.

The marking is effected by stamping or punching the marker signs on the non-working surfaces of the pattern. In large wooden patterns, marking with paint is allowed.

Allowance on patterns for shrinkage of castings. The shrinkage of the castings taking place in connection with the decrease in the volume of the cooled metal is taken into account in giving the patterns a percentage allowance by the formula

$$k = \frac{a_1 - a}{a} 100$$

where a_1 = initial size of casting on solidification, corresponding to the size of the model; a the final size of the cooled casting. The following is the shrinkage allowance k for various cast alloys:

Materials	K in %
Gray case iron	0.5-1
White cast iron	1.5-2
Pearlite wrought iron	1.2-2
Ferrite wrought iron	1-1.5

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Austenite (nonmagnetic) cast iron	1.3-2
High-silica cast iron	1.5-2
High chromium cast iron	1-1.5
Chugal (iron-aluminum alloy)	2.5-2.7
Carbon steel	1.5-2
Manganese steel	2.8-3
Tin bronze	1.0-1.5
Aluminum bronze	1.2-1.8
Zinc brass	1.0-1.5
Copper alloys of aluminum	1.5-2.0
Silumin	1-1.2
Magnesium alloys	1.1-1.4

Castings of simple form without thick walls show the greatest shrinkage; castings of intricate box-like form, ribbed and heavy, show the least shrinkage. The amount of shrinkage is determined more exactly in practice, on sample castings.

Pattern draft. When the details have design tapers, no pattern draft is required. Pattern draft pursuant to GOST 3212-46 is given either by the size of a in mm, or in degrees, by the angle α (Table 17, Fig.1).

Pattern drafts are made by one of the schemes shown in Fig.1, depending on the character of the surfaces of the casting (machined or unmachined), the conditions of operation (conjunction with other details), and the value of the allowable taper, according to the dimensions of the casting.

On unmachined surfaces, the pattern drafts are taken as plus with a side-wall thickness to 8 mm; as plus or minus with side-wall thickness from 8 to 12 mm; as minus with a side-wall thickness over 12 mm. For machined surfaces, the pattern drafts are taken as plus. For surfaces of patterns forming "blocks" in the casting molds, as well as in making molds of loam, an increase of 50-100% in the pattern drafts but not above 3°, is recommended.

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Table 17

Pattern Draft (not more than)

Height of pattern	Metal patterns	Wooden patterns Machine molding		Hand molding	
		a in mm	a	a in mm	a
Up to 20	3°	1	3°	1	3°
20-50	1°15'	1.5	1°30'	1.5	1°30'
50-100	0°45'	2	1°15'	2	1°15'
100-200	0°30'	2.5	0°45'	2.5	0°45'
200-300	0°30'	3	0°30'	3	0°30'
300-500	0°30'	4	0°30'	4	0°30'
500-800	-	-	-	5	0°30'
800-1000	-	-	-	6	0°30'
1000-1200	-	-	-	7	0°30'
Over 1200	-	-	-	8	0°30'

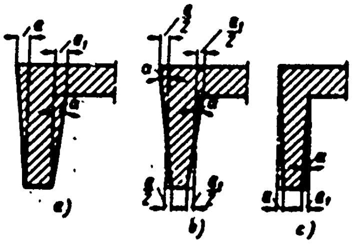

Fig.1. Pattern drafts in patterns: a - on increasing thickness of wall; b - draft of casting on increase and decrease; c - draft on decrease

Fillets and roundings. Fillets prevent the formation of cracks and scab at junction points between the casting walls and also facilitate moldmaking.

Fillets in wooden patterns are made by the following methods: application of a filler on the undemountable corners of a Durability class at r < 5 mm, and of a pattern of Durability class III at r < 8 mm; by gluing wooden cleats (Fig.2) on the undemountable corners in patterns of Durability class II for all radii, in class II patterns for radii more than 8 mm, and in class III models for radii of 10 mm and more; by notching wooden cleats into the corners of patterns of Durability classes I, II, and III. In metal patterns, the fillets are made in the metal, and in most cases by milling. The outer corners are rounded by removing the material of the pattern from the corner.

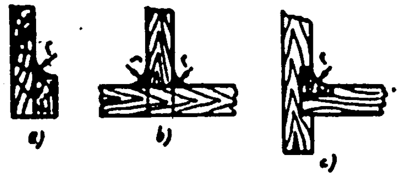

Fig.2. Make-up of fillets: a - gluing fillets along wood fibers; b - gluing fillets transverse to wood fibers; c - notching fillets into demountable corner

Principles of pattern designing. In developing the design of patterns and the procedure of making them, a number of factors affecting the wear of the pattern must be taken into account.

These factors include:

a) the surface wear in the working part of the pattern, owing to the abrasive action of the molding sand when the pattern is pressed home;

b) the wear of the working surface of the pattern due to the use of a working instrument in pressing it home (blows of the rammer, pricks of the vent, wear from the skimming rule at the boxes);

c) wear and failure due to stresses arising in the pattern under the action of forces when the pattern is pressed home into the molding sand (sagging of the walls, destruction of the corners in boxes, etc.);

d) wear and destruction by the action of the forces and impacts in work on jolting and squeezing;

e) wear and destruction from pricking the patterns in releasing the patterns and cores;

f) destruction of the pattern owing to swelling and drying out of the wood.

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The action of these factors differs under various conditions of production. Measures to prevent their action on the patterns should be taken in such a way as to have the wear of the pattern proceed uniformly, and the durability of the patterns should assure the assigned number of strippings of the molds and cores.

The general durability of a pattern depends mainly on the structural foundation, i.e., the base, on which it is built. The base is the principal part of the pattern which determines its dimensions and shape. It depends on the first place on the configuration of the casting. All additions to the base in the form of core prints, tie plates, ribs, bulbs, and other design elements, do not play as great a role in determining the life of a pattern as the base itself does. In designing the pattern, the base is selected as the principal part of the casting. It must be made as durable as possible in the form of a block, box, ring, disk, or frame. But not every casting has such a base. Sometimes a casting has an intricate configuration, and all its elements are not firm enough to attach them to the base. In these cases it is necessary, for the durability of the pattern, to make an artificial base in the form of a molding board, strength rib, etc. For wooden core boxes, the base consists of a foundation connected from the board in the form of a box or obtained by veneering together pieces of wood. The life of a pattern depends on the design development of the pattern base and the durability with which it is made. The maintenance of the pattern dimensions depends on the durability of the base.

Cost of patterns. The average cost of patterns amounts to 3 to 10% of the total cost of the castings, and depends on the metal being cast and the degree of utilization of the patterns. In iron founding, the cost of the patterns is 20-25% higher than in steel founding, and 50-60% higher than in founding nonferrous alloys. The shop cost of patterns is made up of the cost of the basic materials (10-15%), the patternmakers' pay (40 to 50%), and overhead expenses (40-50%).

The labor consumed on metal patterns amounts to 2-3 hours in mass founding

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and 10-15 hours in large-series founding per ton of castings, in either case.

Patterns are stored in a pattern store, in intermediate stores, and in the molding department of the shop. Patterns belonging to one machine are stored according to specifications in a separate area of the store. Small patterns with which the molding is systematically repeated, are kept in the intermediate stores of foundries. The shelves and scaffolding are removed for storing in the intermediate stores and immediately at the working place.

Every pattern must have a rating card in two copies. One copy accompanies the pattern when it is issued from the store, and the second is kept in the pattern store. The card contains information on the time of making and the composition of the model set, the cost of the model, the dates and extent of the repairs, the movement of the pattern in the production, and its use. The card also indicates the place of storage of the pattern in the store: department, section, shelf.

THE MOLDING PROCESS

The process of producing castings consists of the following operations: making the mold (molding), making the cores, filling the mold with liquid metal, knocking out the solidified castings from the mold, cleaning and machining the castings.

The principal operation determining the quality of the casting is molding, the process of making the mold.

The following forms of molds are distinguished in foundry practice.

Permanent molds, mostly made of cast iron or steel, which take hundreds or thousands of castings; permanent molds are termed ingot molds, chill molds, and stamp molds, depending on their purpose.

Semi-permanent molds, made of highly refractory molding mixes and taking a few tens of castings, are only slightly repaired after each casting.

Temporary molds are used only for a single casting, after which they are

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scrapped; they are made of a sand-loam mix, or of a mixture of sand with various other binders (water glass, binder emulsions, artificial resins). The term molding is usually understood to mean the process of making temporary molds.

The Classification of Molding Methods

The following methods of mold making are distinguished: hand molding; machine molding, in which some of the molding operations are performed by the aid of mechanisms; core molding, meaning the assembly of the molds from individual cores made by hand or machine; shell molding, in which the molds are built up out of thin-walled shells. The selection of the method of molding depends on the outlines and dimensions of the detail, the required accuracy, the character and amount of the subsequent machining, and the degree of repetition of the casting. Table 18 gives a classification of the methods of moldmaking and their main fields of application.

Hand molding. Table 19 gives the methods of hand molding.

Table 18

Classification of Molding Methods

Principal method of molding	Methods of molding	Typical casting
Hand (in small-series and series production)	From patterns on floor and in boxes	Various
	On sweep templete	Solids of revolution
	On skeleton patterns	Very large
Machine (in series and mass production)	On molding machines:	Mostly small
	hand:	Mostly small
	pneumatic:	Various
	a) squeeze	Various
	b) jolt and	Special
	combination	Various

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	By aid of stationary and portable sand-slingers	Same
	On sand-blast machines	Special
In cores (in series and mass production)	Building up of mold without jacket and with jacket	Complex configuration Various sizes
Making shell molds	On installations with manual control	Small and medium castings of elevated accuracy
	On single-position semi-automatic machines	The same
	On multi-position automatic machines	The same

Machine molding. In molding on machines the packing of the molding mix in the flask or the stripping of the pattern from the mold, or both operations together, are mechanized. In individual cases, the charging of the molding mix into the flask is also mechanized.

The methods of squeezing the molding mix in machine molding are given in Table 20, and the methods of stripping the mold from the pattern in Table 21.

Molding machines. There are hand, pneumatic, hydraulic, mechanical and electromagnetic molding machines.

Modern foundries employ pneumatic molding machines almost exclusively, as well as mechanical molding machines that pack the molds by centrifugal force (sand slingers).

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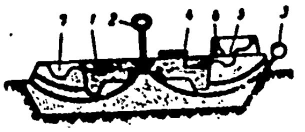
Table 19

Methods of Hand Forming

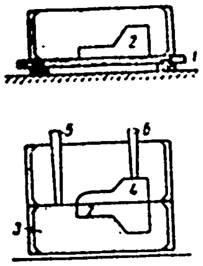
1. Forming of Pattern
Floor Forming
Open Floor Forming



1. Placing of pattern 1 on "bed"* of mold with levelled upper surface, made in floor of shop, and driven home by light blows with a hammer into the earth over the entire height. Horizontal position of upper surface of pattern checked by means of the level 4. Packing of earth around pattern and evening it with top of pattern. Boring of air passages by vent 3. Cutting of runner passage 6 and overflow receiver 7 in pattern. Stripping of pattern by aid of lifting hook 2 and insertion of pouring cup 5.

Used for simple castings in individual production (usually not requiring machining) with flat upper surface (plates, gratings, disks, core frames, etc.).

Flask Molding
Molding in Paired Flasks



3. Drag 3 on lower half of pattern, placed on match-plate 1. Rotation of drag together with match-plate by 180° and positioning it on level area on floor of shop. Laying of upper half of pattern 4 on lower half 2 according to centering pins or dowels. Strewing surface of separation of mold with parting sand. Filling cope forming the riser 5 and the sprue 6. Separation of mold into two halves, stripping of pattern, finishing of working surfaces of mold, setting of cores, and final assembly.

Used for various castings on whole patterns or patterns in parts, having flat surface of separation, in individual and small-series production.

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* The kinds of "bed", soft and hard, and the method of preparing them, are described in courses on foundry production.

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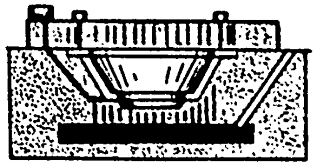
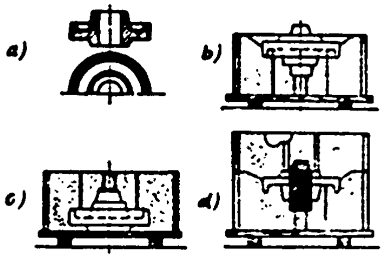
Closed Pit Forming



2. Smoothing of upper surface of mold formed by preceding method, sprinkling of dry parting sand, and covering with flask. The flask is filled with the molding sand, and in this way, a riser, a riser neck, and a pouring cup are formed around a special pattern. The position of the flask is fixed by pegs, and the flask is removed to draw the pattern from the pit, followed by stripping of the mold. The cores are set by setting pins and the flask is finally positioned.

Used for castings of various weights with a flat or figured upper surface with whole patterns or patterns in parts in individual production.

Recess Molding



a) Casting; b) Filling drag; c) Recessing operation; d) Assembled mold

4. Recessing, with a scalpel, the part of the sand at the joint surface that prevents the stripping of the pattern.

Used for casting with whole patterns with a curved surface of separation, in individual production.

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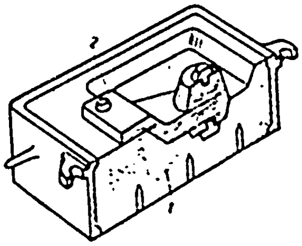
Molding with Gauge Board

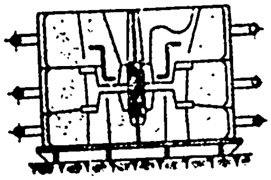


1 - Gauge Board; 2 - Pattern

5. Special insertion of molding sand then packed with particular care (sometimes thickened with cement or plaster) with gaugeboard playing the role of a shaping molding board, allowing the process of preparing a mold with a curvilinear surface of separation to proceed as in molding with a flat surface of separation by scheme 2.

Used for castings with patterns having a curved surface of separation in small scale production.

Three-Box Molding

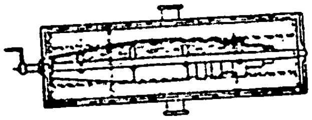


7. See scheme 3 of molding. The third operation is performed in sequence on the cheek and the cope.

Used for castings on patterns that require parting of two surfaces, in individual and series production.

II. Strickle Molding

Molding with strickle rotating on horizontal spingle



8. Finishing of cavity of mold by rotating strickle about horizontal axis lying in parting plane of mold (the strickle corresponding to a radial section of the casting).

Used for molding rollers, pipes and other solids of revolution of elongated shape in individual production.

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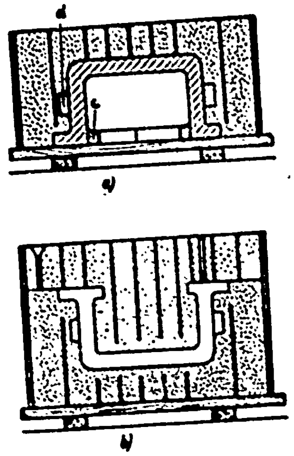
Molding on Patterns with Removable Parts



a - Filling the drag; b - Assembled mold; c - Removable block; d - Removable ring

6. When there are bosses on the outside of the casting, which prevent stripping the pattern from the mold, the parts of the pattern corresponding to these bosses are made removable and are attached to the body of the pattern on cotters or pins. On stripping the pattern from the mold, the removable parts remain in the molding sand and are removed separately.

Used for castings with patterns that cannot be taken apart over the entire cross section, in individual production.

Molding with Strickle on Vertical Spindle

9. Inserting outlines of mold in drag with strickle rotating on vertical spindle. The outlines of the mold are also inserted in the cope by the aid of a strickle.

Used for casting cylinders, covers, boilers, tanks, and other solids of revolution of cylindrical or conical shape.

Molding on Broaching Strickle Inserting

10. Inserting outlines of mold and core by moving a flat strickle along a guide line (the shape of the strickle corresponding to the cross section of the casting).

Used in casting types of curvilinear profile, elbows, and ducts.

Molding on Skeleton Pattern

11. Pattern prepared from separate ribs whose thickness corresponds to the thickness of the casting walls. In molding the sand is swept up from the windows between the ribs by means of a sweep, the advancing working part of which has the same height as the rib, and has the same length as the width of the window.

Used for large castings of various configurations molded in loam or in brick.

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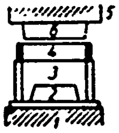
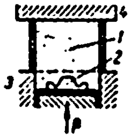
Table 20

Methods of Machine Molding

Molding Method	Characteristics and sequence of operations	Advantages and disadvantages	Field of Application
1. Squeeze Packing  	Filling of molding mix into box 3 and the backing frame 4 installed on it. Squeezing molding mix into box; table 1 platform of machine 1 with match-plate 2 mounted on it is raised during squeezing, pressing the cheek 6 attached to the fixed traverse 5 entering inside the backing frame, and squeezes the mix.	Simplicity of method and of design of molding machine and match-plate; high productivity Vertical non-uniformity in packing of mold	Relatively simple casting in low molds (150-250 mm high)
 	On motion of the match plate upwards, squeezing out the excess mix under the molding box 1 in the space between the movable match plate 2 and the fixed platform of the machine 3, into the molding box 1, pressed against the squeezing traverse 4	Packing of mold is most intense at surface adjoining the pattern Vertical non-uniformity in packing mold. Complex design of machine and match-board	Limited to isolated cases when special molding machines are used
2. Jolt packing	Packing mixture by kinetic energy of impact at each drop from height of 25-80 mm of table of machine (with match-plate and flask with molding mix attached to it). On repeated jolting (for 40-80 impacts) the degree of packing increases with each impact. The number of impacts given by the machine up to 12-140 per min.	The mold packed more strongly at the surface of the pattern. High productivity, universality. Vertical non-uniformity of packing mold. Weak packing of upper part of mold.	Molds in flasks of all sizes. When the flask is higher than 10 mm, a supplementary pacing of the top of the mold by hand ramming or by squeezing is compulsory

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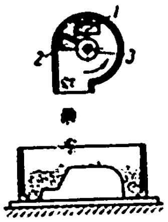
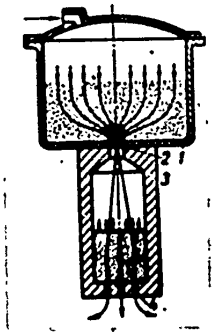
Molding Method	Characteristics and sequence of operations	Advantages and disadvantages	Field of Application
3. Packing by centrifugal force  	Seizure of the molding mix arriving on the conveyer through the opening 1 by the bucket 2 of the slinger head 3, which makes about 1500 revolutions per min, and throws it at high speed into the flask. Packing by means of the kinetic energy of the impact of the mix against the pattern, the flask walls, or the lower layers of the mold. The degree of packing depends on the rotary speed of the bucket and the speed of displacement of the head on the surface of the molding box	Uniform vertical packing of mold. Mechanization of screwing of molding mix into flask. High productivity. Universality	In individual and series production. Fills molding boxes of large dimensions. In large series and mass production fills molding boxes of large and medium dimensions; sand slinger operates in combination with broaching machines installed on carousels
4. Compressed air packing (sand blast process)  	The molding mix carried by compressed air from the reservoir 1 is blasted into molding box 3 through the opening 2 in the bottom plate. The air passes through the opening 4 in the molding box, thus packing the mold. Uniformity and degree of packing are regulated by the location and dimensions of the blast openings 2 and the fan openings 4		May be used for filling molding boxes in mass production (in practice, is used almost exclusively for filling cores

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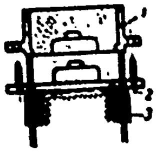
Table 21 Methods of Stripping Molds from Patterns after Packing

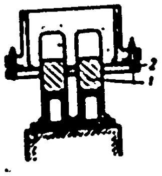
Pin Lift of Flasks



1. The flask 1 with the match-plate 2 is raised by the aid of the four pins 3. In some cases the lifting pins are connected in pairs, or may all form a lifting cleat or a lifting frame.

Used in molding on simple patterns of low height (without steep walls) which part easily from the molding sand.

Broaching the Pattern



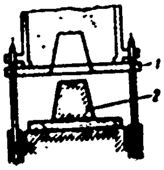
2. Lowering the pattern 1 across the corresponding sections of the broaching board 2 corresponding to its outlines.

Lifting Flask with Broach

3. Combination of method 1 and 2. Lifting flask on broaching board 1, thereby broaching the pattern 2 across the corresponding segments in the broaching plate.

Used in molding with high patterns parting with difficulty from the molding sand, especially when the walls are steep. Across the plate the entire pattern may be broached, or only individual parts of it.

Rotation of Flask



4. a) The table of the molding machine is rotated, together with the matchplate molds that are mounted on it about a horizontal axis. The receiving device is brought under the flask and the molding table with the pattern is raised.

b) Turning the table of the molding machine by 180° (tip over) about axis located outside it. The mold is stripped from the immobile pattern on lowering the receiving table.

Used in molding with high patterns difficult to part from the sand, when the mold has massive sand blocks or deep cavities.

[redacted]

A classification of the types of molding machines is given in Table 22.

In modern machine building, machine mechanized molding is beginning to be more and more widely used in small series production of large castings. In particular, in heavy machine building, pneumatic molding jolting machines are used, with tip-over and withdrawing tables of load capacity 5, 10, and 17 tons, as well as large jolting tables of load capacity 40 tons.

Sand slingers are universal machines for filling molding boxes with the molding sand and packing it at the same time. In the stationary designs, sand slingers are used in assembly line production in combination with hand broaching machines, installed on carousels.

On such installations, which are distinguished by high productivity, cores may also be made. Motive sand slingers, which are portable and move on rails, or are mounted on a monorail crane, are used in foundries of individual and small series production for filling large casting boxes. The characteristics of the sand slingers developed by TsKBLO are given in Table 23.

Core Molding. Molds of dry cores (without the use of a pattern) are built up for casting important and vital articles with intricate external and internal outlines (for example cylinders for air-cooled engines).

In making small and medium details, the assembly is done in machined aluminum or cast iron boxes of special construction called jackets.

Molds can be built up out of cores without using jackets, by binding the cores together with bolts or screw-clamps. In the production of a large casting, the molds are built up of cores in specially prepared, water-impermeable pits.

Making Shell Molds

The one-sided metal matchboard heated to 200-250°C, with the metal patterns, is covered by a molding mix of sand and a thermosetting plastic (usually a phenol-formaldehyde plastic), under the action of heat of the plate, the plastic in the layer of the mixture next to the plate is melted, and a uniform sand-plastic

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Table 22

Classification of Types of Molding Machines

By method of packing mold	By method of actuating	By method of stripping mold from pattern
Hand	Hand*	1) with pin lift for flasks 2) broaching
Squeezing	1. Hand*	1) flasks removed by hand 2) flasks raised by pins
	2. Pneumatic	
	3. Hydraulic*	
	4. Electro-magnetic*	
Jolting	1. Hand*	
	2. Pneumatic	1) hand lifting of flasks. 2) pin lifting of flasks. 3) with frame lifting of flasks. 4) with rotary table. 5) with tipping table.
Jolt-squeeze	1. Pneumatic	1) with hand lifting of flasks. 2) with pin lifting of flask. 3) broaching. 4) with rotary table.
Sand Slingers	1. Mechanical	

Note. Types of machines marked by * are seldom used in modern foundries.

shell, 3-10 mm thick, is formed on the matchboard. After removing the excess molding mix, the matchboard, with the semi-hard shell formed on it, enters the oven

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where the process of hardening the plastic and baking the shell is completed. The hard shell, representing a half, mold, is removed from the matchboard by means of pins and is paired with another shell-half mold, the necessary cores being inserted in the mold. The shell mold so obtained is poured in the usual way. The half molds are attached to each other by screw clamps, or bolts, or are glued together.

Table 23

Characteristics of Sand Slingers Designed by TsKBLO

Index	Type of sand slinger Stationary	 Motive on rail-road ring	 Motive of mono-rail type
Productivity in m^3/hr	10	16	up to 25
Area served by slinger head, in m	28	28 (without movement)	20 (without movement)
Maximum filling radius in m	4.0	4.0	6.8
Minimum filling radius in m	1.83	1.83	2.05
Height of inlet opening in head above floor level, in m:			
maximum	2.0	2.0	1.865
minimum	1.2	1.2	1.22
Volume of replaceable bunker in m^3	4.5	4.5	—
Consumption of electric power per m^3 of sand filled, in KWH	2.24	6.0	1.0
Control of head	Manual	Manual	From working place on slinger head
Dimensions of sand slinger in mm	9765x1950x4450	9700z1950x4350	9640x4070x5300

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The dimensional accuracy of castings made in shell molds is 0.3-0.7 mm per 100 mm, and is occasionally 0.2 mm for 100 mm in directions not intersecting the mold parting. The surface is cleaner than in the ordinary casting in sand and in cores.

The field of application of this method of molding is in mass and series production of small and medium castings of ferrous and nonferrous alloys.

Drying the Molds

As a result of drying, the molds, like the cores, become impermeable to gas and acquire strength in connection with the presence in the molding sands of binders, such as loam, oils, pitches, etc., which are adhesive in the wet state and are strong in the dry state. Dry molds are used only in individual and small series production of large and intricate castings. The molds are also superficially dried in large-series production. Chamber and portable driers, as well as continuous driers are used to dry molds. The superficial drying of molds is done in portable driers or in continuous driers. Gas burners and stationary or portable reflector driers with infrared radiation are also used for drying the molds.

Assembly of a Mold

The assembly of a mold consists in core setting, matching the halves of the flasks, installing pouring and overflow cups, and weighting the molds. In green molding, the process of assembly directly follows the stripping of the molds. In dry molding the mold defects discovered after drying must unconditionally be corrected before assembly.

The main operation of mold assembly is setting the cores in most cases, in the lower part of the mold. To assure correct setting of the cores, special core strickles are used.

The most accurate method of assembling intricate forms is the unit assembly. In contrast to the usual method of successive setting of the cores, most of the cores, in unit assembly, are lowered simultaneously in a special conductor.

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If the core points do not assure the stable position of the core in the mold, additional metal supports, or chaplets, are used, which are made of mild steel (for iron and steel castings). Welded to the metal, the chaplets remain in the body of the casting. For better weldability with the casting, the chaplets are protected from oxidation by tinning or copper plating.

In small-series and individual production, after setting the cores in particularly intricate molds, a control opening of the flask is performed, after which the pouring cups and overflow cups are installed.

To avoid the lifting of the cope during pouring under metallostatic action, the parts of the molds must be tightly connected to each other. For this purpose, weights, screw clamps, shackles, and bolts are used.

Technology of Core Production

Coremaking. Cores are mostly made of core mixes (see above).

To increase the permeability to gas, the cores are provided with vent passages, which it is usually attempted to introduce at core points not in contact with the metal during pouring. To increase core life, the cores are provided with a frame (armature) of steel wire or rods, and large core frames are sometimes of cast iron.

The cores reach the mold assembly room in either the green or the dry form. Dry cores are most widely used. Cores are made by hand or by machine. In hand making of cores representing solids of revolutions, strickles are used. Small cores of uniform cross section (circular or polygonal) are made on special machines by forcing the mix through a nozzle corresponding to the inside profile.

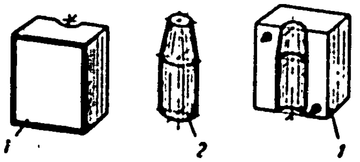

Fig.3

The cores prepared are stored for drying on metal drying plates or shaped pans (dryers) provided in either case with vent openings.

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Figure 3 shows a separable core box for making the core 2, of simplest configuration. The core sand is filled into the assembly box 1 through the upper face.

In cases where it is impossible to fill the core box through the face (the figured core of Fig.4) each half of it is filled separately. At the partings of each of the half cores a wire frame is inserted, and air passages are cut.

The two halves of the box are then tightly connected with each other by blows of a hammer (Fig.5).

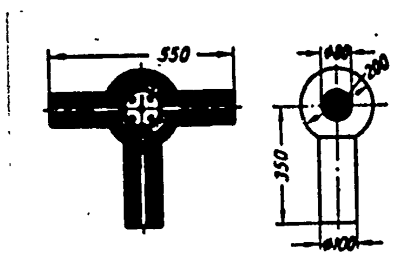

Fig.4

For convenience in making and drying figured cores, they are sometimes made in halves. The matching of these halves may be done by gluing them, after drying, with dextrin glue. Another method of comparing them consists in laying the second half, made and dried in advance, on the first half of the core after filling it, then rotating the box by 180°, and lowering the core onto the drying plate, dry half downwards.

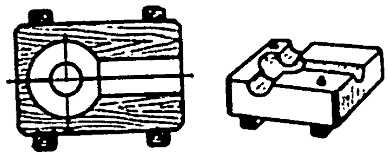

Fig.5

Cores are often assembled from parts: the parts are joined by "rivets" by pouring a low-melting alloy into openings of the core parts prepared in advance for joining.

Coremaking uses machines of the same types as mold making. The squeeze machines are used less often than the others. Jolting machines with a perpendicular table are very widely used in core making. The filling of the box with the core

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mix, the packing of the mix by jolting, the tipping of the table and the stripping of the core from the box is done by machine or manually. For making large cores, pneumatic jolt molding machines with tip-over tables of various sizes are used. Universal jolting tables, beginning with the very smallest sizes, are also used.

Table 24

Characteristics of Sandblast Core Machines Designed by TsKBLO

Index	Machine designed for cores weighing		
Dimensions of core box in mm	Maximum 250x150x200	Maximum 500x300x310	450x240x240
Volume of portion of core mix in liters	0.6	3.6	12.0
Capacity of sand chamber in liters	1.2	--	60
Capacity of bunker in liters	3.86	--	150
Quantity of sand blast per hour	360	360	240
Consumption of free air for one sandblast, in m^3	0.015	0.05	0.1
Dimensions of machine in mm	1170x800x2400	2200x1035x1515	1600x1130x2500

In mass production, the sand slinger in conjunction with a carousel or an assembly line is used, in stripping or assembly line organization of the work of stripping the cores from the boxes and preparing them for filling.

Core making on sandblast machines is a high-productivity process. Cores of the most varied dimensions and configurations, even the most intricate, may be made by this method. The core mix is blown by compressed air into the core box having ventilating openings ("vents") for the escape of air. The operation of filling the core box lasts 5-7 sec. A good organization of the work of feeding the core boxes and stripping the finished cores from them is required if machine time is to be

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adequately utilized.

Table 24 gives the characteristics of sandblast coremaking machines.

Core drying. The hardening of the binding material, depending on its nature, takes place as a result of the removal of moisture or solvent, of oxidation, or of fusion. Depending on the type of core mix, the following limits for the drying temperature have been established:

Core mixes	Temperature in °C
Sand-oil	220-230
Sand on rezatol	220-250
Sand on oxidized petrolatum	220-240
Sand on shale tar	220-240
Sand on biphthal	200-220
Sand on synthetic resins	150-200
Sand-loam on water-soluble binders	160-180
Sand-loam on combination pitch binders	220-240
Water-free sand on pitch binders	230-250
Loamy mixes	325

The drying period depends on the cross section of the cores and on their volume (cf.Table 25), and also on the nature of the binders. With organic binders, the drying time varies from 1-4 hours; cores in which loam is used as a binder, require longer drying, from 6 to 16 hours (at a temperature of up to 300-350°C).

From 2-3 to 30-40 minutes is required for drying cores of mixes using synthetic resins, depending on their volume and the type of drying equipment. For drying cores, chamber dryers (batch type) and continuous dryers are used. For drying large cores, drying chambers of large capacity are used, analogous to those for molds, with hand loading or wheeled trolley. In series production foundries, chamber dryers are often used for medium and small cores, with the cores loaded by

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trucks onto the racks. For drying small cores, drying racks with movable or sector shelves are very convenient.

Table 25

Length of Core Drying

Volume of cores in cm^3	Length of drying in hours	
	Cores using organic binders	Loamy cores
up to 1	1-2	2-3
1-15	2-3	4-5
16-25	3-4	6-7
26-50	4-5	8-9
51-100	5-6	10-111
over 100	6-7	12-16

Continuous action or conveyor dryers are used in mass production and in large series production. The cores are dried in these conveyors on racks of bookcase type, and suspended on a chain conveyor passing inside the dryer. In the vertical continuous dryers, the rack

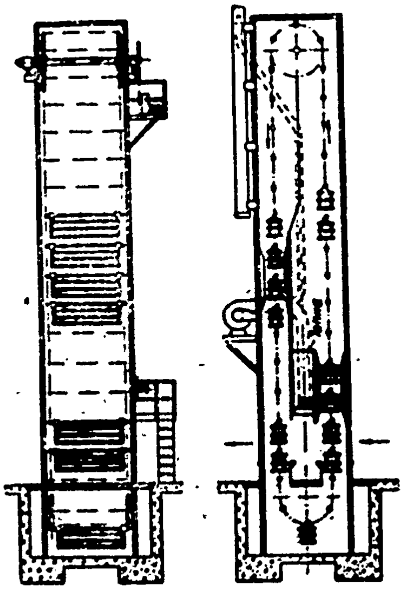

Fig.6

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frames are suspended from a vertically closed two-line conveyor (Fig.6). The products of combustion from the furnace located above the charging port, recycled, are distributed in such a way that in the upper part of the dryer, at about 2/3 its height, the drying temperature is produced. Below this level, on the side of the charging, the zone of heating is located, and on the other side, the cooling zone.

In horizontal continuous driers, the shelves are suspended from a single-line horizontal closed conveyor, the path of which also allows bends in the vertical plane. The drier furnace is located outside its working space, and is connected with that space by branching ducts for recirculating the products of combustion. The 2nd, 3rd and 4th branches of the conveyor pass inside the furnace, which, along the path of the conveyor, is divided into three zones, heating, drying, and cooling, separated from each other by partitions.

The quality of the drying in continuous furnaces is higher, and the fuel consumption lower, than in chamber furnaces, and they are preferred in all cases where the core assortment in mass production permits.

Assembly of Core Sets. After drying, the cores are finished to give them the required dimensions and surface qualities. Before the molds are assembled, the cores are mandatorily subjected to dimensional control, performed in individual and small-series production by a universal measuring instrument, or by the simplest gauges, and, in mass production, by gauges and more complex control devices.

The cores (like the working surfaces of the mold cavities) are in some cases given a wash to obtain a smoother casting surface. In small-series production, refractories, graphite, marshallite, or talc, suspended in water or another liquid, are used as the wash. Sometimes clayey or organic binders are added to this wash.

<u>Gating Systems</u>

The purpose of a gating system is to assure the smooth and shockless feeding of the metal into the mold, to regulate the thermophysical phenomena in the mold so as to obtain a sound casting, and to prevent the entry of slaggy inclusions and

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dirt from the sand into the mold. The elements of the normal gating system are (Fig.7) the pouring cup 1, the riser 2, the skimmer 3, the ingates 4, conducting the metal directly to the casting. The whole gating system must be filled during pouring to avoid aspiration of slag and atmospheric air into the mold.

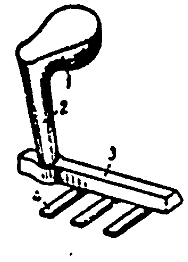

Fig. 7

The selection of the cross section of the elements in gray iron casting should be governed by the rule that the cross section of the downsprue must be larger than that of the skimmer, and the cross section of the skimmer must be larger than the total cross section of the ingates, i.e.,

$$F_d > F_{sk} > \Sigma F_{in}$$

Gating systems with a delay screen are widely used in mass production iron foundries. Such screens consist of a flat core, usually sand-oil, with openings for the passage of metal (Fig.8).

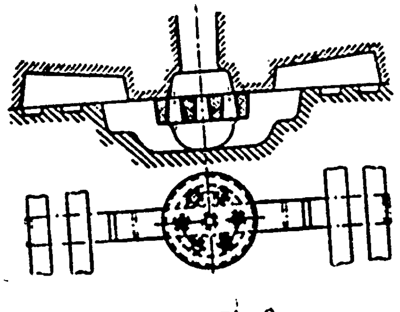

Fig.8

For gate systems with filter screens, the ratio

$$F_d : F_{sc} : F_{sk} : F_{in}$$

is taken from 0.8 : 0.7 : 1.2 : 1 to 1.2 : 1 : 1.2 : 1. The system in this case will still always remain a blocking one.

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The practical calculation of the gating system consists in determining the total cross sectional area of the ingates and in assigning the cross sections of all other elements, depending on the rate and time of filling the mold with metal.

The gating system for steel founding belongs to the category of "undelayed" or "unblocked". The basic cross section, on which the determination of the dimensions of all remaining elements of the gating system is based, is the base of the downsprue.

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MODERN METHODS OF FEEDING STEEL CASTINGS (Bibl.58, 25)

The process of solidification of the liquid metal in the foundry mold and in the formation of a shaped casting is always accompanied by linear and bulk shrinkage. The solidification of the metal, taking place from the periphery towards the center, leads to the formation of shrinkage cavities. Steel is distinguished by a higher amount of shrinkage than other alloys. As a result, the formation of shrinkage cavities in steel castings, and of the accompanying defects, is met more often than in casting iron and certain other alloys.

The volume of shrinkage cavities formed in steel castings and ingots, ranges from 3 to 6%, depending on the chemical composition of the steel, the weight and configuration of the casting, and on the conditions of pouring and solidification. Shrinkage flaws appear in those places where the steel hardens last. Below the shrinkage cavity is a zone of shrinkage brittleness, which likewise lowers the strength of the casting. The places with the greatest danger of shrinkage cavities are the units where the metal accumulates and the outflow of heat is slowed.

The improvement in the design of castings is one of the effective methods of improving their quality. In many cases, however, these improvements do not fully protect the castings from the formation of shrinkage cavities.

The total bulk shrinkage is made up of the shrinkage of the metal in the liquid state, in the temperature range from the beginning to the end of solidification, and from the end of solidification to the temperature of the surrounding medium.

To prevent the formation of shrinkage cavities in castings, so-called risers are widely used. They are artificial reservoirs of liquid metal fed by it to the casting during the entire period of its solidification. The metal arriving from the riser continuously compensates the bulk shrinkage of the solidifying casting.

Massive open risers were until recently used for feeding steel castings. As a result of the great consumption of steel on the riser, the yield of finished steel

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casting amounted to only 30-50%, and even with this, casting defects due to shrinkage were of frequent occurence.

The modern methods of feeding steel castings have been based on the indication of the great Russian metallurgical scientist D.K.Chernov, who established the fact, as early as the end of the last Century, that the most rational method of obtaining a dense casting is the method of gas pressure from all sides during the time of crystallization.

In 1935 the Chernov method for producing aluminum alloy castings was successfully applied by Academicians A.A.Bochvar and A.G.Spasskiy.

The ordinary open or closed riser can operate only where it is placed above the casting.

When the metallostatic pressure of the metal in the casting and in the riser is in equilibrium, no movement of the liquid steel from the riser in the casting will take place, and the casting, not being fed, will solidify with shrinkage cavities. When risers having liquid metal are made in the cavity, then, during the solidification of the casting, the additional pressure of the liquid metal, added to the force of the ferrostatic pressure, will provide the optimum feed conditions.

Closed risers in a low position, acting under pressure, can feed a casting whose height is greater than that of the riser.

There are a number of methods of producing pressure in risers. They include:

1) Use of atmospheric pressure;

2) producing elevated pressure in the riser and at the same time carbonizing the liquid steel and in this way lengthening the interval between the beginning and end of the solidification of the metal in the riser;

3) the pressure produced in the riser as a result of the intense formation of gas by some gas-forming substance specially introduced, accompanying the exothermic process of heating the metal in the riser;

4) pressure produced in the riser as a result of gas formation by a gas-forming

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substance introduced, accompanied by an endothermic process of absorption of the heat of the riser;

5) production of excess pressure in the riser at the instant of crystallization of the metal in the mold, by aid of compressed air.

For the utilization of atmospheric pressure in the riser cavity, a ceramic non-gas-forming rod with a small center opening is introduced into the riser. That part of the rod submerged in the riser is brought down to the thermal center of the riser. In this case the crystallization of the metal on the rod will be prevented, and the rod will serve as a conductor of the atmospheric pressure, which will act on the liquid metal in the riser as long as any rarefraction still remains there.

Excess pressure of more than atsmopheric may be obtained by using graphite or carbon rods. This gives a combination of three factors: a) increased pressure, b) exothermic reaction of combustion of the carbon and partial compensation of the heat losses of the metal in the riser, due to combustion; and c) reduction of metal consumption in the riser, due to carbonization of the metal in the riser.

An unfavorable factor in the use of graphite or carbon rods is the danger of carburizing the metal of the casting and obtaining an elevated carbon content in the zones close to the riser.

The use of a special gas-forming exothermic "charge", which gives off gases producing an elevated pressure in the riser without carburizing the steel, is likewise a very effective means of improving the feed of the castings. For this purpose, e.g., chalk may be used, or a mixture of slag, graphite, and thermite with water-glass. The charge, prepared in a grog or metal cartridge, is suspended in the cavity of the riser and, when the riser is filled with metal, serves as a source of heat for heating the metal of the riser and the gases, thus producing pressure. By varying the composition and quantity of the gas-forming substances, a higher or lower pressure may be produced in the riser. By varying the quantity of exothermic additives, the quantity of heat imparted to the riser may be regulated.

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The use of gas-exothermic charges requires the creation of conditions under which intense gas formation begin only after the mold is filled with metal and a solidified crust of metal is formed on the periphery of the riser.

The increase of the gas pressure developed in the riser must be held within certain limits. If the pressure is too high, the liquid metal of the riser may flow out of the mold, breaking through the crust of solidifying metal. Such discharges of metal from the mold likewise take place when the charge acts prematurely. In this case the metal is ejected through the down-sprue of the gating system.

The purpose of the grog cartridge is essentially to prevent the premature formation of gas by the charge when it decomposes under the action of the heat of the liquid metal. The heating of the material of the cartridge requires a certain quantity of heat withdrawn from the metal of the riser, and, as a result, increases the dimensions of the riser.

A gas-producing rod or cartridge is inserted in such a way that its lower end reaches the thermal center of the riser. Inside the rod (Fig.9) there is a small transverse channel, through which, at the moment of pouring, and at the moment of solidification of the casting, the excess gases leave the riser.

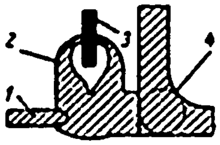

Fig.9 - 1 - Runner; 2 - Riser; 3 - Gas-Forming Rod; 4 - Fed Unit of Casting.

The use of this method to assure the feed of liquid steel to the castings during their solidification has proved most expedient under industrial conditions. The pressure, of the order of 1.3-2.0 atmospheres, so developed in the risers, is sufficient to obtain a dense casting at a high yield of finished casting, running up to 80-85%.

The effectiveness of the action of open risers may be increased by providing excess pressure over them, by the aid of compressed air (Fig.10).

This method of feeding castings may be used only on a large casting of rela-

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tively simple configuration. It cannot be recommended for use in all cases.

Present methods of feeding castings allow castings of good quality to be turned out even in cases where formerly, owing to structural features of individual units, their casting was not possible. Covered risers of small size may be made in the rods, and inserted directly in the areas of accumulation of material (Fig.11).

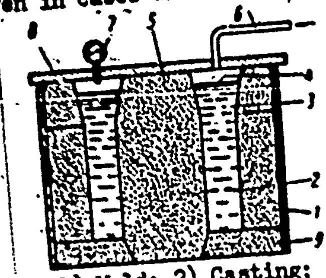

Fig.10 - 1) Mold; 2) Casting; 3) Riser; 4) Thermal Insulating Material; 5) Rod; 6) Tube with Compressed Air; 7) Manometer; 8) Metal Plate; 9) Flask.

The following typical cases of the arrangement of closed risers acting under pressure, are possible with respect to the casting:

a) the riser is placed on the same level as the casting (Fig.12);

b) the riser is set up above the casting (Fig.13);

c) at individual expanded places of the casting, independent risers are set, which may be done at various height levels.

The pouring may take place by passing all the metal through the riser. In these cases, the hottest metal will be in the riser towards the end of the pouring. These methods of feeding castings allow high grade steel castings of complex configuration to be obtained with a high yield of suitable metal.

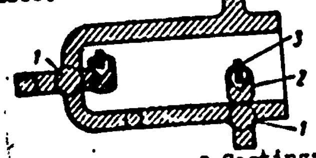

Fig.11 - 1) Fed Unit of Casting; 2) Closed Riser in the Form of Rod; 3) Gas-Forming Rod.

Technology of Knocking Out and Cleaning the Casting

Table 26 gives the process sheet of working the castings after pouring the molds.

Table 27 gives the principal characteristics and states the regions of application of mechanisms to knock out and clean the castings.

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The cleaning of the castings, and the removal of the fins and remnants of the beaten-off runners and risers is performed on various types of universal snagging machines: two-sided stationary, suspended lighthouse type, portable with flexible shaft, etc.

The grinding wheels used are mostly of carborundum and alundum.

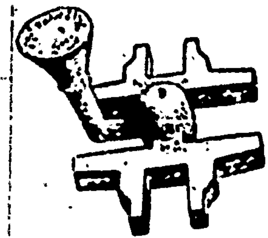

Fig.12

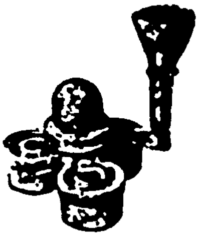

Fig.13

The chipping of the castings, their sawing and cleaning, is done by hand, using hand and pneumatic chipping tools.

Table 26

Process Scheme of Working Castings after Pouring Molds

Operation	Method of Performing	Equipment and Devices
Extraction of molds	Hand knockout Mechanized knockout	Pneumatic tool Suspended vibrators: a) jaw; b) on hanging frame Knockout screen: a) pneumatic vibrating; b) pneumatic jolting; c) mechanical vibrating Squeezing mechanisms.
Extracting cores from castings	Hand knockout Mechanized knockout	Pneumatic tool Jaw vibrators. Vibrating machines. Hydraulic chambers.
Removal of gates and risers	Hand knockout Oxygen frame cutting Machine cutting	Burner cutter. Gasoline cutter. Eccentric press. Disc saw. Band saw.
Cleaning the surface of the castings	Cleaning with jack stars and burnishing Cleaning with free-flowing abrasives: a) quartzite sand; b) cast iron	Drums: a) batch type; b) non-periodic action. Sand-blast machines, pneumatic: a) drum; b) universal chambers; c) special chambers. Sand slingers, centrifugal: a) drum; b) universal chambers; c) special chambers. Sand-hydraulic chambers.

Operation	Method of Performing	Equipment and Devices
Chipping the castings (removal of fins and edges, snagging of surface, cleaning and sizing of openings)	Hand chipping and mechanical chipping	Pneumatic tool Grinders: a) stationary; b) tower; c) portable Grinding and polishing machines; a) universal; b) special Metal-cutting machines: a) boring; b) milling
Inspection of castings		Instrumentation. Instruments for determining hardness. Defectoscopes. Devices for hydraulic testing.

In spite of the simplicity of the work of chipping and polishing the castings, the volume of this work becomes so great, with the increasing scale of foundry production, that it becomes timely to build specialized milling and snagging machines to perform these operations on certain castings. In the largest plants, this type of specialized machines is already in mass production (GAZ imeni Molotov).

Table 27

Mechanisms for Knockout and Cleaning of Castings

Mechanism	Purpose and Characteristics	Field of Application
Jaw vibrator	Knocking sand out of flasks and cores out of castings. The jaw of the vibrator, attached to the body, is applied during knockout to wall of suspended flask or casting.	Individual and small-series production of light and medium castings.
Suspended vibrating frame	Knocking sand out of flasks. The vibrators, suspended from a frame, are provided with hooks, by which the flasks are seized by the lugs. The knockout is caused by gravity. Capacity of frame: 1 to 3 tons	All forms of foundry work, from individual to mass production, for molds within the carrying capacity of the frame

Mechanism	Purpose and Characteristics	Field of Application
Pneumatic vibrating screen	Knocking sand out of the flasks, which are placed on a beam resting on the vibrator heads. The sand runs through a suspended screen, while the casting remain on the screen. Mechanisms resembling the jolting mechanisms of molding machines are used instead of vibrators for knocking out heavy flasks. Capacity of knockout screens: 1 to 10 tons or more.	Foundry work with mechanized continuous transport of the molding sand
Mechanical vibrating screen	An eccentric or disbalance mechanism produces the vibration. Horizontal or inclined screens are used. With inclined screens, the sand sifts through the screens and at the same time the castings descend along the screen in the direction of the slope. Capacity: 0.25 to 10 tons or more.	Foundries with conveyorized transport of the molding sand. Powerful mechanical knockout screens of capacity up to 40 tons are used in heavy machine-building
Automatic mold knockout	Consists of a mechanical vibrating screen, onto which the contents of the flasks - the castings and molding sand - are forced out by means of a pneumatic knockout. The sand is sieved downward through the screen, while the castings go to one side along the slope of the screen. The molds for knockout are pushed off the foundry conveyor under the push-rod by means of a pneumatic knockout. The two pneumatic mechanisms are successively put into operation automatically by means of an electric limiter of the flask travel.	Foundries pouring molds on conveyor with flasks of standard dimensions and absence of cross-pieces in lower flasks
Pneumatic vibrating machine for core knockout	Lifting of the cores remaining after the knockout, from the mold into the casting cavity. The casting is pressed in the machine between the support and the pneumatic chuck. The vibrator for knocking out the core is then turned on.	Series and mass production
Hydraulic chamber for core extraction	The cores are crushed and removed from the castings by a stream of water playing on them under pressure of up to 125 atmospheres. Advantages: absence of dust and possibility of using the water	Large castings with massive cores in individual and series production.

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Mechanism	Purpose and Characteristics	Field of Application
	for removing and washing the sand, which, after settling can be reused. When a jet of water mixed with sand is used, effective cleaning of the surface of the castings is achieved simultaneously with the core removal (sand-hydraulic cleaning). The castings enter the chamber on trolleys or are placed on a rotating circle.	
Cleaning drum	The surfaces of the castings are cleaned as a result of the friction between the castings when the drum revolves, and of the abrasive action of the white iron jack stars placed in the drum. The cleaning takes 0.5-2 hours (depending on the character of the castings). Aspiration of the dust given off during cleaning is mandatory. Drums of circular and square cross section are used.	Cleaning castings of all types and dimensions within the limits set by the size of the drum*
Pneumatic two chamber continuous-acting sand-and-shot blast apparatus	Cleaning surface of castings with a jet of free-flowing abrasive material — sand or iron shot — under pressure of compressed air. The sand or shot is entrained from the lower chamber through the opening of the cock by compressed air in a tube, and passes through a hose into a nozzle for cleaning the castings. The proper reserve of sand coming from the upper chamber is always assured by means of a system of valves in the lower chamber. Dry quartzite sand with sharp grains 0.75 to 1.5 mm in size, or iron shot, 0.5 to 1.5 mm in size, is used as the abrasive.	Cleaning castings of all types and dimensions** The apparatus is used in conjunction with chambers and drums of various types, in which the castings to be cleaned are placed.
Sand-shot blast chamber	The castings to be cleaned are placed in the chamber on a trolley or a revolving table, and are cleaned by a blast of sand (or shot) from a sand-blast apparatus. The chamber is equipped with mechanisms to return the used sand (or shot) to the sand-or-shot blast apparatus, and with ventilation devices.	Individual and small-series production of medium and large castings.

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Mechanism	Purpose and Characteristics	Field of Application
Sandblast drum	The castings to be cleaned are placed in the drum, and are tumbled when it revolves, being subjected at the same time to the action of a sandblast from several nozzles, connected by hose to the sandblast machine.	Series production of small castings
Centrifugal shot slinger	The principal mechanism for centrifugal shot-slinging cleaning consists of two parallel discs with radial blades between them. The shot enters at the center of the wheel. When the wheel revolves at 2000-2500 rpm, the shot is hurled by the blades, at high speed, into the working chamber, against the surface of the castings being cleaned.	Cleaning castings of small and medium size in chambers and drums of various designs
Shot-slinging drum	The cavity of the drum is formed by a curved plate conveyor, the front of which is covered by a removable cover. When the conveyor moves, the castings in the drum are tumbled, and their entire surface becomes accessible to the action of a continuous blast of shot, coming from above out af a shot slinger. The duration of a cleaning cycle is 10-15 min.	Series and mass production of light and medium castings(up to 250 kg)
Universal shot-slinging chamber	The castings are placed on a revolving table and enter the chamber on it. There they are subjected to the action of a blast of shot from one or two shot slingers. After the castings have been cleaned on one side, exposed to the shot, they are inverted and then cleaned again.	Individual and small series production of castings weighing up to 2000 kg
Continuous-action shot slinging chamber	The castings are hung on hooks from a horizontal endless belt suspension conveyor passing through the chamber. Within the chamber the castings are given a slow rotary motion and offer their entire surface to the action of the shot-blast from a row of shot slingers installed along the chamber walls. The number of shot slingers ranges from 2 to 8.	Mass-production foundries

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* (Table cont'd) Cleaning in ordinary drums is a difficult and time-consuming operation, and has been displaced by cleaning in sand slinging equipment (drums, chambers) which throw the abrasive by centrifugal force.

** Sand-shot jet cleaning of castings consumes very much power, and is also harmful from the viewpoint of industrial hygiene. It is gradually being displaced by other methods of cleaning - shot-slinging, with centrifugal application of the abrasive, and by the hydraulic method.

THE MELTING OF CAST IRON (Bibl.14,25,61,40)

Furnaces for Melting Cast Iron

The selection of the type of melting unit to obtain liquid iron depends on the following main factors:

1) Chemical composition, superheat temperature, and purpose of the metal;

2) Conditions of operations of the shop;

3) Volume of output;

4) Weight of castings;

5) Source of thermal energy, etc.

Modern foundries use the following types of furnaces for melting iron: cupola furnaces, reverberatory furnaces, electric furnaces, mainly arc and induction, cupola furnaces in conjunction with a reverberatory or electric furnace (the so-called dual or duplex process).

The principal melting unit everywhere used in iron founding, is the cupola, a Russian invention of the 18 Century.

Principal Raw Materials Used in Melting Cast Iron

The charge materials. The metallic charge consists of pig iron (sometimes also remelt) (GOST 4832-49, 4833-49, 4834-49, 805-49, 4831-49; ChMTU 3433-53; ChMTU 3432-53; ChMTU 3431-53), iron and steel scrap (GOST 2787-54), various ferro-alloys, foundry returns (risers, gates, spoiled castings, shavings) observing the following approximate ratio of the individual components: pig iron 20-40%; iron

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scrap and foundry returns, 40-60%; steel scrap up to 40%, and ferro-alloys according to calculation. The metallic charge must be properly prepared before melting.

Fuel. The fuel used for cupola furnaces is foundry coke, (GOST 3340-49), foundry anthracite (GOST 18-49) and heating anthracite.

These types of fuels may be replaced by the following substitutes: Blast-furnace coke (GOST 513-54; 2014-53; 3132-46), peat coke, charcoal.

The fuel for reverberatory furnaces consists of various kinds of brown coal and coal, as well as mazut (GOST 1501-52). Various fuel gases may be utilized as a source of heat in melting in the cupola or reverberatory furnace. The principal properties of fuel are given in Volume I, page 529.

Fluxes. Limestone, dolomite, fluorspar, apatite, open-hearth slag, are used as fluxes in smelting iron. The most widely used and cheapest fluxes are limestone and open-hearth slag.

The primary function of fluxes is to convert into slag the ash of the fuel and non-metallic materials included in the charge, as well as the products of oxidation of the melt and of the melted lining of the furnace.

Refractories. For lining the working space of cupolas and reverberatory furnaces, grog brick of refractoriness not less than 1670°C (GOST 390-54 and 3272-46) is mainly used. For cupolas and furnaces with a basic lining, magnesite brick or stabilized dolomite brick is used.

Melting Iron in Cupolas

The design of cupolas. The cupola is an ordinary shaft countercurrent furnace.

The molten iron and the slag that is formed, pass between lumps of fuel in the coke bed, and accumulate, until tapped, in the well or the breast.

The cupola is the only melting unit that allows the continuous melting of metal for many hours of foundry production.

The hourly productivity of cupola furnaces varies widely according to their dimensions, the character of the raw materials, the quantity of air supplied, and

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the design. Table 28 gives the characteristics of cupola furnaces.

Main indexes of iron melting in cupola. Coke bed height, 600-1000 mm above the bottom row of tuyeres; coke charge height, 130-150 mm; consumption of coke per ton of metallic charge, from 10 to 14%; consumption of flux, from 25 to 35% the weight of coke; air blast pressure from 400 to 1000 mm of water; quantity of air per square meter of cupola cross section in base belt 100-150 m^3/min; temperature of superheat of iron 1350-1440°C. With a blast containing added oxygen, the temperature reaches 1500°C; the temperature of the stack gases over the coke bed is 400-500°C; ratio of CO_2 to CO in exhaust gases from 50-50 to 70-30; time spent by metallic charge in cupola furnace from moment of charging to melting, 25-45 min.

Physico-chemical features of the process of melting iron in the cupola furnace. The main source of heat for melting and superheating the iron in the cupola furnace is the combustion of the oxygen of the fuel, which follows the following reactions:

$$C + \frac{1}{2}O_2 = CO;$$

$$C + O_2 = CO_2;$$

$$CO + \frac{1}{2}O_2 = CO_2.$$

Together with the reactions of oxidation of the carbon of the fuel, which takes place with the liberation of heat, the reaction of reduction of the carbon dioxide gas by carbon, with the formation of carbon monoxide, also takes place in the cupola.

The cupola may be divided arbitrarily into four zones, according to the character of the process of interaction between the carbon of the fuel and the oxygen of the blast. The following processes take place in the several zones of the cupola.

1) Well zone. There are practically no processes of oxidation. The gas phase consists mainly of carbon monoxide. The liquid phase consists of metal and slag, the solid phase, of incandescent coke.

2) The oxygen zone (located above the tuyeres). Intense combustion of fuel. The gas phase consists of carbon dioxide, carbon monoxide, oxygen, and nitrogen.

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Table 28

Principal Characteristics of Cupolas (Bibl.3)

a)	b)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
c)	0,7–1	1,5–2,5	2,5–3,5	3,5–4,5	4,5–5,5	5,5–7	7–8,5	8,5–10	10–12	12–14	14–16	16–18	18–20	20–22	22–25
d)	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	2000
e)	800	900	1000	1200	1300	1400	1500	1600	1800	2000	2100	2200	2300	2400	2800
f)	25	30	40	60	75	90	120	130	170	200	240	280	300	350	400
g)	5	10	15	20	25	30	40	45	50	60	75	90	105	125	150
h)	200	250	300	300	400	400	400	450	500	500	550	600	600	650	650
i)															
j)	–	6	8	11,8	14,5	16,4	20,6	29,4	36,4	40,3	52	64	75	81	100
k)	–	7,9	10,6	15,5	18,3	21,3	26	36,6	43,6	47,5	60	76	84	96	118

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* The smaller values relate to cupola furnaces with a single row of tuyeres, the larger values to such furnaces with a multi-row system of tuyeres.

Note. When the cupola furnace is operating with a blast enriched by up to 30% of oxygen, the relative productivity reaches 11 tons/hour - m^2. The cross section areas of the tuyeres is determined by the formula $F_{tuy} = 0.3\ F_{cup}$. The wells for a cupola furnace are built with a capacity of half an hour to one hour of its productivity.

a- Index; b- Cupola No.; c- * Hourly productivity in tons; d- Inside diameter of shaft in plane of tuyeres, in mm; e- Outside diameter of shell, in mm; f- Consumption of air in m^3/min; g- Power of fan motor, in HP; h- Diameter of air duct in mm; i- Total weight of charge, in tons; j- a) without well; k- b) with well.

The iron is molten.

3) The reducing zone. The reaction of reduction of carbon dioxide by carbon, with formation of carbon monoxide, becomes widespread. The iron, heated in the fourth zone, here melts.

4) The zone of preparation and preheating of the charge. Preheating of fuel

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and metal charge. Chemical interaction between products and combustion, solid metal charge, and fuel. Dissociation of the limestone.

Together with the melting of iron in cupolas, a high superheat of the iron must also be attained. The principal factors assuring the production of a high degree of superheat are the increase (up to certain limits) of the quantity of air forced into the cupola, and the increased consumption of fuel; the increase in the strength and combustibility of the fuel; the utilization of coke of optimum size; the preparation of the coke for the heat and its classification (in this way an iron tapping temperature of over 1420°C may be obtained); superheating the blast air; conditioning the blast air; proper preparation of the metal charge, and a literal conduct of the melting process; melting with the blast air containing added oxygen.

During the process of melting the iron in the cupola, its chemical composition changes. As a result of this, some of the elements of the iron are burned out, while the content of others is increased. As a rule, the content of iron, silicon, and manganese in the metal are reduced during the process of melting.

The most unfavorable factors are a considerable increase in the sulfur content of the metal, and a certain relatively small increase in phosphorus.

It is only in cupolas with a basic lining that the sulfur and phosphorus content can be reduced under certain conditions of melting.

The variation in the carbon content depends on a number of factors.

The factors favoring the increased carbon content during the process of cupola melting are as follows: increase in melting temperature, increased consumption of coke, increased manganese content, high well, low content of carbon in the metal charge, and basic furnace lining.

The factors tending to reduce the carbon content in the remelted iron are as follows: addition of steel scrap to the charge, increased silicon content, high initial carbon content.

The oxidation losses of silicon, and manganese will be the greater, the higher

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the concentration of these elements in the metal charge. The value of the relative oxidation losses of iron, silicon, and manganese, depending on the conditions of melting, the furnace lining, the quality of the fuel, and the other condition, is as follows: iron, 0.2-1%; silicon, 10-30%; manganese, 15-40%.

The primary factors leading to elevated losses of these elements are a low melting temperature, decreased fuel consumption, presence of a considerable quantity of iron oxides in the metal charge.

Depending on the sulfur content of the fuel during cupola melting, the sulfur content in the iron may increase by 50-100%.

The factors leading to increased sulfur content in the iron include working with high-sulfur fuel, using fine sizes of fuel, low melting temperature, high wells, and excessive height of the coke bed.

The saturation of the iron by sulfur is counteracted by the high melting temperature (operation on an oxygen enriched or pre-heated blast), increase of the manganese content in the iron, as well as by increase of carbon and silicon, increase of manganese dioxide in the slag, operations with basic furnace lining and basic slags, increased lump-size of coke, forced operation of cupola.

In the ordinary cupolas, the phosphorus of the metal charge passes completely over into the metal. If phosphorus anhydride is present in the fluxes and slag, about 50% of it is reduced and likewise passes into the metal.

The phosphorus content can be reduced only in cupolas with a basic lining with a cold run of the melting and a low silicon content in the peak; such melting conditions are inexpedient.

Slag is a by-product of the cupola. The weight of slag amounts to about 6-10% of the weight of the metal to be remelted. Cupola slag is formed as a result of the interaction of the fluxes with the oxides and the impurities: oxides of iron, silicon and manganese formed as a result of the burn-off of the corresponding elements (about 2% the weight of the metal), the oxides from the disintegrated lining (2-4%),

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the impurities introduced with the metal charge (up to 2%), and the fuel ash (up to 2%).

A cupola acid slag usually contains about 50% of silica, 25% of calcium oxide, 15% of alumina, and 7% of iron oxides. The basic slag contains about 35% of silica, 45% of calcium oxides, 10% of magnesia, 7% of alumina, and other substances.

Design features of special cupola furnaces. Cupolas with preheated well. Cupolas with a well usually yield iron at a temperature 50 to 100°C lower than the same cupolas without a well under similar conditions. In order to compensate for the lowering of the iron temperature, wells heated by mazut, pulverized coal, or gas, or heated by an electric current, may be used.

One variety of the ordinary cupola furnaces is a combination of the cupola with a hearth, heated by high frequency currents.

Cupolas with several rows of tuyeres. Cupolas with two or three rows of tuyeres operate more economically than those with only a single row.

Cupolas operating under a blast with added oxygen. Such cupolas differ little in design from the normal types. They are equipped with apparatus for supplying oxygen, the source of which may be the gasification of liquid oxygen, oxygen gas obtained directly from an oxygen plant, or oxygen from cylinders. Oxygen may be introduced into the cupola together with the air or separately, by means of pipes inserted in the tuyere openings.

Iron at a temperature of about 1500°C may be produced in cupolas with oxygen added to the blast air, which is very important for turning out malleable, modified, synthetic, and other special types of cast iron. Such cupolas were first introduced into founding on a large scale in the USSR industry.

If a high degree of superheat is required in a certain part of the metal melted by the cupola, oxygen may be used for blowing through the iron in the breast or the well. In this case, owing to the reactions of oxidation of the silicon, manganese and in part the carbon, a very high metal temperature can be obtained. Such metal

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must be afterwards modified.

Cupolas with preheated blast air. Cupolas operating on a preheated blast, may be divided into three groups:

1) Cupolas in which the physical heat of the cupola gases is utilized to preheat the blast air. In such installations, the blast air is preheated to 100-150°C.

2) Cupolas in which the physical and chemical heat of the cupola gases is utilized to preheat the blast air.

Table 29

Principal Characteristics of Reverberatory Furnaces

Index	Capacity of furnace in tons			
	5	10	20	30
Area of sole in m^2	6	8	10	14
Dimensions, (length, width and height) in meters	7.4 x 2.0 x 2.2	9.5 x 2.3 x 2.5	10.0 x 2.6 x 2.7	11.0 x 2.8 x 2.8
Duration of heat in hours	5	6	8	10
Mean hourly productivity in tons	1	1.66	2.5	3
Total weight of furnace in tons	65	100	120	170
Consumption of fuel, per heat, in % of weight of charge, when operating:				
on coal	40	38	35	30
on fuel oil	25	23.5	22	20

In this case a blast air temperature of up to 350-400°C is obtained. The metal tem-

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perature with such preheating reaches 1420-1450°C.

3) Cupolas in which separate furnaces are utilized for preheating the blast air, without utilizing the heat of the cupola gases. When separate furnaces are used, it is possible to heat the blast air to over 400°C, with a corresponding increase in the superheat temperature of the metal (to about 1480°C).

The operation of cupolas with preheated blast air is more complex than that of cupolas with ordinary or oxygen blast. It is possible to combine the preheating of the blast air with a small enrichment in oxygen.

Cupolas using liquid, gaseous, or pulverized fuel. To economize coke and increase the superheat temperature of the metal, liquid or pulverized fuel may be supplied through nozzles introduced into the tuyeres or somewhat above them.

Melting Iron in Reverberatory Furnaces

Design and function. Reverberatory furnaces for melting iron have a limited application and are used mainly in those cases where at the same time a large quantity of iron (iron with a very high degree of superheat) is desired, with low carbon and sulfur (malleable cast iron) or in the production of rolled iron beams. Reverberatory furnaces are divided, according to their construction, into stationary and rotary. Their capacity ranges from 5 to 40 tons. Furnaces of 7-15 and 25 tons are used more frequently than other sizes. The process of melting and the care of the furnace are simple. The costs of the installation of such a furnace are low.

Table 29 gives the principal data on furnaces of capacity 5 to 30 tons.

Physico-Chemical Features of the Melting Process

Melting in reverberatory furnaces may be run both either on solid or on liquid charges.

In operation on a liquid charge, the iron is first melted in a cupola.

As a result of the physico-chemical processes taking place in the furnace, the elements in the iron undergo the following oxidation losses: carbon, 10-30%;

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silicon, 20-50%; manganese, 25-65%; sulfur, 0-50%. The content of iron in the metal increases by 1-2%. When rotary reverberatory furnaces are used the oxidation losses of the elements are somewhat lower.

The total loss of material in oxidation during a heat in reverberatory furnaces amounts to 4-7%. A heat on a liquid charge yields the following oxidation losses of the elements of the iron: carbon, 15-20%; manganese, 5-10%. The silicon, phosphorus, and sulfur are practically unchanged.

Melting in Electric Furnaces

Electric furnaces are used in cases where a high grade alloyed, low-carbon and low sulfur iron with a high superheat temperature is required.

A heat in an electric furnace can use either a solid or a liquid charge. The latter method is more economical and is more often used (the iron is first melted in a cupola). For melting iron, electric arc furnaces with an acid lining and capacity up to 10 tons are mostly used. Less often, the type DHK furnaces, of capacity from 0.25 to 0.5 and 1 ton, which are usually used for producing nonferrous castings, and high frequency induction furnaces with a motor generator, of capacity up to 4.0 tons, or with a vacuum-tube generator, of capacity up to 60 kg, are less often used for melting iron.

Features of the heat. A heat in an electric furnace gives the smallest oxidation loss of metal. The quality of the metal produced is higher than with any other metal. The consumption of electric power when melting on a liquid charge in a triphase arc furnace amounts to 130-180 KWH per ton of metal. When a solid charge is used, the consumption of electric power is as follows:

Type of furnace	Capacity of furnace	Consumption of electric power
Triphase arc	0.5 ton	550-600 kw-hr/ton
The same	1.5 ton	525-575 "
	3 ton	500-550 "

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Type of furnaces	Capacity of furnace		Consumption of electric power	
Triphase arc	5	ton	450-500	kw-hr/ton
DMK type furnace	0.25-1	ton	600-650	"
High frequency with vacuum-tube generator	10-30	kg	900-1200	"
High frequency, with motor generator	60	kg	700-800	"
The same	100	kg	600-700	"

In furnaces with a basic lining, the consumption of electric power, is 30-60 KWH higher than in furnaces with an acid lining. The oxidation loss in heats in arc furnaces with an acid lining is 5-10% for carbon and 15-20% for manganese. In furnaces with a basic lining 5-10% of silicon and 10-15% of the manganese is lost by oxidation.

In high-frequency furnaces, up to 5% of the carbon is lost by oxidation, up to 10% of the silicon, and up to 10% of the manganese. The total oxidation loss does not exceed 2-3%. With a liquid charge, the oxidation loss is practically unnoticeable.

The duration of a heat in basic furnaces is 30-40 minutes longer than acid furnaces.

Melting of Malleable Cast Iron

The process of melting in the production of ferrite malleable cast iron is determined by the content of the principal elements, carbon, silicon, and manganese. The optimum composition of the iron used in USSR industry is as follows: carbon, 2.2-3.2%; silicon, 0.9-1.45%; manganese, 0.35-0.6%.

The content of sulfur and phosphorus is held within minimum and practically attainable limits: sulfur, 0.08-0.15%; phosphorus, 0.06-0.15%.

The alloying elements, chromium and nickel, are present in the malleable cast

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iron as unavoidable associates in quantities not exceeding 0.1% for nickel and 0.06-0.07% for chromium.

Irons with a higher chromium content than those indicated above are unsuitable for the production of ferrite malleable cast iron by the usually adopted process.

The irons usually contain traces of aluminum and titaneum. The introduction of titanium in quantities up to 0.1% to accelerate the process of its heat treatment finds limited application.

For melting these irons, practically any melting unit can be used.

In modern industrial practice, the production of malleable cast iron most often makes use of the duplex process.

In the machine-building industry, the foundries turn out malleable cast iron of mark KCh 35-10 only by the duplex process, which is most improved and answers best to the conditions of assembly-line mass production.

The malleable cast irons of marks KCh 30-3, KCh 35-4, KCh 30-6 and KCh 33-8 are also turned out in cupola furnaces. Electric furnaces, converters, with lateral air-blast, "Mechta" type furnaces, and coreless induction furnaces are used only occasionally, but the importance of these processes in the industrial production of malleable cast iron is negligible.

Irons of marks KCh 30-3 and KCh 35-4 are used only for decarburized white-heart iron mainly in the production of fittings. The principal marks of ferrite malleable cast iron are KCh 33-8, melted in cupolas, and KCh 35-10, melted by a duplex process, or, only as an exception, in electric furnaces.

Malleable cast iron of mark KCh 37-12 has no established application and is obtained as a byproduct in the production of mark KCh 35-10 iron.

Mark KCh 30-6 is used as an exception, since the improvement of the process of cupola melting assures the production of a higher grade iron of mark KCh 33-8.

In USSR industry, malleable cast iron has the widest use in automobile building and agricultural machine building. Its use is more limited in machine-tool building

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and the construction of expensive machines. The use of malleable cast iron in the other branches of machine building is negligible.

A tendency to the replacement of malleable cast iron by high-grade modified irons in tractor building, has been noted.

Features of Process of Cupola Melting in Production of Malleable Cast Iron

The optimum compositions of the cupola iron used, (in %), are as follows:

Components	For cupola process of producing KCh 38-8	For duplex process of producing KCh 35-10	
		Cupola and electric furnaces	Cupola and reverberatory furnaces
Carbon	2.9-3.1	2.5-2.9	3.2-3.4
Silicon	0.8-1.1	0.7-1.2	1 -1.2
Manganese	0.3-0.5	0.3-0.4	0.4-0.5
Phosphorus	0.1-0.15	0.12-0.15	0.12-0.15
Sulfur	to - 0.15	0.1-1.2	0.10-0.12
Chromium	to - 0.05	to - 0.07	to - 0.07

The features of the process of melting in the cupola furnace are determined by the task of obtaining a low carbon and low silicon iron. The allowable content of impurities, phosphorus and sulfur, as well as chromium, are assured by the careful selection of the charge materials. There are practically no special processes for reducing the content of the impurities phosphorus and sulfur in the production of malleable cast iron. Typical selections of the charge materials are the following:

For the cupola process:

Foundry iron of marks from LK-0 to LK-4	25-32%
Steel scrap	45-48%
Foundry returns	22-25%
Spiegeleisen of mark Z-3	0.5%

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For duplex process:

Foundry iron, marks LK-0 and LK-1	17-23%
Steel scrap	33-43%
Foundry returns	36-41%
Blast-furnace ferrosilicon marks FS-1 and FS-2	2.5-4.0%

The most important condition for obtaining low carbon iron from the cupola is the selection of a design and operating conditions that will assure the assigned carbon content of the iron, intense melting and superheat of the iron.

Intense melting is assured by increasing the content of air supplied to the cupola. This also reduces the carbon content of the metal, and consequently also reduces metal penetration by carbon.

At a constant air consumption, the intensity of melting increases, with decreasing coke consumption, while the carbon content of the metal is also lowered.

The design of the cupola, to preheat the air and enrich it with oxygen, allows cutting the fuel consumption and increasing the intensity of melting.

At constant consumption of coke and air, the carbon content of the metal varies uniquely with the carbon content of the charge. The relative metal penetration caused by carbon increases with the reduction of the carbon content in the charge.

In order to turn out low carbon irons, any of the existing cupola designs may be used, modifying only its hearth part to diminish the carburization of the liquid metal.

The modification of the crown part of the cupola for turning out low carbon iron consists of the following steps: a) in the complete elimination of the hearth, placing the tuyeres at the level of the sole; b) in the considerable reduction of the height of the hearth; and c) in the replacement of part of the coke in the hearth by a refractory plug. In gas-heated cupolas, the complete replacement of the coke bed in the hearth by the refractory material is possible.

The methods most widely used are the reduction in the height of the hearth and

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the replacement of the coke bed by a refractory plug.

The Process of Cupola Smelting in the Production of Malleable Cast Iron of Mark KCh 33-8

The iron is turned out in ordinary cupolas of a productivity of 2 to 10 tons an hour, coke-fired, using 380-530 Kg of coke per ton of finished casting, figured on conventional fuel, with the yield of 32-55% of finished casting.

A feature of the designs of these cupolas is the reduction in the height of the hearth, which does not exceed 100-180 mm above the lower edge of the main row of tuyeres. The composition of the charge materials and the optimum analysis of the iron produced by the cupola are given above. The steel scrap should make up not less than 35-40% of the charge. The sum of the carbon and silicon must not exceed 3.8-3.9%.

For the best separation of the slag, its fluidity is increased by adding flourspar or dolomite in addition to limestone and open-hearth slag.

The addition of alumina within the range of 0.02-0.05% as a deoxidizer, and in part, a modifier, is an absolute condition for making KCh 33-8 iron. The temperature of the iron at the taphole of the cupola is held between 1400-1420°C. The metal is drawn continuously from the cupola into ladles or into the mixer.

The Duplex Process of Melting Malleable Cast Iron of Mark KCh 35-10

The duplex process with cupola (with lowered hearth) and an electric furnace (in automobile building). A cupola of productivity 20 tons/hour has the following specifications:

Productivity, tons/hour	20
Fuel	coke
Diameter of cupola in throat; mm	1740
Cross sectional area of cupola, m^2	2.35
Useful height, mm	6100

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Number of tuyeres in first row	8
Number of tuyeres in second row	9
Cross section of tuyeres in first row, mm	260 x 120
Cross section of tuyeres in second row	70 x 100
Total cross section of tuyeres, m^2	0.325
Ratio of cross section of cupola to cross section of tuyeres	7 : 1
Blast air consumption in tuyeres, m^3/hour	16,000 *
Pressure of blast air at tuyeres, mm water	700
Coke consumption per ton of iron, in kg	130-140
Temperature of metal at taphole, in °C	1390-1410

The cupola is equipped with a rotary mixer of 7-8 tons capacity. The charge consists of 20% of foundry iron LK-00 **; 40-45% of carbon and low-alloy steel scrap; and 40-35% of foundry returns. The cupola iron product contains 2.8-2.9% carbon; 0.7-0.9% silicon; 0.35-0.4% manganese; 0.1-0.12% sulfur; 0.15-0.2% phosphorus; up to 0.07% chromium.

3.7% of blast-furnace ferrosilicon, and apatite-nepheline ore as required, is added to the cupola.

The cupola operates with an open slag hole. A typical slag composition is: 50% SiO_2; 20% AlO_3; 5% CaO; 1% MgO; 20% Fe_2O_3; and 1% P_2O_3.

The cupola is operated in two shifts of continuous operation.

The iron is uniformly collected from the cupola with a ladle of 1.25 ton capacity and is routed to the electric furnace, in which it is usually superheated to 1520-1560°C and brought up to 2.5-2.7% carbon, to 0.9-1.1% silicon, with the other elements held at the level already given for cupola iron. For this purpose up to

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* The maximum flow of the airblast is 20,000 m^3/hour, pressure 1600 mm of water.

** It is useful to add pig of marks LK-0 to LK-4 with an appropriate addition of blast-furnace ferrosilicon.

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0.2% of 45% ferrosilicon, up to 0.25% of 75% ferromanganese, and low carbon steel scrap is added to the electric furnace.

The specifications of the electric furnaces are as follows:

Capacity of furnace in tons	10	10	15
Productivity of furnace in tons/hour	15	15	15
Transformer power in KW	2000	2000	1800
Working voltage	104	120	104
Diameter of shell in mm	3060	3200	3300
Diameter of electrodes, in mm	350	350	350
Consumption of electric power in KWH/ton	120	175*	120

The furnaces are lined with an acid refractory, dinas, with repair of the slope once a day. A typical composition of the slag is as follows: 70% SiO_2; 10% Al_2O_3; 10.0% Fe_2O_3; 3.0% CaO; MgO, traces.

The life of the furnace lining is about 100 days of continuous operation. The metal is tapped uniformly from the furnace in 1-ton ladles. The metal in the ladle is deoxidized by adding 0.02% of alumina. From the tapping ladle the iron is repoured into casting ladles of 100-250 kg capacity, and is then poured into the molds.

This process assures stable production of malleable cast iron of tensile strength not less than 35 kg/mm^2 and elongation not less than 10% with a heat-treatment cycle of 72 hours for castings of cross sectional diameter up to 40 mm.

The duplex process using a cupola with silicate bed and an electric furnace, in automobile building. A cupola of productivity 10-12 tons/hour has the following specifications:

Productivity, tons/hour	10-12
Fuel	Coke

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*At high superheat of metal for thin-walled castings.

Diameter of cupola at throat, in mm	1400
Cross sectional area of cupola, m^2	1.43
Useful height, in mm	5000
Number of first row tuyeres	6
Number of second row tuyeres	6
Cross section of first row tuyeres, in mm	115 x 350
Cross-section of second row tuyeres, in mm	65 x 115
Ratio of cupola cross section to cross section of tuyeres	6 : 1
Blast air to tuyeres in m^3/hour	9600–10700
Pressure of blast air at tuyeres in mm of water	750–900
Level of silicate bed from lower edge of tuyeres in mm	220
Height of bed from lower edge of first row of tuyeres, in mm	1100
Weight of bed in kg	950
Weight of metallic bed, in kg	1000
Weight of coke charge in kg	90
Weight of limestone in kg	30
Metal temperature at taphole in °C	1365–1390

The arrangement of the silicate bed is dictated by the necessity of maintaining a sufficient layer of coke on its surface to assure the melting of the residues of metal and to prevent the cooling of the liquid iron.

The charge consists of 23% of foundry iron of mark LK-0, 13-35% of carbon and low-alloy steel scrap, and 40-45% of foundry returns. The cupola iron contains 2.5-2.6% carbon; 0.9-1.2% silicon; 0.3-0.4% manganese; 0.12-0.15% phosphorus; and not more than 0.06-0.1% of chromium. 2.48% of blast-furnace ferrosilicon and ferrophosphorus are added, if necessary, to the cupola. The cupola operates with an open slag hole. The regime of operation of the cupola is in two shifts of continuous operation.

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The iron is uniformly collected from the cupola with a 1 ton ladle and is routed into an electric furnace, in which it is superheated to 1515-1525°C, and the composition of the elements in it is brought up to 2.4-2.5% of carbon; to 1.2-1.35% silicon; to 0.35-0.45% manganese, maintaining the remaining elements at the same level as in the cupola iron. For this purpose, up to 0.7% of 45% ferrosilicon, and up to 0.3% of 75% ferromanganese and low-carbon steel scrap is added to the furnace.

The specifications of the electric furnace are as follows:

Capacity of furnace in tons	10
Productivity of furnace in tons	12-13
Transformer power in KW	2500
Working voltage	130
Diameter of shell in mm	3000
Diameter of electrodes in mm	300
Consumption of electric power in KW/ton	110

The furnace is lined with an acid refractory, dinase, with repair of the slope once a day. The metal is poured from the furnace uniformly in 1 ton ladles, from which, by means of pouring ladles of 200-100 kg capacity, the metal is poured into the molds. On removal from the electric furnace, the metal is deoxidized in the ladle by adding 0.02% of alumina.

This process assures the production of iron of considerably higher quality, with a tensile strength of 37.4 kg/mm^2, with an average elongation of 15.6%, and a heat-treatment cycle of 55-60 hours.

The duplex process using a cupola and reverberatory furnace (in agricultural machine building). The melting of the iron by the duplex process is done in a cupola of productivity 5-6 tons/hour, followed by transferring the metal directly into a shortened reverberatory furnace with lowered arch, with a bath of capacity 10-14 tons. The composition of the cupola iron is distinguished by an elevated content of carbon and silicon, as is given above. In the reverberatory furnace, the iron is

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superheated to 1500°C and is brought to a content of up to 2.45-2.65% carbon; up to 1-1.2% silicon; up to 0.4-0.5% manganese; up to 0.12% phosphorus, and up to 0.1% sulfur.

The oxidation loss of carbon in the furnace increases with the superheat temperature and with the iron oxide content of the slag. The cupola burns 8.9-10.6% of coke per ton of metal charge. The consumption of fuel oil in the furnace is 9.5 to 10%, depending on the volume of production.

Before the iron is charged, the furnace is heated to 1300-1400°C (in 40-60 minutes) after which the metal is introduced under the taphole. The hourly productivity of the unit is 6-6.5 tons of liquid iron. The heat in the cupola is completed first, and in the following hours the metal remaining in the furnace is poured.

The iron is tapped from the cupola at 1340-1365°C. It is discharged from the furnace at 1390-1415°C. During the process of superheating the iron in the reverberatory furnace a thin surface layer of metal is oxidized, and as a result the carbon content in the following portions of iron discharged from the furnace is sharply lowered.

Special Processes in Melting Malleable Cast Iron.

Boron-Modified White Iron

White iron, with a slight increase of the chromium content above the optimum value (0.05-0.07%) is entirely unsuitable for the production of ferrite malleable cast iron. The chromium retards particularly strongly the process of graphitization in both stages of annealing, and the complete dissociation of both the structurally free and the eutectoid cementite is not accomplished.

It has been experimentally fully established that a slight addition of boron to high-chromium iron assures its graphitization during annealing cycles of the usual duration. The amounts of boron added depends on the chromium content of the iron and range from 0.001-0.003% of the weight of the liquid metal.

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Table 30 gives the compositions of white cast iron and the additions of boron necessary to produce black-heart malleable cast iron from it.

Table 30

Chemical Analysis of White Iron, in %

C	Si	Mn	P	S	Cr	B	Addition of boron, in %
2.63	1.01	0.35	0.1	0.12	0.08	0.001	0.002
2.72	1.12	0.34	0.09	0.12	0.12	0.002	0.004
2.65	1.08	0.34	0.09	0.12	0.15	0.003	0.006

Ferroboron in the crushed form (granule size 1-3 mm) is added by throwing a package on the bottom of the ladle before filling it from the electric furnace. The ferroboron is added at the same time as the alumina.

The use of a gate made of castings with an elevated chromium content, modified by boron, does not give unfavorable results for the following heats.

Manganese-modified white iron is used in the process of producing ferrite malleable cast iron to prevent the segregation of graphite in the cross sections of thin-walled castings. Under the condition of large-series and assembly line production, this measure allows pouring the molds with iron melted in a single melting unit.

Under the conditions of melting iron by the duplex process given above, the production of high-grade white cast iron for castings 30-40 mm in sectional thickness is made possible by increasing the manganese content to 0.5-0.6%.

For modification, 75% ferromanganese of mark Mn-1 or Mn-2 is used. Its assimilarity depends on the mass of metal in the ladle and is taken on the average at 75%. The ferromanganese is added to the ladle before filling it with metal, in the form of 1-3 mm granules. The modification with manganese to increase the manganese content in white cast iron to 0.8-1.2% is also practiced in the production of pearlite

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malleable cast iron with granular pearlite.

Metallurgy Outside the Furnace (Ladle Metallurgy)

Treatment of Liquid Iron After Tapping from the Furnace (Bibl.14,61)

Various methods of treating the liquid iron at the time of tapping or thereafter, (in the well of the cupola, in the taphole, while filling the ladle, and in the ladle itself) have become widespread in the industry.

In this way the outside furnace processes of desulfurizing, alloying, and modifying, which substantially change the composition and physico-mechanical properties of the iron, are performed.

Desulfurizing iron. Treatment of iron in the ladle, before it is poured into the molds can effect a considerable reduction of the sulfur content. Special desulfurizing agents are used for this purpose.

The desulfurizing agents most widely used is calcined soda. When soda is added in quantities of 0.3-1% of the metal weight, the sulfur content of the iron can be cut by 50%.

Magnesia, a mixture of soda and calcium carbide, a mixture of calcium carbide and sodium chloride, etc., can also be used for this purpose of desulfurizing iron.

Alloying of iron. By adding various elements or ferro-alloys to the ladle, well superheated cupola iron may be alloyed.

The following elements may be utilized for alloying iron in the ladle.

Manganese is introduced in the form of a high-content ferromanganese. Silicomanganese may also be used.

Chromium is introduced in the form of ferrochromium. In this case the chromium content of the iron may be brought up to 0.5% and over.

Nickel is introduced in the form of an alloy containing 90% of nickel, or in the form of pure granulated nickel.

Molybdenum is introduced in the form of ferromolybdenum. Mo in the iron may be

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brought up to 1% and over.

Phosphorus is introduced in the form of high-content ferrophosphorus. By addition to the ladle, the phosphorus content of the iron may be brought up to 1% or more.

All the above enumerated elements, in melting large quantities of alloyed iron, may be expediently added directly to the charge. To produce relatively small quantities of alloyed cast iron, it is expedient to add these elements to the ladle, or, still better, to the taphole of the cupola when ladling the iron.

Modification of cast iron. Modification is one of the most widely used metals of obtaining high-strength iron (cf Vol.6, Chapter V).

It is an obligatory condition of the effective action of modifiers and the production of high-grade castings that the metal shall be at a sufficiently high temperature when the modifiers are introduced.

The best effect of any modification is obtained when the metal is melted in cupolas operating on a blast with added oxygen, or on a hot blast. The modification is also successful when the iron is directly treated with oxygen (in the well or ladle) or when it is reheated in the electric furnace.

In producing the usual modified gray cast iron, ferrosilicon or silicocalcium is added to the liquid metal.

The quantity of modifier added is generally determined by the mark of the cast iron being produced, and ranges from 0.4 to 1.2% of the weight of the iron (in calculating for ferrosilicon of mark Si 75). Smaller amounts of additive used in producing lower grade cast iron and larger amounts are used in producing higher grade cast iron. With large additions of modifiers, the superheat of the iron must be higher.

In order to reduce the heat losses of the liquid metal, preheating of the modifiers to 400-600°C is recommended.

Depending on the capacity of the casting ladle in which the modification takes

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place, the degree of grinding of the modifier varies. For small ladles of 50 kg capacity, the grain size of the modifying additions must range from 2 to 5 mm; for 100 kg ladles, 5 to 10 mm, and for still larger ladles, from 10-20 mm.

The best structure and mechanical properties of the iron are obtained when it is poured within two to five minutes after the end of the interaction between the modifying additions and the liquid iron.

High-strength cast iron may be obtained by mixing ordinary liquid gray iron with liquid low-silicon iron. Modification, either by low-silicon iron or by molten ferroalloys, very effectively improves the mechanical properties of cast iron.

Together with the use of modifiers causing the graphitization of iron, it is possible to use stabilizing modifiers, which are added to strengthen mild gray cast iron. In this case elements inhibiting graphitization are used as modifiers. Good results are obtained from stabilizing modifiers such as ferrosilicon, ferrochromium, or copper containing 15% silicon, 25% chromium and 30% of copper in the mixture. This modifier is used in an amount of about 1% of the metal.

High-strength cast iron with rounded graphite is produced by modification of cast iron with magnesium or its alloys, with subsequent or simultaneous modification by silicon (ferrosilicon) or silicocalcium. A feature of this process is likewise the necessity for having a sufficient superheat of the iron (1400-1450°C). The magnesium remaining in the cast iron (0.04-0.1%) assures the formation of graphite of rounded form, and yields cast iron of high strength and plasticity.

The percent of absorption of magnesium, depending on the method of its introduction, ranges from 5 to 40. The smallest absorption is observed on utilization of pure magnesium and the largest when it is used in the form of a rich alloy (with copper, silicon, nickel, etc).

This method of treating iron not only improves the mechanical properties but also sharply reduces the sulfur content (to 0.01-0.02%).

An excess of magnesium in cast iron leads to cementite formation on part or all

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of the surface, casting cavities, and brittleness.

Iron modified with magnesium must be poured without delay, since the effect of the modification decreases with the passage of time, and then disappears entirely.

The maximum time that the metal remains in the ladle should not exceed:

With ladles of up to 100 kg capacity	3 minutes
With ladles of 100 to 500 kg capacity	5 minutes
With ladles of 500 to 3000 kg capacity	10 minutes
With ladles of 3000 to 6000 kg capacity	15 minutes
With ladles over 6000 kg capacity	20 minutes

STEEL MELTING

Principal Raw Material (Bibl.50,60,8,23,24,59,51)

Charge Materials.

The charge materials in melting steel are coke steelmaker's pig iron (GOST 805-49), charcoal steelmaker's pig iron (GOST 4831-49), high grade coke and charcoal iron (GOST 805-49 and 4831-49), secondary ferrous metals (GOST 2787-54), and various blast furnace, electrothermal and metallothermal ferroalloys.

The composition of the most widely used ferroalloys is prescribed by (GOST 1415-49).

Oxidizers. In the production of steel, iron ore, rust, manganese ore, air, and pure oxygen, are used as oxidizers.

Iron ore must contain not less than 80% of iron oxide, with a minimum content of silicon, phosphorus, and sulfur. Its lump size must be 50-200 mm, its dust content not over 10%, and the ore must be dry.

Rust. Rust may be used as an inferior substitute for iron ore. The weight of rust required is several times more than that of the ore it replaces, and the process of oxidation is delayed.

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Manganese ore is used when the cementation process must be conducted and manganese in the steel held high. When it is used, the carbon cannot be rapidly burned out. Owing to the high percentage of gangue in manganese ore, it must be concentrated before use in steel founding.

Fluxes. For the formation of slag both in acid and in basic processes of melting, fluxes necessary for the formation of a slag of the assigned composition are used. Limestone, lime, fluorspar, bauxite, chamotte scrap and quartz sand are used.

The Melting Processes

Steel for figured casting is melted in converters, open-hearth, electric arc, and induction furnaces, by the acid or the basic process. At the same time, in steel foundries with mass production, where an uninterrupted supply of liquid steel is required, a duplex or triple process of steel making is used (cupola, converter, electric furnace).

Table 31 gives a short characterization of the processes of melting steel for shaped founding.

The reaction of the basic process of melting steel is shown under numbers 4, 6-14, 18-26. The reactions of the acid process of melting steel are shown by number 4, 6, 8-13, 15-17, 26-29.

The Physicochemical Feature of the Process of Steel Making

Oxidation of the impurities. The task of any process of steel production is to convert the metal charged into the furnace into steel of an assigned mark. The composition of the charge, depending on the type of melting unit, the character of the process, and on the local conditions, may be varied, within the widest limits, from 100% of iron to 100% of steel foundry returns.

After melting the metal charge, and after the formation of slag, the character of the processes are determined by the features of the physicochemical interactions taking place between these liquid phases in the high-temperature region. The oxida-

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tion of the impurities of the liquid metal takes place according to reactions 11-13 (Table 31).

Table 31

Short Characterization of Various Processes of Melting Steel for Shaped Castings

Process	Main source of heat	Main source of oxygen	Main raw materials	Function and applications
I. Conversion a) Basic (seldom used)	Physical heat of molten iron Oxidation of phosphorus and carbon	Oxygen of air	Thomas pig	Unimportant castings of mild carbon steel
b) Acid (small Bessemer	Physical heat of molten iron Oxidation of silicon and carbon	Oxygen of air	Converter iron	Castings of average importance, mostly with low carbon content
II Open-hearth a) Basic scrap process	Combustion of gaseous or liquid fuel	Products of combustion and iron ore	Steel scrap and solid iron	Heavy castings of carbon and alloy steel with low phosphorus content
b) Basic scrap-ore process	The same	The same	Steel scrap and liquid iron	Heavy castings of carbon and alloy steel with low phosphorus content
c) Acid scrap process	The same	Products of combustion and iron ore	Steel scrap	Large castings of carbon and low-alloy steel
III Electro-metallurgical a) Basic electric-arc furnace	Heat of electric arc	Iron ore	Steel scrap and iron	Thin-walled castings of important function out of carbon and alloy steel with low sulfur content
b) Acid electric-arc furnace	The same	—	Steel scrap	Thin-walled castings of important function out of carbon and low-alloy steel

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Process	Main source of heat	Main source of oxygen	Main raw materials	Function and applications
c) Basic induction furnaces	Induction electric current	Iron ore	Steel scrap	Production of alloy steel and alloys with special physical properties
d) Acid induction furnace	The same		The same	The same

Principal Metallurgical Reactions of Steel Making (Thermal Effects of Reactions Per Mole of Substance at t = 20 - 25°C and Constant Pressure).

Reactions of Combustion and Oxidation

1. $C_{(гр)} + O_{2(г)} \rightarrow CO_{2(г)} + 94\,230 \pm 100.$
2. $C_{(кокс)} + O_{2(г)} \rightarrow CO_{2(г)} + 96\,407.$
3. $C_{(аморфн)} + \frac{1}{2} O_{2(г)} \rightarrow CO + 29\,970.$
4. $CO_{(г)} + \frac{1}{2} O_{2(г)} \rightarrow CO_2 + 67\,600 \pm 100.$
5. $H_{2(г)} + \frac{1}{2} O_{2(г)} \rightarrow H_2O + 57\,812.$
6. $Si_{(т)} + O_{2(г)} \rightarrow SiO_{2(\alpha\text{-кварц})} + 208\,300 \pm 300.$
7. $2P_{(красн)} + \frac{5}{2} O_{2(г)} \rightarrow P_2O_{5(т)} + 360\,400 \pm 2000.$
8. $Fe_{(\alpha)} + \frac{1}{2} O_{2(г)} \rightarrow FeO_{(т)} + 64\,300 \pm 100.$
9. $FeO_{(т)} + Fe_2O_{3(т)} \rightarrow Fe_3O_{4(т)} + 4800 \pm 300.$
10. $Mn_{(т)} + \frac{1}{2} O_{2(г)} \rightarrow MnO_{(кр)} + 98\,100 \pm 700.$

Reactions of Oxidation of Impurities by the Oxygen of Ferrous Oxide

11. $2FeO + Si \rightarrow SiO_2 + 2Fe + 78\,900.$
12. $FeO + Mn \rightarrow MnO + Fe + 32\,280.$
13. $FeO + C \rightarrow CO + Fe - 36\,000.$

14. $CaO + SiO_2 \rightarrow CaSiO_3 + 21\,730 \pm 100.$
15. $FeO + SiO_2 \rightarrow FeSiO_3 + 5000 \pm 300.$
16. $2FeO + SiO_2 \rightarrow Fe_2SiO_4 + 11\,300 \pm 300.$
17. $MnO + SiO_2 \rightarrow MnSiO_3 + 1300 \pm 1000.$
18. $2CaO + SiO_2 \rightarrow Ca_2SiO_4 + 28\,400.$
19. $3CaO + SiO_2 \rightarrow Ca_3SiO_5 + 28\,700.$

20. $2Fe_2P + 5FeO \rightarrow P_2O_5 + 9Fe - 35\,100.$
21. $3CaO + P_2O_5 \rightarrow Ca_3P_2O_8 + 164\,000.$
22. $4CaO + P_2O_5 \rightarrow Ca_4P_2O_9 + 165\,000.$

23. $FeS + Mn \rightarrow MnS + Fe + 21\,700.$
24. $FeS + MnO \rightarrow MnS + FeO - 6000.$
25. $FeS + CaO \rightarrow CaS + FeO + 730.$

См. реакции 11—13.
26. $3FeO + 2Al \rightarrow Al_2O_3 + 3Fe + 201\,410.$

27. $SiO_2 + 2C \rightarrow Si + 2CO - 148\,900.$
28. $SiO_2 + 2Fe \rightarrow Si + 2FeO - 78\,900.$
29. $SiO_2 + 2Mn \rightarrow Si + 2MnO - 14\,410.$

The oxidation of carbon accompanied by the formation in the metal of carbon monoxide bubbles in the open-hearth and electric melting process, is termed the boiling process, and leads not only to the decarburization of the metal, but also assures the energetic mixing of the metal, the equalization of conditions and temperatures, and the removal of the dissolved hydrogen.

The process of boiling precedes the removal of silicon, manganese, and phos- STAT

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phorus.

Dephosphoration of steel. The most complete purification of steel from phosphorus is achieved under the following principal conditions: high content of ferrous oxide and calcium oxide in the slag, low silica and phosphoric anhydride in the slag, low carbon and manganese in the steel, and reduced temperature.

To avoid the reduction of phosphorus from the slag and its passage into the metal, oxidizing slag containing phosphates must be removed as completely as possible from the furnace before the beginning of the reducing period of the heat. The best dephosphoration conditions are assured by basic open-hearth furnaces.

Desulfuration of the steel. The desulfuration of the steel is performed after the completion of the boiling period of the steel. The successful progress of the desulfuration process is assured by the observation of the following conditions: the ferrous oxide in the metal and slag must be minimum; the slag must be active, with a high content of free calcium oxide; the temperature of the metal and slag must be high enough to assure the progress of the desulfuration reaction; the slag must have a low viscosity, and its quantity must be sufficiently great.

Steel with the lowest sulfur content may be produced in basic electric-arc furnaces. The metal is freed of sulfur during the reducing period. The quantity of slag in this period must not be lower than 4% by weight of the metal. To make the transfer of the sulfur from the metal to the slag as complete as possible, charcoal or powdered coke is added to the slag mixture. In this case, the reaction of combination of the sulfur in the slag into calcium sulfide,

$$FeS + CaO + C = CaS + Fe + CO - 31,530 \text{ cal}$$

is rendered irreversible, since one of the reaction products, the CO gas, is removed from the slag. The increase in the fluidity of the slag is effected by adding a certain quantity of fluorspar.

In melting acid Bessemer steel, a certain reduction in the sulfur is effected

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by treating the iron, before pouring into the converter, with active desulfurizers (mainly calcined soda or a mixture of calcined soda and calcium carbide).

Deoxidation of steel. The primary function of deoxidation is to free the steel of oxygen. The process of deoxidation consists of two stages:

a) Reduction of the ferric oxide dissolved in the steel by the aid of a deoxidizer which under the given conditions has a higher affinity for oxygen than iron has.

b) Removal from the steel of the oxides formed as a result of deoxidation.

In basic furnaces, the process of deoxidation is performed after the removal of the slag of the first oxidation period. The deoxidation may be performed either by the direct interaction of the deoxidants with the liquid metal (the so-called "settling" deoxidation), or by interaction of the deoxidant with the slag, by reducing the concentration of ferric oxide in the slag, on account of which a transfer of the ferric oxide from the metal into the slag takes place (diffusion deoxidation). Ferrosilicon, ferromanganese, carbon, carbon-containing substances (for example coke), alumina, and various compounded deoxidants, are used as deoxidizers.

Liquid iron may be used for the preliminary deoxidation in certain processes.

Order of introducing the ferro-alloys in the deoxidation of steel. Ferromanganese is added soon after the beginning of the refining in order to utilize the deoxidant properties of manganese; ferrochromium is added to well deoxidized hot steels; nickel is added to steel during the boiling period. Nickel is not oxidized in the liquid metal. The later addition of nickel, especially of electrolytic nickel, may increase the saturation of steel with gas. Ferrotungsten is added to the hot steel at the beginning of the refining. The steel with the added ferrotungsten must be added well mixed and held in the furnace. Before melting high-tungsten steel, a "washing" heat, containing a small percentage of tungsten, is recommended. In turning out chromotungsten steel, the ferrotungsten is first added, and then, after 15-20 minutes, the ferrochromium. Ferromolybdenum is added to the steel at the be-

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ginning of refining or during the boiling period. Ferrotitanium is added to well deoxidized steel 15-20 minutes before tapping. With a good mixing, up to 70% of the ferrotitanium is taken up. Ferrosilicon, in producing silicon steel, is added to the steel at the end of deoxidation. Ferrovanadeum is added to carefully deoxidized steel 20 to 30 minutes before tapping it.

Oxygen in the metallurgy of steel. Oxygen is a powerful agent for intensifying the processes of steel making.

The enrichment of the converter blast air with oxygen allows a considerable acceleration of the process of blowing through, the utilization of chemically cold iron for reworking, and the additional reprocessing of steel scrap, and it improves the quality of the steel.

The use of oxygen in the production of open-hearth steel for spraying the fuel oil, for enriching the air, for premelting the scrap, and for blowing into the bath during the refining process, allows a considerable saving of fuel and shortening of the heat.

The utilization of oxygen as blast in the bath of electric steel melting furnaces leads to an acceleration of the processes of dephosphorizing and decarburizing, and also facilitates the production of mild special types of steel.

Furnaces for the Production of Steel in the Steel Foundry.

Acid Bessemer converters. Table 32 gives the principal data characterizing acid Bessemer converters.

Table 32

Characteristics of Converters

Index	Capacity in tons			
	1	1.5	2	2.5
Diameter of working space in mm	700	800	900	1000
Outside diameter of cylindrical part in mm	1250	1460	1570	1670

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Index	Capacity in tons			
	1	1.5	2	2.5
Total height in mm	2900	3000	3300	3500
Air consumption in m^3/min	60	75	100	125
Blast pressure in atmospheres	0.2	0.3	0.3	0.4
Total weight of shell and lining in tons	3.7	6.1	8	-

Open-hearth furnaces. Table 33 gives the principal measurements of open-hearth furnaces of 5 to 40 tons capacity in operation on the basic process.

Table 33

Principal Dimensions of Open-Hearth Furnaces

At level of sill of working windows

Capacity in tons	Width in m	Length in m	Sole area in m^2	Depth of bath in m
5	1.5	4	6	0.35
10	2	5	9.5	0.4
12	2.1	5	10.5	0.42
15	2.25	5.6	12.6	0.45
20	2.4	6.3	15	0.48
30	2.7	7.4	20	0.54
40	3	8.3	25	0.57

The scheme of construction of a gas-fired furnace is given in Fig.14.

Electric steel melting furnaces. High-grade steel for thin-walled shaped castings is most easily produced by the electric melting process.

Table 34 gives the specifications of three-phase electric-arc furnaces.

In turning out high-alloy steel for light castings, in steel-shape foundries, high-frequency furnaces are used. They are also employed for melting the special

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alloy additives added in liquid form to the ladle containing liquid metal obtained from open-hearth or arc furnaces.

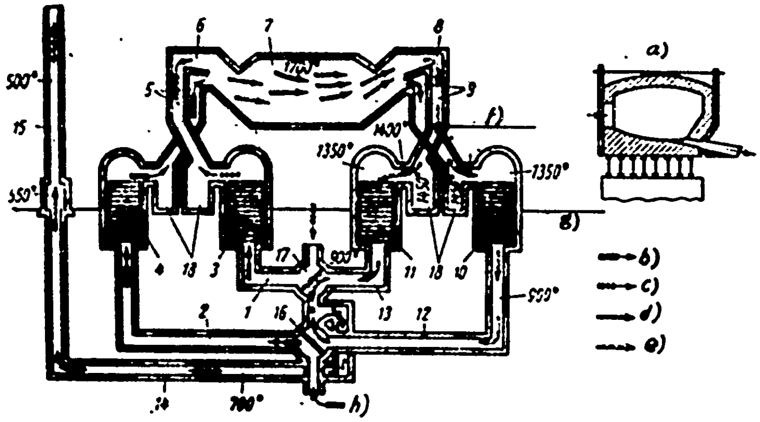

Fig.14 - Scheme of Open-Hearth Furnace: 1) Air Duct; 2) Gas Duct; 3) Air Regenerator; 4) Gas Regenerator; 5) Vertical Ducts; 6) Head; 7) Working Space; 8) Head; 9) Vertical Ducts; 10) Gas Regenerator; 11) Air Regenerator; 12) Gas Duct; 13) Air Duct; 14) Flue; 15) Smoke Stack; 16) Gas Valve; 17) Air Valve; 18) Slag Wells a) Cross section; b) Pure gas; c) Air; d) Working gas; e) Spent gas; f) Level of working hearth; g) Level of sub-hearth; h) Supply of gas from gas main.

Table 34

Specifications of Arc Steel Melting Electric Furnaces, Type DC and DChM

Index	DS-0.5	DS-1.5	DS-3	DS-5	DChM-3A	DChM-10-A
Capacity of furnace in tons	0.5	1.5	3	5	3	5
Allowable overload in %	20	20	20	20	20	20
Transformer power in KVA	400	1100	1500	2250	800	2000
Low-frequency voltage	190/110	200/116	210/121	220/127	210/121	220/127

Index	DS-0.5	DS-1.5	DS-3	DS-5	DChM-3A	DChM-10-A
Diameter of carbon electrode in mm	150	235	300	350	225	350
Diameter of melting space in mm	1100	1600	2000	2400	2000	2400
Depth of bath to sill in mm	215	275	340	430	450	500
Duration of melting in hours	1.5	1.5	1.75	1.75	-	-
Power consumed for melting 1 ton of solid charge in KWH	650	625	600	575	160	140

Table 35

Characteristics of High-Frequency Furnaces of Type PO

Index	Furnace type			
	PO-75	PO-100	PO-300	PO-600
Capacity in kg	100	250	500	2000
Power of generator in KW	75	140	300	600
Voltage	1400	1400	1900	1900
Frequency of supply current in cycles	2000	2000	500	500
Duration of heat in min.	30-40	35-45	60-75	70-85
Consumption of electric power for melting 1 ton of solid charge in KWH	900-1000	700-900	800-850	600-700

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High-frequency furnaces are built with a capacity ranging from fractions of a kilogram to 10-12 tons.

Table 35 gives the principal characteristics of type PO high-frequency furnaces.

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NONFERROUS CASTING

Principal Raw Materials

Charge Materials. The principal nonferrous charge metals, according to the grade and mark of the alloys, are used pursuant to the corresponding GOST in the form of pure metals or ready alloys.

Metals used in nonferrous casting: primary aluminum, by GOST 3549-47; secondary aluminum, by GOST 295-47 and 1583-53; magnesium, by GOST 804-49; copper, by GOST 859-41; nickel, by GOST 849-49; tin, by GOST 860-41; lead, by GOST 3778-47; zinc, by GOST 3640-47; silumin, by GOST 1521-50; magnesium alloys, by GOST 2581-44 and 2856-45; tin bronzes, secondary, by GOST 613-50 and 614-50; secondary brasses, by GOST 1020-48; brasses, by GOST 1019-47; various alloys.

Fluxes. In the production of nonferrous castings, the fluxes most frequently used are the chlorides of barium, potassium, calcium magnesium, manganese, zinc, and sodium. The fluorides of potassium, sodium, and calcium, cryolite, etc, are also used. The fluxes find their greatest use in the production of alloys of aluminum and magnesium.

Master alloys and their use. Master alloys are used to introduce, into industrial alloys, elements having melting points far above that of the main component of the alloy.

Master alloys are widely used in the production of aluminum and magnesium alloys, as well as in the production of special bronzes and brasses.

The main requirements that master alloys must meet are as follows: low melting point, uniformity of alloy, high content of high-melting components, and brittleness. Double master alloys contain one high-melting constituent, triple master alloys contain two. Master alloys are most often prepared in high-frequency furnaces.

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The Melting of Nonferrous Metals and Alloys

Table 36 gives the melting and pouring points of various nonferrous alloys.

Table 36

Melting and Pouring Points of Nonferrous Alloys

Alloy	Temperature in °C Melting point	 Pouring point
Copper	1250-1300	1170-1200
Tin bronzes	1200-1300	1100-1150
Aluminum bronzes	1150-1200	1050-1150
Zinc brasses	1150-1200	950-1100
Special brasses	1100-1150	920-1000
Aluminum alloy waste and shavings	750-800	660-750
Zinc alloys	500-570	430-500

Oxidation loss of metal and the atmosphere of the furnace. The oxidation loss of nonferrous metals and alloys during the process of their remelting depends on the composition of the alloy, the atmosphere of the furnace, the temperature, the duration of the heat, the character of the charge, and the type of the furnace.

Alloys containing elements with a high chemical affinity for oxygen and a low boiling point have high oxidation loss.

The data presented in Table 37 may be used for rough calculations.

Table 37

Oxidation Loss of Metal

Metal	Percentage oxidation loss Virgin metal	 Scrap and shavings
Copper	0.5-1.5	1.5-2

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Metal	Percentage oxidation loss	
	Virgin metal	Scrap and shavings
Aluminum	1.5-2.5	3-5
Bronze	2-3	5-6
Brass	2.5-3.5	5-12

Technology of production of nonferrous alloys. Table 38 gives the main data on the technology of production of the frequently used nonferrous alloys.

Table 39 gives the characteristics of the furnaces for melting nonferrous metals.

Table 38

Technology of Production of Nonferrous Alloys.

Alloy	Principal Raw Materials	Furnaces Used	Principal Data on Technology of Melting	Protective Cover
Bronze	Secondary bronze and scrap (less often clean materials)	Crucible, reverberatory, electric-arc and induction furnaces	When clean materials are used, copper is melted, then deoxidized with copper phosphide, after which zinc, aluminum, and other elements are added in the pure state, or as master alloys. Tin is added last.	Quartzite sand, broken glass, charcoal, borax, soda, potash etc
Zinc brasses	Secondary brass (less often clean materials)	Same	When clean materials are used, the copper is melted, then the zinc is added.	Charcoal
Special brasses	Brass with analysis certificate (less often clean materials)	Same	When clean materials are used, the copper is melted, then the master alloy is added. In producing brasses containing iron, manganese or aluminum, the aluminum is added last of all to the melt.	Not compulsory

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Alloy	Principal Raw Materials	Furnaces Used	Principal Data on Technology of Melting	Protective Cover
			In melting silicious and silicoplumbous brasses, copper, in which small portions of a copper-silicon rich alloy have been added, is melted. The zinc and lead are added before tapping.	
Nickel and copper-nickel alloys	Nickel and copper in master alloy	Crucible, induction furnaces with iron core, and without iron core, sometimes high-frequency vacuum furnaces	In melting nickel, half the metal is first melted under the flux, then the rest of the metal is added in several portions. In melting copper-nickel alloys, the copper is heated to 1300°C, and the nickel is then added. In melting an alloy with equal quantities of Cu and Ni, both metals are thrown in simultaneously (the Ni on bottom). In melting complex alloys, the Fe is introduced together with the charge or in the form of a master alloy. Mn is added in part to the charge and the remainder after the principal components have been melted. Zn is added after deoxidation. Secondary charge materials are in all cases put in first. Deoxidation is effected by a mixture of aluminum and magnesium, each 1% of metal weight	Glass, fluorspar, borax, calcined soda, mixture of potash (25%) and ground glass (75%)
Aluminum and its alloys	Aluminum, master alloys, alloys with analysis certificate	Crucible, reverberatory, and induction furnaces; resistance furnaces	Aluminum is melted first and the master alloy is then added If high-grade castings are required, the following methods are used: 1) melting under flux; 2) refining	(1) [redacted] STAT ,0% $CaCl_2$,50% (2)$CaCl_2$,15% Fluorspar, 85%

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Alloy	Principal Raw Materials	Furnaces Used	Principal Data on Technology of Melting	Protective Cover
			by gas (Cl and N); refining with heavy substances ($ZnCl_2$); 4) freezing out; 5) crystallization under 4-5 atmospheres pressure; 6) refining (sodium, etc).	
Magnesium alloys	Magnesium and master alloys	Crucibles (steel) and crucible resistance furnaces. Melting may be in furnace or in portable or stationary crucible.	(1) Flux (40-50% of metal weight) is melted in crucible; then Mg, master alloys and other additives, all heated to 120°C, are added.	(1) Anhydrous $MgCl_2$, 8% KCl_2, 37% $MgCl_2$, 85%
			(2) Small quantity of flux first added, then 50% of metal and flux again. After melting, Mg with flux is added in several portions.	(2) Anhydrous $MgCl_2$, 6% KCl_2, 35% NaF 2% CaF_2, 3%
			Care must be taken to have the Mg covered by the flux at all times. Easily fusible metals (Zn and Cd) are added at the end. After the whole charge is melted, the metal in the crucible is well mixed. Consumption of flux with former method of melting is 3-4%, with latter, 6-8%. Oxidation loss of metal 1.5-2.5%.	
			In remelting foundry returns up to 30% of flux is consumed.	(3) $MgCl_2$; 60% NaCl 40%
Zinc alloys	Zinc and master alloys	Iron or steel crucibles. Induction furnaces with iron core	Crucible is heated. Zn is added. Cu added in form of fine brass scraps. Pb, Cd, Sn added in pure form. Cu and Al added in form of 30% Cu-Al master alloy.	
Babbitt metal	Babbitt with analysis certificate (as an exception, pure metals)	Steel and iron crucibles	Technology of melting depends on composition of Babbitts and character of charge	Charcoal

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Table 39

Characteristics of Furnaces Used for Melting Nonferrous Alloys

Type and Mark of Furnace	Purpose	Principal Characteristics and Technical Indexes					
		Capacity, kg	Heated by	Consumption		Hourly Production, kg	Oxidation Loss, %
				Rated Fuel %	El. Power KWH/ton		
Crucible Hearth	Melting bronzes and brasses	100-500	Fuel Oil	10-14	-	100-300	5-8
Crucible Hearth	Same	100-500	Coke	15-20	-	100-300	5-8
Crucible PGP-0.18 PTP-0.25 RTS-0.30	PGP: melting RTS: distrib. for melting and preheating Al and Zn alloys	180-250	Fuel Oil	30-40 kg/hr	-	120-150	5
RTS-0.15		150-300	and gas	15-20 kg/hr	-	-	-
Reverberatory Furnaces "Moshta"	Melting bronzes and brasses	300	Fuel Oil	20-30	-	150-170	Up to 10
"Georgadze"		500-2000	"		-	250-500	3-5
"Monoplav"	Same	320-800	"		-	300-400	7-8
Furnaces for melting Al alloys NOP-1	Melting various aluminum alloys	1,000	"	15-20	-	400	-
NOP-2		2,000	"	20	-	450	-
NOP-3		3,000	"		-	500	-
NOP-7		7,000	"		-	500	-
NOP-12		12,000	"		-	800	-
Electric arc DM-0.25	Melting bronzes and brasses	250	Electric power	-	325	280	-
DM-0.50		500		-	300	480	-
Resistance-chamber stationary electric furnaces PK-40	Melting aluminum	150	Same	-	-	60	-
PK-80		280	Same	-	-	100	-
Resistance-chamber rotary electric furnaces A-90	Same	300	"	-	-	125	-
A-120		500	"	-	-	150	-
A-300		7,000	"	-	-	1,000	-
Electric crucible furnaces: SAK-0.15	Melting and preheating aluminum and copper alloys	150	"	-	650	50	1.5
SAK-0.25		250	"	-	600	75	1.5
SA-0.15A		150	"	-	600	55	1
SA-0.25A		250	"	-	550	85	1
SA-0.5A		500	"	-	550	125	1
SAM-0.5A		500	"	-	47	550	1
SAM-1.0A		1,000	"	-	34	1,500	1.5
SET-0.10B		100	"	-	1,000	50	3
SBT-0.15		150	"	-	75	150	3
SMT-1		1,000	"	-	720	125	3
Elec. ind. furn. with iron cores	Melting bronzes and brasses	600	"	-	300	400	1-2
Rotary gas recup. furn. flameless combustion	Melting magnesium alloys	1000-2000	Gas	450 m^3/hr	-	300-500	-

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Special Methods of Casting

The special methods of casting include casting in permanent metal molds, pressure casting, centrifugal casting, and casting in cast molds (precision casting).

Casting in Metal Molds

Casting in metal molds is used in series and mass production of castings of aluminum, copper, and magnesium alloys, and also of iron and steel.

Casting in metal molds considerably improves the economic indexes of production, by comparison with those of ordinary casting. The production of finished castings from 1 m^2 of mold area is increased by a factor of 4 to 5; the output per production worker increases by a factor of 2.5-3; the consumption of mold materials (with combination molds) decreases by a factor of 8 to 10; the machining allowances are decreased and the appearance of the casting is improved. The production cost of the articles is lowered by about 25%.

For casting in permanent molds, metal molds with horizontal and vertical joints; folding (Fig.15) and shake-out molds, rotating and mounted on pins (Figs.16 and 17) are used. The latter are usually used for medium and large size details. Special

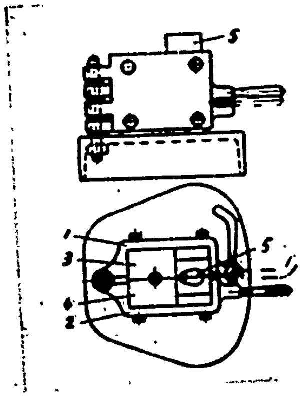

Fig.15 - Metal Mold of Folding Type: 1 and 2, Folds; 3 and 4 Halves of Mold; 5, Casting Cup.

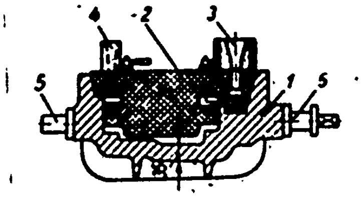

Fig.16 - Shake-out Mold: 1) Lower Metal Part of Mold; 2) Upper Part, Sand Core; 3) and 4) Gate and Riser; 5) Pins for Rotation.

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machines with varying degrees of mechanization of the process are also used.

The principal elements of metal molds include matrices and cores.

In designing the molds the minimum number of joints should be aimed at.

A large number of joints complicates the work, lowers the productivity, reduces dimensional accuracy of the casting and gives it a poor appearance. But at the same time it also makes it easier to eliminate the air from the mold.

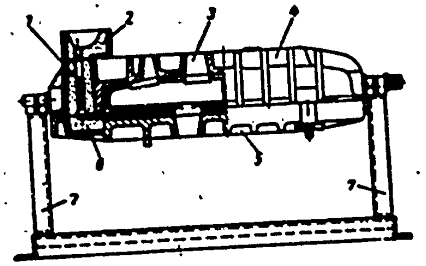

Fig.17 - Metal Turning Mold for Large Size Detail: 1) Core of Downsprue; 2) Casting Cup; 3) Central Core; 4) Body of Mold; 5) Second Half of Form; 6) Core of Ingates; 7) Risers.

To prevent the buckling of long matrices, they are made in parts, taking account of the thermal expansion on heating.

The iron, steel, copper and aluminum are used as materials for making permanent metal molds (cf Table 40).

The life of metal molds, when the correct operating regime is followed, in casting iron articles of small weight and simple configuration amounts to 8000-10,000 pieces, and with medium sized castings, up to 3000 pieces; for light steel castings, 500-700 pieces, for medium castings 100-250 pieces and for large castings 20-25 pieces. In casting articles of medium complexity, from low-melting alloys, the life of the molds runs up to 15,000-20,000 pieces.

To increase the life of metal molds and to prevent the superficial formation of cementite castings, the working surfaces of the molds are periodically covered with heat-insulating refractory materials, and with mold washes. Individual coatings, containing, for example, aluminum, ferrosilicon, or graphite, may also serve as surface modifiers.

Examples of the composition of coatings are given in Table 41.

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Table 40

Materials for Making Metal Molds (Bibl.11,61,62,71)

Material of Mold	Chemical Composition in % or Mark						Purpose of Mold
	C	Si	Mn	P	S	Other	
Iron	3.4-3.7	1.8-2.2	0.8-1.1	0.1-0.2	0.05-0.1	-	Small iron and steel castings
	3.4-3.6	2-2.5	0.6-0.7	0.1-0.2	< 0.1	0.1 Ni 0.4 Cr	Small and medium iron castings
	2.8-3.6	1.6-2.2	0.4-0.8	0.1-0.2	0.06-0.1	-	Castings of simple configuration of aluminum alloys and copper alloys
	3.3-3.6	1.7-2.25	1-1.05	0.1-0.2	0.07-0.1	1 Cu. 0.5-0.6 Cr	Same, of large dimension and complex configuration
	3.1-3.4	1.6-1.9*	0.8-1.2	< 0.25	< 0.12	0.1-0.25 Cr 0.35 Ni	Same, of particularly complex configuration with sharp transitions
Steel	4KhVS, 4KhNV, 5KhNV, 3KhV8						For thin, complex profiles and insertions requiring much labor to make, in casting of aluminum alloys and copper alloys
	St. 4, St. 5, 4KhVS						Metal cores of mold in casting nonferrous alloys
	St. 3, St. 4						Small details of mold (hooks, handles, etc.)
Copper	M1						Inserts for carrying off heat in casting nonferrous alloys
Aluminum	Followed by anodizing the working surface						For small batches (50-200 pieces) of small uncomplicated castings of low-melting alloys

* Silicon content indicated for modified cast iron.

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Table 41

Compositions of Coatings for Metal Holds (Bibl.11,68,71)

Ingredients	1	2	3	4	5	6
For Iron Castings in Grams ***						
Aluminum in powder	-	-	100	-	-	-
Chamotte in powder	-	-	-	-	50	75
Refractory clay	150	-	-	-	200	2 0
Marshallite	-	100-150	-	-	300	300
Water glass	45	30-50	15	100	-	-
Sodium chloride	15	-	-	-	-	-
Dutch soot	-	-	-	-	-	250
FeSi (75%) in powder	-	-	-	500	-	-
Water, in liters	1	1	0.5	-	*	**

For Steel Castings (parts by volume)						
Marshallite	74	-	-	-	-	-
Alkali sulfite	20.5	-	-	-	-	-
Fodder molasses	3	-	-	-	-	-
Refractory clay	2	-	-	-	-	-
Water glass	0.5	-	-	-	-	-

Ingredients	1	2	3	4	5	6
For Copper-Alloy Castings ** in %**						
Boiled oil	96	-	-	-	-	-
Zinc oxide	-	-	-	8.0	-	-
Powdered graphite	4	-	-	-	-	-
Kaolin	-	-	-	15.8	-	-
Naphthene soap	-	30	20	15.5	-	-
Kerosene	-	6	6	4.5	-	-
Mazut	-	57	67	51.5	-	-
Bone Meal	-	7	7	5	-	-
For Low-Melting Aluminum and Magnesium Alloys *** in Grams**						
Boric acid	-	-	-	-	60	-
Zinc oxide	80	-	280	-	100	-
Water glass	280	500	280	60	30	30
Whiting	220	300	110	140	-	80
Titanium dioxide	180	-	120	-	-	-
Black graphite	-	500	-	-	-	-
Calcined asbestos (in powder)	-	-	80	80	-	-
Water in liters (hot)	4	2.5	4	1.8	1	1

* To a creamy mass.

** To required consistency.

*** Composition 1 and 2 are used for small and medium castings; composition 3 and 4 for thin-walled castings. Composition 5 is used as the ground paste in casting particularly fine walled articles; after the ground coat, a mold wash of composition 6 is applied. Better results in preventing the formation of cementite on the surface of the castings is given by coating the mold, after each pouring, with acetylene soot.

**** Composition 1 is used in tin bronzes; compositions 2 and 3 for brasses; composition 4 for brasses and aluminum bronze.

***** Composition 1 is used for surfaces forming the most complex and thin cross sections (1-3 mm) in the casting; composition 2 for covering working surfaces on the molds; composition 3, for cross sections in castings larger than 3 mm; composition 4, for the surfaces of matrices, formed by the gates and risers; composition 5, for manganese alloys (working surfaces and cores); composition 6, the same warming mold wash, is used for the surfaces forming gates and risers.

Note. Liquid water glass of modulus of 2.5-3 and sp.gr. 1.45 is used in the above compositions.

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Nonferrous alloys for casting in metal molds must have high fluidity at only a slight superheat, adequate strength at a temperature close to the crystallization point, and minimum shrinkage.

The chemical composition of the iron being poured has a great influence on superficial cementite formation on castings.

Table 42 gives the compositions of iron (in C and Si) that are least subject to cementite formation on the surface.

For data on the compositions, properties, and regions of application of the nonferrous alloys cast in metal molds, see Volume 6, Chapter VI.

Table 42

Recommended Compositions of Iron for Casting in Metal Molds (Bibl.68)

Character of castings	Thickness of casting walls in mm	Content in %	
		C	Si
Without sand molds	3-5	3.4-3.8	3.2-3.4
	6-10	3.4-3.8	3-3.3
	11-20	3.3-3.7	2.8-3
	21-40	3.2-3.6	2.6-2.8
	41-80	3.2-3.5	2.4-2.6
With sand molds	3-5	3.4-3.8	3-3.2
	6-10	3.4-3.8	2.8-3
	11-20	3.3-3.7	2.4-2.7
	21-40	3.2-3.6	2.2-2.4
	41-80	3.2-3.5	2-2.4

The technological principles of designing details to be cast in metal molds. Details to be cast in metal molds must be designed with an eye to the following basic requirements.

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1) The length of the joint of the mold must assure free removal of the casting.

2) The surface of separation must be, as far as possible, flat.

3) Castings must not contain depressions preventing their removal from the mold and tending to destroy the mold, It must likewise be free of projecting parts that retard the shrinkage of the metal.

4) The castings must not have sharp transitions in wall thickness. This is especially true of iron castings in which cementite on the surface is formed at the thin places of the walls under rapid solidification.

Table 43

Design Parameters of Articles Cast in Metal Molds (Bibl.11,61,62)

Parameters	Material of casting				
	Iron	Steel	Al	Mg	Cu alloys
Radii of external and internal angles of pouring in mm	3	3	1	3-8	1.5
Thickness of unmachined walls in mm	3	15*	1	3	2
Inclination on vertical walls, counting from plane of separation of mold, in %	1.75	1.75-2.5	0.5-1	1°	0.75-1.75
Angle of metal cores forming the inner surface, in %	10	**	1.5-3	$2^{\circ}30'$	1.5-3

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* When combination molds are used (metal and sand core) the wall thickness is taken as 8-10 mm.

** In pouring steel, sand cores are mostly used.

5) The design of a casting should as far as possible assure the obtaining outside contours over the surface of the mold, i.e., without use of a core.

Table 43 gives a few parameters used in designing articles to be cast in metal

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molds.

The allowance for machining depends to a considerable extent on the accuracy of manufacture of the mold.

Table 44 gives rough values of the allowances for machining.

In fixing the tolerances for machining and the tolerances for inaccuracy of dimensions in casting nonferrous alloys into metal molds and under pressure, we may guide ourselves by the data in Table 45 and 46.

Table 44

Allowances for Machining and Allowable Deviations from the Measurements of Iron Castings, Placed in Metal Molds (Bibl.61), in mm.

Dimensions of article in mm		Tolerance per side				
Length	Width or diameter	Low or inner lateral surface	Inner lateral surface	Upper surfaces	With machined working surfaces (±)	With cast unmachined working surfaces (±)
To 25	To 20	0.7	0.8	1	0.3	0.5
25-40	15-40	1	1.2	1.5	0.4	0.6
41-60	25-60	1.2	1.4	1.7	0.5	0.8
61-100	30-100	1.4	1.6	2	0.5	1
101-160	50-160	1.6	1.8	2.2	0.6	1
161-250	100-250	2	2.2	2.5	0.8	1.2
251-400	100-400	2.2	2.4	2.7	1	1.2
401-600	150-600	2.6	2.8	3	1.2	1.4
601-1000	200-1000	3	3.2	3.5	1.2	1.5
1001-1600	200-1600	3.2	3.4	4	1.2	1.5

Pressure Casting

[redacted] making castings of alloys of magnesium, aluminum, zinc, and copper, and in isolated cases, of lead-tin alloys as well.

The pouring of the metal (fluid or semi-fluid) into the metal mold is effected under a pressure of several hundred atmospheres. The method of pressure casting may also combine details of materials of high strength, insulating materials, or those operating under friction and subject to wear (metallic, ebonite, porcelain, etc) with low-melting foundry alloys.

Table 45

Allowances for Machining of Castings of Pure Alloys in mm (Bibl.63)

Dimensions of casting in mm	Allowances per side Classes of accuracy (casting under pressure) 1st and 2nd	3rd, 4th, 5th, (casting into metal molds)
To 40	0.3	1
40-100	0.5	1.5
100-250	0.7	2
250-400	1	2
400-630	-	3
630-1000	-	3
1000-1250	-	4
1250-1600	-	4

Fig.18 and 19 show examples of inserts (armatures) cast in a casting.

To manufacture the working parts of molds coming in contact with the poured metal, alloy high-grade fireproof steel is used, for example 3Kh2V8, 5KhNM.

Table 47 gives data on the service life of molds of 3Kh2V8 steel with castings weighing about 0.5 kg. The life of the mold is shortened with a higher weight of casting and is longer with a smaller weight.

Details to be pressure-cast should be designed taking the following require-

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ments into account.

1) The outer outlines of the casting, and the outlines of its inner cavities,

Table 46

Allowances for Dimensions of Castings of Nonferrous Alloys Cast Under Pressure (Classes 1 and 2) and Into Metal Molds (Classes 3,4, and 5) (Bibl.63)

b)	a)														
	c)					d)					e)				
	1-class.*	2-class.*	3-class.	4-class.	5-class.	1-class.	2-class.	3-class.	4-class.	5-class.	1-class.	2-class.	3-class.	4-class.	5-class.
up to 25	0,05	0,08	0,2	0,4	0,6	0,04	0,06	0,2	0,4	0,6	0,10	0,20	0,3	0,5	0,6
25–40	0,06	0,10				0,05	0,08				0,10	0,20			
40–63	0,08	0,12	0,3	0,5	0,7	0,06	0,10	0,3	0,5	0,7	0,10	0,20	0,4	0,5	0,7
63–100	0,10	0,15				0,08	0,15				0,20	0,30			
100–250	0,12	0,20	0,4	0,6	0,8	0,10	0,20	0,4	0,6	1,0	0,20	0,40	0,5	0,7	1,0
250–400	0,15	0,40	0,5	0,8	1,0	0,12	0,30	0,4	0,7	1,0	0,25	0,50	0,7	1,0	1,2
400–630	—	—	0,7	1,0	1,2	—	—	0,5	0,8	1,0	—	—	1,0	1,5	1,7
630–1000	—	—	1,0	1,2	1,5	—	—	0,5	0,9	1,2	—	—	1,2	1,8	2,0
1000–1250	—	—	1,3	1,5	1,7	—	—	0,6	1,0	1,2	—	—	1,5	2,0	2,2
1250–1600	—	—	1,5	1,8	2,0	—	—	0,7	1,0	1,2	—	—	1,7	2,2	2,5

* In case of necessity, the accuracy classes may be assigned by the OST system for machined castings: class 3a for linear dimensions up to 50 mm, class 4 for dimensions up to 120 mm, and class 5 for dimensions over 120 mm.

a) Deviation from dimensions in mm (±); b) Dimension of casting in mm; c) All linear dimensions of castings; d) Thickness of walls, ribs, flanges, etc, not subject to machining; e) Linear dimensions of unmachined surfaces, of partly machined surfaces, and dimensions in joints.

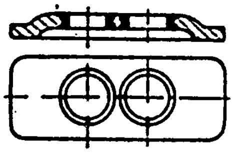

Fig.18 - Pouring Anti-Friction Bronze Inserts Into a Silumin Detail.

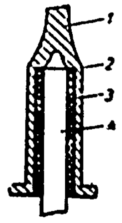

Fig.19 - Casting a Bushing Into a Cylinder: 1) Gate; 2) Casting; 3) Bushing; 4) Core Cutter.

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must favor the unhindered removal of the casting from the mold and the core from the casting.

Table 47

Service Life of Molds for Pressure Casting (Bibl.35,64,71)

b)	a)	
	c)	d)
e)	150 000	300 000
f)	45 000	120 000
g)	40 000	100 000
h)	5 000	10 000

a) Service life of mold (number of castings); b) Alloy cast; c) Mean; d) Maximum; e) Zinc; f) Manganese; g) Aluminum; h) Copper.

2) The casting walls must be as thin and uniform in cross section as possible, without local accumulations of metal.

3) The angles must be smoothly rounded with a radius not less than 0.5-1 mm.

4) Strength ribs and channel sections must be used to strengthen the details.

Table 48 gives the main parameters which must be used in designing details to be pressure-cast.

Figures 20-22 gives examples of the reconstruction of details in going over to pressure casting.

Table 48

Design Parameters for Details to be Cast Under Pressure

e)	a)		b)		c)			d)		
	f)	g)	h)	i)	j)	k)	l)	m)	n)	
									o)	p)
q) . .	1–5	0,8	0,2	0,5	1	5	10	0,8	6	10
r) . .	1,5–4,5	1,2	0,5	0,7	1,5	4	8	1	6	15
s) . .	1,2–4,5	1	0,5	0,7	1,5	3	5	1	10	20
t) . .	2–5,5	1,5	0,7	1	2,5	3	4	1,5	12	u)

a) Wall thickness in mm; b) Minimum taper in % of height; c) Limiting openings; d) Limiting sizes of cuts in mm; e) Name of alloys; f) Normal; g) Technically attainable; h) Outside; i) Inside; j) Minimum diameter, in mm; k) Not passing thru, equal to no. of diameters; l) Passing thru, equal to no. of diameters; m) Minimum spacing; n) Minimum diameter; o) Outside; p) Inside; q) Zinc; r) Magnesium; s) Aluminum; t) Copper; u) not obtained.

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The cleanness of the cast surface corresponds on the average to the 4-6th classes by GOST 2789-51; as the molds wear down, the cleanness of the surface is reduced.

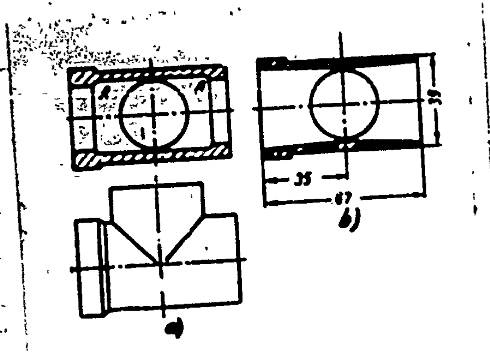

Fig.20 - T-piece a) Before Going Over to Pressure Casting; the Detail had Cuts at the Fillets, Preventing the Rapid Extraction of the Core; b) After Going Over to Pressure Casting, the Cores are Tapered.

Alloys for pressure casting must have the smallest possible shrinkage in the liquid and solid states, and sufficient strength at high temperatures, a narrow temperature range of crystallization, and high fluidity at low superheat.

Table 6, Chapter VI, gives a characterization and properties of alloys used for pressure casting.

Pressure casting machines are built with pressure chambers of piston-action and of compressor action.

The main parts of the machine are the compression chamber (cold or hot) and the mechanisms to control the mold and the compression chamber.

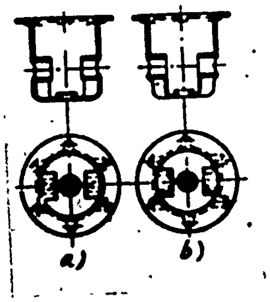

Fig.21 - Design of Casting in Going Over to Pressure Casting: a) Before Changeover; b) After Changeover.

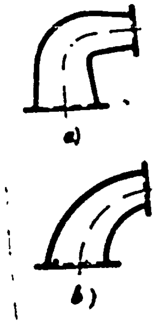

Fig.22 - Elbow: a) Before Changeover; b) After Changeover to Pressure Casting.

The compressor machines in which the metal is cast into the mold under the pressure of compressed air directly onto the mirror of the melt, placed in a closed boiler or bucket, are used only for casting unimportant details of low-melting alloys, mainly household articles.

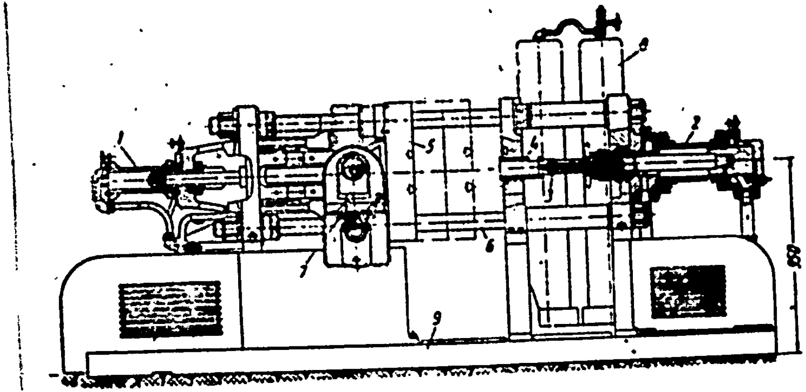

Fig.23 - Machine with Horizontal Cold Compression Chamber: 1) Hydraulic Cylinder for Shifting Molds; 2) Hydraulic Cylinder for Pressing; 3) Pressing Piston; 4) Compression Chamber; 5) Movable Table (Mold Holder); 6) Guide Rods; 7) Control of Machine; 8) Accumulaters; 9) Base.

The most widely used are the hydraulic machines with cold compression chamber, of the horizontal type (Fig.23) and vertical type (scheme on Fig.24). In these machines there is a separate melting unit, installed by the side of the machine.

Machines with vertical compression chambers operate on the scheme shown in Fig.24. Into the steel cylinder (the cyl-. of the compression chamber), the metal 1 is poured in the semi-fluid state, and is pressed by the piston 2 into the mold 3, which during the time of casting adjoins the runner. On the backstroke of the pi-

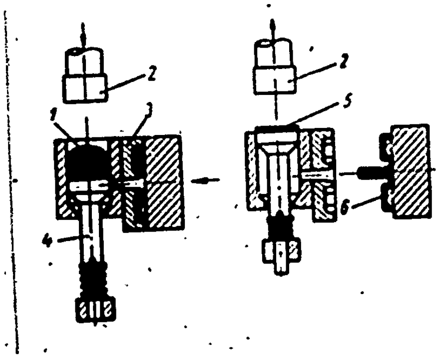

Fig.24 - Scheme of Operation of Machine with Vertical Cold Compression Chamber.

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ton 2, the counter-piston 4 is likewise raised, thus removing the excess metal 5 from the cylinder. The mold is then uncovered, and the casting 6 is pushed out.

Characteristics of Machines for Pressure Casting

Machine type	511	512	515
Maximum weight of casting in kg;			
of light alloys	1	1.8	1
of copper alloys and zinc alloys	1.5	4	2
Maximum surface of casting in plane of separation of mold in cm^2:			
of copper alloys	110	200	200
of light alloys	220	400	400
Maximum distance between fixed and moving halves of mold in mm	600	1000	1000
Maximum travel of halves of molds, in mm	310	440	500
Number of castings per minute*	2-3	1.5-2.5	2-3

Centrifugal Castings

According to the configuration of the casting, hollow and solid castings with free shrinkage, and hollow and solid castings with shaped configuration of castings and inhibited shrinkage are distinguished.

Any alloys may be used for castings, including alloys possessing low fluidity, as well as various combinations of alloys such as, for example, bronze and copper on iron and steel, etc.

The molds into which the metal is cast may be either whole or in parts, sand or metal (using various methods and degrees of cooling).

To increase the service life of the metal mold, to improve the casting surface,

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* The higher values relate to the zinc alloys.

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and to regulate the rate of cooling (preventing the formation of cementite on the surface in casting iron), the inner surface of the mold is coated with various thermal insulating powders and mold washes (Table 49).

Table 49

Coatings for Molds (Bibl.65,67,73)

Ingredients	Compositions				
	1	2	3	4	5
Refractory clay	-	-	-	2	13
Alkali sulfite	-	10	-	20.5	-
Water glass	1	20	-	0.5	-
Black for silvery graphite	2	20	-	-	-
Molasses	-	-	-	3	-
Salt	-	1	-	-	-
Drying oil or oxol	3	-	-	-	-
Powdered chalk	-	20	-	-	-
Zinc oxide	3	-	-	-	-
Crushed window glass or aluminum powder	1	-	-	-	-
Solar oil	-	-	-	-	55
Rosin	-	20	-	-	12
Bentonite	-	-	1	-	-
Marshallite	-	-	2	74	-
Water	-	10	6	-	-

Note: Composition 1, in parts by volume, is in the form of a ground paste for rough application; Composition 2 in parts by weight; used in casting hollow iron articles, bushings, shells, etc; Composition 3, parts by volume, used in casting thin-walled plumbing pipe in a double coating, followed by application of acetylene soot; Composition 4, in parts by volume, used in steel castings; Composition 5, in parts by volume, used in casting alloys.

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In casting directly into a metal mold (without a lining or lining powder application) the following ratios of the thickness of its walls to the diameter and thickness of the casting is taken (Bibl.65):

Outside diameter of casting in mm	Up to 100	100-200	200-300
Thickness of casting in mm	10-20	20-25	25-30
Thickness of mold wall in mm	30-35	35-40	40-45

Configuration

Outside diameter of casting in mm	300-400	400-500	> 500
Thickness of casting in mm	30-40	40-50	50-100
Thickness of mold wall in mm	45-50	50-60	60-80

The molds may be rotated about their vertical or horizontal axis, and accordingly two types of machines are used, vertical and horizontal.

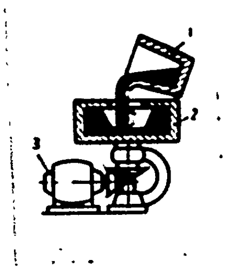

Fig.25 - Scheme of Centrifugal Casting with a Vertical Axis of Rotation of the Mold: 1) Ladle; 2) Rotating Mold; 3) Electric Motor.

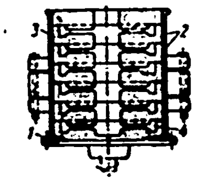

Fig.26 - Scheme of Centrifugal Casting of Wheels; the Axis of Rotation Coincides with the Axis of Symmetry of the Casting: 1) Rotating Table; 2) Flask; 3) Sand Mold; 4) Cavity Forming Casting.

When the ratio of the length of the castings to their diameter is not more than unity, it is expedient to cast on machines with a vertical axis of rotation of the

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molds (Fig.25).

On machines with vertical axis of rotation of the mold, details of shaped configurations such as flanges, gear wheels, pulleys, locomotive tires, wheels, etc., are also cast (Fig.26).

In casting shaped details not having an axis of symmetry (brake bands, levers, yokes, etc) the vertical axis of rotation usually lies outside the casting (Fig.27).

On horizontal centrifugal machines, hollow articles having a cylindrical inside surface, as well as solid articles (water and sewer pipe, gun-barrels, motor shells, bushings, ingots, wagon axles, etc) can be cast.

In rare cases, mainly for casting pipes, ingots, gun-barrels, and similar details, an axis of rotation with an angle of inclination to the horizon of 3-6° is used to assure sufficiently rapid runoff of the metal from the spout to the casting box.

The rotary speed of the mold in RPM may be determined by the formula

$$n = \frac{K}{\sqrt{\gamma (R-a)}},$$

where K = constant equal to 5520; R = outside radius of casting in cm; a = thickness

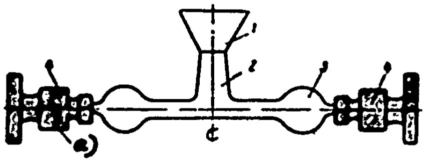

Fig.27 - Scheme of Centrifugal Casting of Shaped Articles - Vertical Axis of Rotation Lies Outside the Casting: 1) Pouring Cup; 2) Downsprue; 3) Closed Ring Runner; 4) Cavities of Castings a) On circumference of 12 details.

of casting in cm;   = specific gravity of alloy cast in g/cm^2.

The RPM calculated by this formula allows the production of the high-grade

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casting from iron and nonferrous alloys with a ratio between the outer and inner radii of the casting R/r = 1-3.

For steel castings, the upper limit of the ratio of the radii is below 3, and is determined in practice.

To assure the proper quality of the casting (without longitudinal fissures on the outer surface), with a high ratio of the radii, we must, for example, have recourse to a smooth or stepwise variation of the RPM during the rotation of the mold, as the layer of liquid metal increases.

The RPM for a vertical mold in casting hollow articles must be higher than that calculated, and is taken with the factor 1.18.

The free surface of hollow articles cast on a vertical machine represents a paraboloid of revolution, in which the thickness of the wall of the casting varies with height. This difference in the thickness of the walls must not exceed that established by the specifications for the method.

If at an RPM calculated by the formula given above, the difference in wall thickness exceeds the assigned difference, the rate of the rotary speed is corrected by the formula

$$n = K\sqrt{H},$$

where H = height of casting in cm;

$$K = 846\sqrt{\frac{1}{D_2^2 - D_1^2}}.$$

Here D_2 and D_1 are respectively the upper and lower diameters of the free inside surface of the paraboloid in cm.

In forming the outline of a casting of exceptional form with a vertical axis of rotation (by schemes of Figs.26 and 27), the speed must be sufficient to fill the cavity of the mold and exactly reproduce the outlines of the casting.

With this method of casting, the rotary speed of the mold is [redacted]y selected

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at a circumferential speed $v = \pi Rn/30$ of the point of the casting most remote from the axis of rotation. This speed usually ranges from 3 to 5 m/sec, and in occasional cases may reach as much as 8 m/sec.

The rotary speed may likewise be corrected according to the pressure exerted by the liquid metal on the wall of the mold, by the formula

$$p = \gamma\left(h + \frac{\omega^2}{2g} R^2\right);$$

where p = relative pressure in g/cm^2; γ = specific weight in g/cm^3; ω = angular velocity in 1/sec; g = acceleration of gravity (981 cm/sec^2); R = distance from axis of rotation to the point at which the pressure is measured, in cm; h = hydrostatic head, in cm.

Table 50

Composition and Properties of Details Cast by the Centrifugal Method

(Bibl.65,66,12,67,73)

Material Casting (Composition in %)	Name of Casting	Position of Axis of Rotation	Mold	Mechanical Properties of Casting		
				Tensile strength in kg/mm^2	Elongation in %	Brinell Hardness
Cast iron 3.6-3.65 C; 1.75-2 Si:0.5-0.55 Mn; 0.55-0.6 P; 0.07-0.08 S	Pipes, diameter 100-250 mm	Horizontal	Metal chill to 200°C, coated	24-26	-	175-200 (after heat treatment)
Cast iron 3.3-3.6 C; 3-4 Si; 0.8-1.2 Mn; to 0.2 Cr; 0.15-0.2 Ti; 0.06-0.08 S	Pipes, diameter 100 mm	The same	Metal chill to 300-400°C, with mold wash	-	-	-
Cast iron 3.5-3.65 C; 1.6-1.7 Si; 0.6 Mn, 0.5 P, 0.04 S	The same	The same	Loam	Ring strength 46	-	175-200
Cast iron 3.2-3.6 C; 2.0-2.4 Si; 0.7-1.0 Mn; 0.2-0.3 P, < 0.11 S; 0.2 Cr	Engine cylinder	The same	Metal, with dust application, chill to 200°C	20.7-22.1	-	212-240
Cast iron 3-3,3 C; 1.8-2.2 Si; 0.5-0.7 Mn; 0.3-0.4 P; < 0.12 S	The same	The same	Thin-walled (thickness 2-6 mm), dry sand facing on insert	-	-	190-210
Cast iron 3.4-3.6 C; 1.55-1.4 Si; 0.7-1 Mn; 0.11-0.17 P; 0.08-0.14 S modified with 75% FeSi	The same	The same	Metal mold in sections, with ground coat and mold wash, chill to 200°C	30.6-31.6	-	238-241

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Material Casting (Composition in %)	Name of Casting	Position of Axis of Rotation	Mold	Mechanical Properties of Casting		
				Tensile strength, in kg/mm²	Elongation in %	Brinell Hardness
Malleable cast iron anti-friction ChM-1-3: 2.3-3 C, 0.6-1.3 Si**; 0.6-1.2 Mn; to 0.2 P; 1-1.5 Cu	Bushings and other small details	Up to diameter 300 mm, vertical	Metal mold, with mold wash, chill to 100-200°C; for small details - core	45-55	2-3	200-240
Cast iron for nitriding, steel 4KhNMYuA*: 2.4-2.8 C; 2.86-2.9 Si; 1.42-1.44 Mn; 1.16-1.2 Cr; 0.81-1.26 Al; 0.08-0.09 P	Bushings	Horizontal	Metal, with dry sand coating, chill to 350-400°C	29.4-37.3	-	Nitrided layer 500-700 H_m
Heatproof austenite cast iron 2.04-2.64 C; 1.63-2.52 Si; 0.6-0.97 Mn; 1.71-2.36 Cr; 15.3-18.2 Ni; 6-8 Cu; 0.11-0.32 P; 0.1-0.018 S	Bushings, shells	The same	The same	21-29	2-3.5	135-175
Bronze, Br. OTsS 4-4-17	Bushings	Horizontal	Metal	20.9-21.4	20	56-62
Brass: 30 Zn; 2 Al; remainder Cu	The same	The same	The same	60	18	119
Bronze: 2-3 Fe; 0.8-1.5 Mn; 8.5-10.5 Al; remainder Cu	Worm gears	Vertical	Metal with loam core inserts	-	-	-
Bimetallic: Nickel-boron cast iron: 2.5-3.25 C; 0.5-1.5 Si 0.5-1.25 Mn; 3.5-4.5 Ni; 0.7-1 B; 0.05 P on tube of steel 10	Bushings	Horizontal	Metal, with pouring into tube heated to 850-900°C	-	-	58-62 in cast state
Bimetallic cast iron 3.4-3.8 C; 2-2.5 Si; 0.6-1 Mn; 0.8-1.4 Ni; 0.2-0.5 Mo; 0.2-0.5 Cr; ≤ 0.1 S on steel disc	Brake drums	The same	Metal, with casting on steel disc	20	-	190-230
Bimetallic Bronze: 80 Cu; 3-4 Pb; 3-4 Si; on steel: 0.05-0.2 C; 0.12-0.25 Si; 0.5-0.6 Mn	Bushings	The same	Metal	-	-	-
Bimetallic antifriction alloy: 10 Pb; 0.5 Mn; remainder Al; on secondary aluminum	The same	The same	The same	-	-	-
Steel 30	Thick walled rings (thickness 70-100mm)	Vertical	Metal chill, with refractory clay	55-56.3	15-16	-
Steel 0.35-0.4 C; ≤ 0.3 Si; 0.65-0.8 Mn; ≤ 0.03 P; ≤ 0.04 S; 0.9-1.1 Cr; 0.5-1.5 Cu***	Gear wheels	The same	Metal, with loam core inserts	150*	-	190*
Steel 35	Tubes, diameter 300 mm; wall thickness 80 mm	Horizontal	Metal chill	56.6	22.3	-

* Normal MAP 294 AMTU 50.

** Without copper, 1-1.3 Si.

*** After heat treatment.

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In casting into green molds, the value of p is taken up to kg/cm^2, while in casting into dry sand or metal molds it is taken in the range of 3-5 kg/cm^2.

Table 50 gives the compositions and mechanical properties of the castings that are most typical for centrifugal casting.

Castings with Melt-Away Patterns (Precision Casting)

The method of exact (precision) casting with melt-away patterns is based on the following principle: by the aid of a single-piece flask made of a refractory substance, a pattern is formed out of a low melting mass with a paraffin-stearine base, and is subsequently removed without residue by melting off, leaving a cavity into which liquid metal of the required composition is cast.

Details may be cast from any desired alloys, ferrous and nonferrous, by the method of precision casting. Such may include high-alloy fire-resistant alloys and super-hard alloys, which are poorly amenable, or not at all, to forging, stamping, rolling, and machining.

Precision casting allows the production of castings of any configuration, of elevated accuracy (by GOST 2689-54) and cleanness (by GOST 2789-51 to 4th-6th classes), which require hardly any machining, or none at all.

The methods of casting used, favor the production of castings of very thin cross sections (thickness 0.3-0.4 mm), of minimum cross section of walls of hollow castings (0.6-0.8 mm), and openings of 2-2.5 mm in diameter, with a height of 4-5 mm.

Details weighing from 1 to 50 kg may be produced by the method of precision casting (body and details of instruments, small gear wheels, blades of gas turbines and turbocompressors, armatures of bronze and rustless steel, cutting tools and surgical instruments, small automobile details, details of cameras and details of still and motion-picture cameras, sewing and textile machines, and also art castings).

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The process of precision casting consist of the following operations. Preparation of the patterns and their assembly into blocks ("fir-trees"); molding; removal of the patterns (by melting away); baking the mold; melting the metal; pouring the mold; knocking out, cutting away the castings from the "fir-trees", and cleaning them.

The patterns are made by pouring a special pattern composition into dies, which, in turn, are made either from a master pattern or from a special drawing.

Allowing for the two types of shrinkage (by the pattern composition and the cast metal), master patterns are usually made of steel, bronze, or aluminum alloys, and are machined on metal-cutting machines, and are then hand finished and polished.

The dies are made of steel, bronze, or duralumin. For producing small numbers of castings with low accuracy requirements, the dies may be made, from a master pattern, in plaster, cement, rubber, or plastics.

The simplest method is to cast the dies, from a master pattern, in easily machined and low-melting alloys. The cheapest of such alloys is one containing 87% Pb and 13% Sb. The surface cleanness of the dies should not be lower than the 6th class.

A die can be used for numerous castings of the mold composition in its cavity. Steel dies take 60,000-80,000 castings of the mold composition before being worn out.

Table 51 gives the most widely used pattern compositions.

The pattern mixture is usually injected into the cavity of the die in a thick, pasty state, under a pressure of 3-5 atmospheres by the aid of a simple metal syringe. In large-scale production, where the required strength of the patterns is high, this operation is mechanized by using special presses, including equipment for melting the pattern mixture and holding it at constant temperature (Fig.28). With details of thin cross section and intricate configuration, the mold mixture is introduced in the liquid state by the method of free pouring.

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The patterns so prepared, after careful cleaning off the fins, are assembled into blocks or "fir trees" by melting away the patterns, using heated knives or an electric soldering iron, with the gating system usually made separately.

Table 51

Compositions for Precision Casting Patterns (Bibl.68,69,70,72,45)

	Compositions, in % by weight				
Ingredients of mixture	1	2	3	4	5
Stearin	-	27-30	50	50	-
Paraffin	18	70-65	50	50	-
Ethylcellulose	-	3-5	-	-	-
Rosin	50	-	-	-	50
Polystyrene	30	-	-	-	30
Ceresine	-	-	-	-	20
Dibutyl Phthalate	2	-	-	-	-
	Physical-Mechanical Properties				
Linear shrinkage in %	1.2	1.6	2.3-2.6	1-1.2	0.65-0.75
Temperature of composition in casting, °C	140-150	90	90	42	175
Bending strength, kg/cm^2	-	38	31.2	20	73.4
Sag, in mm	-	0.8	0.88	0.66	0.53
Tensile strength, kg/cm^2	-	13.5	7.8	-	53
Elongation, in %	-	0.75	0.6	-	1.4
Method of filling dies	Under pressure	Free pouring and under pressure	Free pouring	By syringe under pressure of 3-4 kg/cm^2	Under pressure of 60 kg/cm^2

Note: Compositions 1, 2 and 5 are for intricate castings with rigid tolerances; compositions 3 and 4 for casting with relatively low accuracy requirements.

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After natural drying, the "fir trees" are covered with a special ceramic investment in two layers.

The coated and dried "fir tree" (Fig.29) is placed in a single-piece flask or

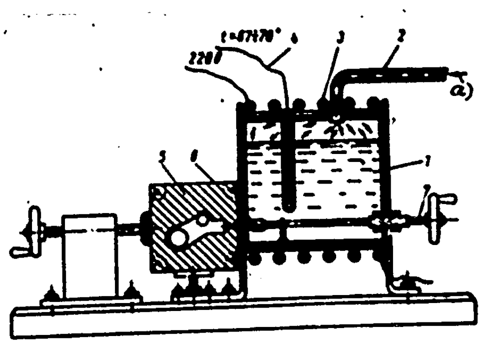

Fig.28 - Pouring the Dies with the Wax Mixture: 1) Wax Mixture; 2) Air Duct; 3) Electric Heater; 4) Thermometer; 5) Die; 6) Needle; 7) Mechanism for Inserting and Withdrawing the Needle.

a) P = 3 + 6 Atmospheres.

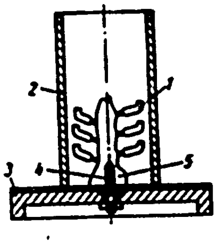

Fig.29 - Scheme of Setting Up the Wax Patterns on the Plate Under the Flask: 1) Patterns; 2) Flask; 3) Plate; 4) Pin Holding Pattern Block; 5) Downsprue.

iron pipe of dimensions depending on the castings to be made, and the space between the walls of the flask and the "fir tree" are filled with a dry or liquid molding mixture, or filler. The lower and upper parts of the flask are filled with a mixture of refractory clay and sand (in a layer 25 mm thick) to prevent the sand from flowing out of the flask, or iron covers are made, one of which is provided with an opening for the pouring cup.

The molding mixture is packed into the flask by light hammering on the flask or by vibrating the mold on special jolting tables, mechanical or pneumatic. The amplitude of the oscillations of the table is 1.5-3 mm and their rate is 350-400/min (Fig.30).

Table 52 gives a few of the most widely used compositions of molding mixtures of fillers.

The molds are exposed to the air for 2-3 hours, after which the patterns are removed. For this purpose the molds are placed upside down in a dryer, where the pattern mixture is melted away, usually at temperature 120-150°C, in 3-4 hours, or on tables heated by steam or hot air. The pattern mixture melted away is repeatedly used.

For the final removal of the residues of the pattern mixture, as well as to strengthen the refractory film, the molds are baked at constant elevated temperature, up to 800-900°C, in electric, oil or gas ovens for 3-4 hours.

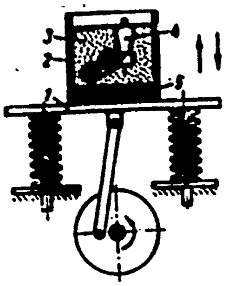

Fig.30 - Jolting Table for Filling Molds with Mixture: 1) Vibrating Table; 2) Flask; 3) Molding Mixture; 4) Wax Pattern; 5) Porous Bottom.

To shorten the production cycle, shell molds are used, in which the melting away of the pattern mixture from the coated "fir trees", and the baking to form a strong refractory surface film on them, are done before molding. "Fir trees" in the form of shells are strong enough to be stored and transported, and their molding is done immediately before the pouring.

The furnace used for melting the metal must be of a design meeting the requirements of precision casting.

Furnaces of two types are used: indirect-heating arc furnaces, and high-frequency furnaces. The indirect-heating furnaces are simple in design, operate on 50-60 volts, obtained from one or two ST-24 welding transformers at current strength 450-500 AMP. The power consumption is about 1 KWH kg of metal; it takes 12-15 minutes to melt 10-12 kg of metal. This type of furnace, however, does not assure a

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sufficiently clean metal, owing to the difficulty of removing the slag from it during melting, and owing to the carburization from graphite dust and small pieces of the electrodes that get into the metal.

Table 52

Compositions of Molding Mixtures or Fillers for Precision Casting (Bibl.69,70,72)

Ingredients of the mixture	Compositions, in % 1*	2**	3***	4
Fused quartz glass	99-98	-	-	-
Technical borax, or boric acid	1-2	1-2	1-2	-
Ground chamotte	-	99-98	-	-
Quartz sand	-	-	99-98	90
Alumina cement	-	-	-	10
Water	-	-	-	To required consistency

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* For details of particularly high accuracy and very intricate configuration.

** For details with high accuracy with intricate configuration and with large surfaces.

*** For details of medium complexity and accuracy.

Note: The dry compositions 1, 2 and 3 are for smaller details, composition 4 is for larger details in flasks of diameter 500 mm and height over 500 mm.

High frequency furnaces may be used with motor or vacuum-tube generators. Tables 53 and 54 give their characteristics.

For melting nonferrous alloys with low-melting points, crucible furnaces, either oil or gas fired, may also be used.

The metal is cast into the mold either by free pouring or under compressed air pressure of 4-5 atmospheres on the surface of the metal (in electric-arc rotary

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furnaces). In this case, steel is cast into hot molds, while nonferrous metals are cast into cold molds.

Table 53

Characteristics of High-Frequency Furnaces with Motor Generator

Main parameters	PO-75	PO-100	PO-300	PO-400
Capacity of furnace in kg	100	250	300	1000
Power of generator in KW	75	140	300	600
Voltage of furnace	1400	1400	1900	1900
Frequency of current, cycles	2000	2000	500	500
Duration of melting in minutes	30-40	35-45	60-75	60-75
Power consumption in KWH	900-1000	700-950	800-850	600-700
Service life of crucible (number of melts)	60-70	70-80	80-90	80-90

After solidification, the castings are removed from the mold and are then carefully cleaned and inspected.

In the design of details to be cast by the precision method, the following rules, in addition to the general rules, must also be taken into account.

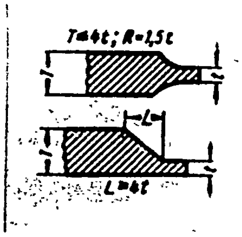

Fig.31 - Junctions of Walls of Different Thickness.

1) Requirements for the cleanness of surface and mechanical strength should be specified only for those parts of the detail where this is necessary.

2) The castings must have no isolated massive units.

3) At junctions between walls of not more than a fourfold ratio between t

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different cross sections should be allowed, while the transitions from the greater thickness to the smaller should be smooth, with the radius R = 1.5t or tapered at the ratio L : 4 ≥ t (Fig.31).

4) When walls located at different angles meet, sharp angles, and especially sharp interior angles, must be avoided; at the points of transition it is necessary to provide the minimum radii and tapers at the angles, avoiding crossed ribs (Fig.32, a-d).

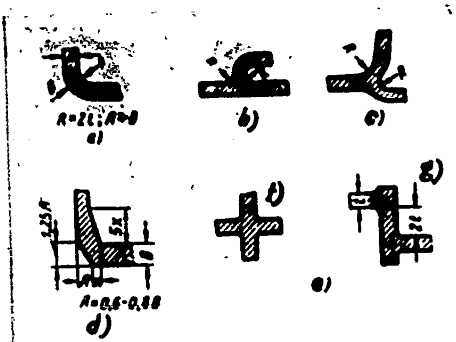

Fig.32 - Meeting of Walls at Various Angles. a) a; b) b; c) c; d) e; f) Incorrect; g) Correct.

5) The castings must have the smallest possible numbers of blind openings and of cavities of small transverse dimensions, while the height of bores open at both ends, if of small diameter, must be limited to 1.5-2 diameters.

6) The minimum thickness of the wall of the detail must be considered to be 1.5 mm, and corresponding to this thickness, the diameter of a given opening is taken as 1.5 mm; the radius at acute angles must not be less than 0.25 mm.

Table 54

Characteristics of High-Frequency Furnaces with Vacuum-Tube Generator

Type of generator	Rated power in KW	Nominal output power in KW	Operating frequency of current, in cycles	Capacity of crucible in kg
LGPZ-30	100	60	$(2\div2.5)\cdot10^5$	Up to 15
LGPZ-60	160	100	$(1\div1.5)\cdot10^5$	Up to 30

7) To assure the maximum uniformity of the cross sections of the walls, it is recommended that the openings and lightening holes made in the castings shall remain within the range of diameters to height ratios indicated in Figs.33, a-e.

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8) Large smooth areas must be avoided by corrugating or by providing depressions of various forms (Fig.34).

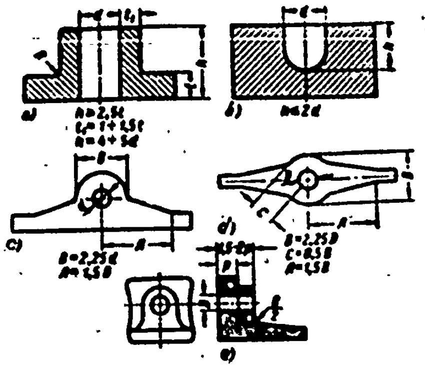

Fig.33 - Providing Uniformity of Wall Thickness.

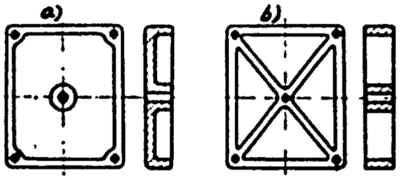

Fig.34 - Method of Eliminating Large Flat Areas. a) Incorrect; b) Correct

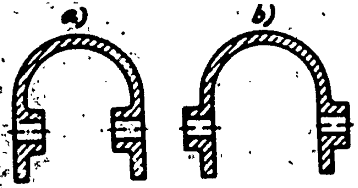

Fig.35 - Location of Lugs on Casting. a) Incorrect; b) Correct.

9) It is recommended that the lugs for drilling of openings should have cast centers.

10) The ribs and lugs should be made on the outer surfaces of the casting (Fig.35).

11) Cuts should be made in the castings only where such cuts are special and are widely spaced.

Failure to observe these requirements results in hot cracks, porosity, blow holes and shrinkage cavities in the castings.

According to the specifications, the castings are heat-treated under the assigned conditions.

Steel details, as a rule, are annealed to eliminate the stresses and improve the machinability.

The peculiarities of precision castings of carbon and low-alloy steel, especially those containing more than 0.3% C, include the formation, on the surface of the casting, of a layer 0.1-0.4 mm thick with a reduced carbon content.

Table 55 gives the mechanical proper-

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ties of details of carbon steel cast by the precision method.

Table 55

Mechanical Properties of Details of Carbon Steel, Cast by the Precision Method

a)	b)			c)			d)		
	e)	f)	g)	h)	i)	j)	k)	l)	m)
n) 25	40	8	78	45	18	82–86	55	6	82
n) 35	50	6	86	56	15	86—89	69	6	86
n) 50	62	5	90	66	11	95—100	95	3	94

a) Mark of steel; b) After casting; c) After normalizing; d) After temper-hardening; e) Tensile strength in kg/mm^2; f) Elongation in %; g) Brinnell hardness; h) Tensile strength in kg/mm^2; i) Elongation in %; j) Brinnell hardness; k) Tensile strength in kg/mm^2; l) Elongation in %; m) Brinnell hardness; n) Steel.

TECHNOLOGICAL PRINCIPLES OF THE DESIGN OF CAST MACHINE DETAILS

The casting must have the simplest possible geometrical figure or must consist of a combination of simple figures, assuring the minimum consumption of metal for the given design.

In designing castings, every effort must be made to achieve maximum simplification of the patterns and core boxes; the form of the individual surfaces of the casting must approach as closely as possible to a plane, or to the surface of a solid of revolution.

In the design of a casting provision must be made for the unhindered drawing of the pattern from the mold. The pattern should be without removable parts and have no complex surfaces of separation. It is particularly important to avoid removable parts in patterns of details to be shaped on machine tools and intended for machining without layout.

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The absence of shaded areas in the pattern on its illumination by parallel beams in a direction perpendicular to the surface of separation with the mold may serve as a general criterion for this requirement (Fig.36).

For the free extraction of the patterns from the molds, design tapers of the vertical surfaces of the castings must be provided.

GOST 2670-44 recommends the following tapers for casting in sand molds, depending on the height (length) of the design element h:

h in mm	< 25 1/5	25-500 1/10 1/20	> 500 1/50
Taper	11°30'	5°30' 3°	1°

With machine pattern-drawing, the tapers may be taken within the limits of 1/20 to 1/100.

For the inside surfaces of the castings a taper of 1/20 is usually taken. Large castings with massive cross sections may have tapers of 1/100, and, in individual cases, 1/150.

In casting in metal molds (chills) the taper of the outside walls of the casting should be between 1/70 and 1/100, and that of the inside walls, formed by metal cores, from 1/10 to 1/30*.

The tapers for the surfaces of the main part of the castings or of individual elements thereof (lugs, ribs, side bulges, openings for bushings, etc) should be taken in accordance with the character of the detail and its possible position in the

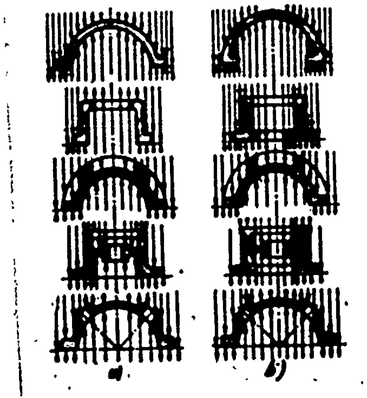

Fig.36 - a) Casting of Correct Design without Shaded Areas; b) Casting of Incorrect Design, Requiring Removable Parts of the Pattern or Additional Cores.

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* Cf also above, Tables 41 and 42.

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mold (Fig.37).

Large horizontal planes, turned upward during casting, should be avoided, since the gases formed in the mold and liberated by the metal can be retained on these planes.

The design of the casting must assure the possibility of unhindered filling of its mold by the liquid metal. Sharp changes in the direction or rate of flow of the metal in the mold are not recommended.

The design of cast details must correspond either to the simultaneous or the successive solidification of the casting. In the former case the maximum possible uniformity of the cross sections is desirable, while in the latter case it is desirable to have a gradual increase in the massiveness of the walls in the presumed direction of solidification (Fig.38).

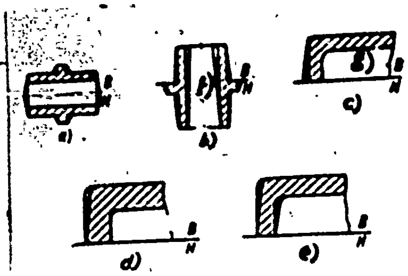

Fig.37 - Relation Between the Direction of the Taper and the Character of the Casting and Method of Molding: a) with Horizontal Position in Mold; b) with Vertical Position in Mold; c) with Thin Walls; d) with Thick Walls; e) with Formation of an Inner Cavity by a Block in the Mold. a- a; f- Core; g- Core; h- Core; i- Block.

The design of a casting must allow for shrinkage and the inhibition of that shrinkage - mechanical inhibition - by the mold and core, and thermal, as a result of the varying rate of solidification of the different parts of the casting (Fig.39).

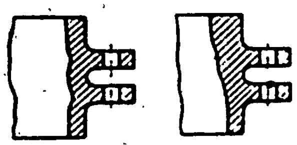

Fig.38 - Construction of the Design of a Casting Corresponding: a- to Simultaneous Solidification; b- to Successive Solidification.

To avoid the production of internal stresses, resulting in buckling of the castings, cracks, etc, the design of the

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ing should provide for the most uniform possible cooling of all cross sections and should allow free shrinkage.

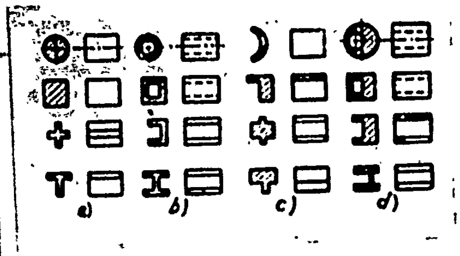

Fig.39 - Schemes of Design of Castings: a- with Free Shrinkage; b- with Mechanically Inhibited Shrinkage; c- with Thermally Inhibited Shrinkage; d- with Mechanically and Thermally Inhibited Shrinkage.

Tables 56-58 give the values of the maximum deviations in dimensions and weight for an iron or steel casting in sand molds, as prescribed by GOST 1855-55 and 2009-55. The 1st class of accuracy, corresponds, as a rule, to mass production (machine molding on metal patterns); the 2nd class to series production (machine molding with wooden patterns); and the 3rd class to individual production (hand molding on wooden patterns).

Table 56

Allowable Deviations in Dimensions of Gray Iron and Steel Castings of Accuracy Class I in mm (±)

a)	b)						
	c) 50	d) 50	120–260	260–500	500–800	800–1250	1250–2000
c) [illegible]	0.2	0.[illegible]	—	—	—	—	—
120–260	0.3	0.4	0.6	—	—	—	—
260–500	0.4	0.6	0.8	1.0	—	—	—
500–1250	0.6	0.8	1.0	1.2	1.4	1.6	—
1250–3150	0.8	1.0	1.2	1.4	1.6	2.0	2.5
3150–6300	1.0	1.2	1.5	1.8	2.0	2.5	3.0

a) Maximum dimension of casting in mm;
b) Nominal dimension in mm; c) Up to;
d) Over.

Table 56a

Allowable Deviations in Dimensions of Gray Cast Iron and Steel Castings of Accuracy Class II, in mm (±)

a)	b)						
	c) 50	50–120	120–260	260–500	500–800	800–1250	1250–2000
c) 240	0.5	0.8	1.0	—	—	—	—
260–500	0.8	1.0	1.2	1.5	—	—	—
500–1250	1.0	1.2	1.5	2.0	2.5	3.0	—
1250–3150	1.2	1.5	2.0	2.5	3.0	4.0	5.0
3150–6300	1.5	1.8	2.2	3.0	4.0	5.0	6.0

a) Maximum dimension of casting in mm;
b) Nominal dimension in mm; c) Up to.

Tables 59-62 give the standard dimensional and weight tolerances developed for malleable cast iron and nonferrous metal castings by TsNIITMASh. These tolerances

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we recommend.

Table 57

Allowable Deviations in Dimensions of Gray Cast Iron and Steel Castings of Accuracy Class III, in mm (±)

a)	b)						
	c) 50	50–120	120–260	260–500	500–800	800–1250	1250–2000
c) 500	1.0	1.5	2.0	2.5	—	—	—
500–1250	1.2	1.8	2.2	3.0	4.0	5.0	—
1250–3150	1.5	2.0	2.5	3.5	5.0	6.0	7.0
3150–6300	1.8	2.2	3.0	4.0	5.5	6.5	8.0
6300–10 000	2.0	2.5	3.5	4.5	6.0	7.5	9.0

a) Maximum dimension of casting in mm; b) Nominal dimension in mm; c) Up to.

Table 58

Allowable Deviation in Weight of Gray Cast Iron and Steel Castings in % (By GOST 1855-55 and 2009-55)

a)	b)		
	I	II	III
c) d)	5 4 3	7 6 5	8 7 6

a) Nominal weight of casting in kg; b) Accuracy; c) Up to; d) Over.

Table 59

Allowable Deviations from Dimensions of Malleable Cast Iron Castings, in mm (±)

Dimension of Casting, in mm	Accuracy Class 1st	2nd
To 100	0.5	1.5
101-250	1	2
251-400	1	2.5
401-650	1.5	3
651-1000	1.5	3.5
1001-1600	1.5	4

The dimensions of castings for the case of machine molding, must take account of the corresponding dimensions of the flasks.

In designing castings, provision must be made for the unhindered cutting off the gates, runners, etc., and also for knockout of the cores and removal of the

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framework.

The design of castings must take into consideration the conditions under which the details are to be operated. Thus, for instance, if a cast detail is designed to operate under pressure, its design should provide means for attaching the core by means of core prints, without having recourse to chaplets.

Table 60

Allowable Deviations from Dimensions of Copper Alloy Castings, in mm (±)

Dimension of Casting, in mm	Accuracy Class 1st	Accuracy Class 2nd
To 150	0.5	1
151-250	0.5	1.5
251-600	1	1.5

Table 61

Allowable Deviations from Weight of Malleable Cast Iron Castings, in %

Weight of Casting, in kg	Accuracy Class 1st +	Accuracy Class 1st −	Accuracy Class 2nd +	Accuracy Class 2nd −
To 0.1	6	6	11	10
0.2-0.5	6	5	9	9
0.6-3	5	5	8	8
3.1-12	5	4	7	7
12.1-50	4	4	6	6
Over 50	4	3	5	5

The drawings for castings must show the base surfaces for machining of the detail, which are the starting points in making and testing the patterns and castings.

The base surfaces must, insofar as may be possible, form a pattern and be con-

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tained in a single flask, to exclude the influence of the curvature of the flasks and cores.

Table 62

Allowable Deviations from Weight of Copper Alloy Castings, in %

Weight of Casting, in kg	Accuracy Class 1st +	1st −	2nd +	2nd −
To 0.1	6	5	11	10
0.1–0.2	5	5	10	9
0.2–0.4	5	4	9	8
0.4–0.8	4	4	8	8
0.8–1.5	4	3	8	7
1.5–3	3	3	7	6
Over 3	3	2	6	5

There should be only a single base surface along each of the three axes of spatial coordinates, and only in exceptional cases should there be two more such surfaces.

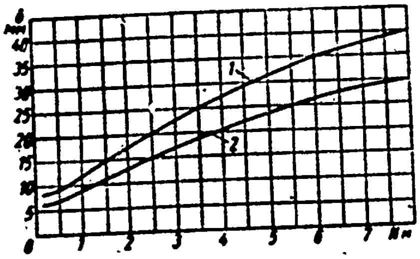

Fig.40 – Minimum Thickness of Casting Walls as a Function of the Dimensions

1) Steel; 2) Cast Iron

In view of the possibility of a certain buckling of the castings, it is recommended that the minimum dimension of the base surfaces be taken, and that their position be so selected as to yield the shortest distance to all the surfaces to be machined.

Selection of the wall thickness of castings. The choice of the minimum allowable wall thickness of the castings should consider the dimensions of the de-

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tails, the weight of the casting, the function of the wall, the kind of metal, and the method of manufacture. In sand mold castings, the thickness δ of the walls of iron and steel castings, especially large ones, may be determined from the diagram of Fig.40 according to the casting dimension N, which value is determined by the formula

Table 63

Thickness of Walls for Small and Medium Iron Castings

Dimension in mm	Weight in kg	Thickness of Walls in mm
100-200	To 5	6
201-400	6-10	7
401-600	11-50	9
501-1000	51-100	12

Table 64

Minimum (usual) Wall Thickness in Sand Mold Castings

Material	Minimum thickness of walls of details, in mm		
	Small	Medium	Large
Gray cast iron	6	10	15
Malleable cast iron	5	8	-
Steel	8	12	20
Nonferrous alloys	3	6	-

$$N = \frac{2l + b + h}{3} \text{ meters,}$$

where l, is the length; b, the width; h, the height of the casting in m.

For N ≥ 8 m, the thickness of the walls is taken at not less than 40 and 30 mm

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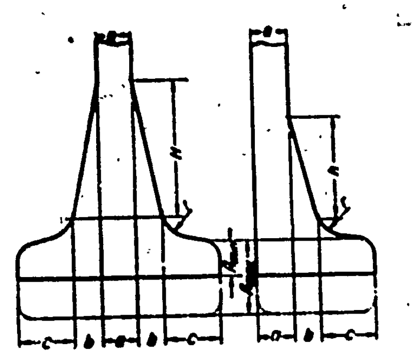
for steel and iron castings, respectively.

The wall thickness of small and medium iron castings may be taken, on the average, from the data of Table 63. The wall thickness for the corresponding steel castings may be taken by the formula

$$s = \frac{L}{100} + 4 \text{ mm},$$

where L = maximum dimension of casting in mm.



a	b	c	H	h	r	A_{min}	A_{max}
8–10	5	12	40	30	5	10	25
10–12	5	12	40	30	8	12	30
12–14	6	14	50	30	8	14	35
14–16	6	14	50	40	10	16	40
16–18	7	16	60	40	10	18	40
18–20	7	16	60	40	10	20	45
20–22	8	18	70	50	10	22	45
22–24	8	18	70	50	15	24	50
24–26	9	20	80	50	15	26	50

Fig.41 – Dimensions of Wall Flanges, in mm.

Taking the thickness of cast walls less than those given in Table 64 is not recommended. In high castings it is recommended that the thickness of the walls be increased in the direction towards the feed source.

In walls requiring flanging, the constructions of the flanges shown in Fig.41 is recommended.

The difference in the thickness of walls, especially when they make contact with each other, must be made as small as possible. In cases where a great difference in cross-section is unavoidable, the massive parts should be built up, for example, the guides of machine tools, which, it is recommended, should be screwed on.

The thickness of the inside walls of a casting, in view of the inferior conditions of solidification, should be about 80% that of the outside walls.

The allowable deviations in the thickness of the walls and ribs of iron and steel castings, as related to the maximum dimensions of the castings, are given in Table 65.

To avoid defects at the presumed places of installation of chaplets, thin cast-

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ing walls should have local bulges, so that the mass of the metal will be sufficient to melt away the chaplets.

Table 65

Allowable Deviations in the Thickness of Unmachined Walls and Ribs, in mm (±)
(by GOST 1855-55 and GOST 2009-55)

a)	b)	c)					
		I		II		III	
		d)	e)	d)	e)	d)	e)
f) 500	6—10	0.3	0.5	0.5	0.8	1.0	1.0
	10—18	0.5	0.8	0.8	1.0	1.5	1.5
	18—30	0.8	1.0	1.0	1.0	1.5	1.5
500—1250	10—18	0.5	1.0	1.2	1.5	1.5	2.0
	18—30	0.8	1.0	1.5	1.5	2.0	2.0
	30—50	1.0	1.2	1.8	2.0	2.0	2.5
1250—2500	18—30	0.5	1.5	1.2	2.0	1.5	2.5
	30—50	0.8	1.5	1.5	2.5	2.0	3.0
	50—80	1.0	2.0	1.8	3.0	2.0	3.5

a) Greatest dimension of casting, in mm; b) Thickness of wall or rib, in mm; c) Accuracy class; d) Iron; e) Steel; f) To.

Design of Angles, Transitions, Contacts. The primary condition for the production of castings free of casting defects and stresses is the smooth transition of cross sections and the absence of acute angles. Sharp transitions from one wall thickness to another are not allowed. If the ratio between the thicknesses of the walls is within the range of 1:2, the transition may be formulated in the shape of fillets; with a greater difference than this, the transition must be wedge-shaped.

Fillet radii from 1/6 to 1/8 the arithmetic mean of the cross sections be-

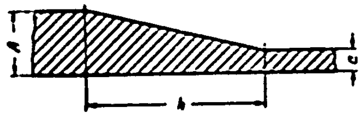

Fig.42 - Gradual Change of Cross Sections at A : a > 2.

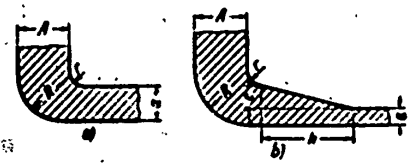

Fig.43 - Corner Junction of Walls: a) with a Ratio of Thickness Less Than 2; b) with a Ratio of Thickness More than 2.

-ing connected are recommended. Greater fillet radii are not recommended, since they can cause local bulges. GOST 2716-44 recommends the following series of radii for cast fillets: r = 1; 2; 3; 5; 8; 10; 15; 20; 25; 30; 40 mm.

The number of different fillet radii used in the same casting should be a minimum. As far as possible, all the fillets should have the same radius.

The gradual change of cross sections should not exceed 1:4 in iron castings, i.e. $\frac{A - a}{h} \leq \frac{1}{4}$, where A - a = difference of cross sections and h = segment of length over which this difference is formed (Fig.42). For steel, this ratio should, it is recommended, be reduced to 1/5.

To avoid local bulges and obtain smooth transitions, the corner junctions, at a ratio of wall thickness $A/a \leq 2$, are made with an outside radius r equal to the wall thickness A, and with an inside radius of rounding r, equal to 1/6 to 1/3 of the mean arithmetical thickness of the walls, i.e., $r = \frac{1}{6}\left(\frac{A + a}{2}\right)$ to $\frac{1}{3}\left(\frac{A + a}{2}\right)$ (Fig.43,a).

When the difference in the wall thickness is great, the construction of transitions according to Fig.43,b, where $c \approx 3\sqrt{A - a}$; $a + c \leq A$; $h \geq 4c$, is recommended. For a steel casting, $h \geq 5c$. Figure 44 gives the following variations of the allowable (right) and the recommended (left) junctions of two walls:

	a)	b)	c)	d)
A:a . .	1	1	1	1,25
Angle of intersection°	75–105	<75	>105	75–105
R	r+a	r+a	r+a	r+a

	e)	f)
A:a .	>1,25	>1,25
Angle of intersection°	75–105	<75
R	r+a+c	r+m=r+a+c

The radius R in the allowable schemes a, d, d, e are used for reasons of design; h for cast iron is taken as approximately equal to 4c, for steel, approximately equal to 5c; the value of c is selected according to the following ratios:

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$A:a$ . . .	$>2,5$	$1,8-2,5$	$1,25-1,8$	$<1,25$
c . . .	$\frac{0,7A-a}{2}$	$\frac{0,8A-a}{2}$	$\frac{A-a}{2}$	—

Junctions of three walls may be designed by the scheme of Fig.45 where:

a) $c \approx 3\sqrt{A-a}$; $a + c \leq A$; $h \geq 4C$ for cast iron and $h \geq 5c$ for steel;

b) $c \approx 1.5\sqrt{A-a}$; $a + 2c \leq A$; $h \geq 8c$ for cast iron and $h \geq 10c$ for steel casting,

or by the schemes of Fig.46, where: a) $A \approx 1.25a$; $\alpha = 75$-$105°$; b) $A \approx 1.25a$ and $\alpha < 75°$; c) $A > 1.25a$, $\alpha = 75$-$105°$; d) $A > 1.25a$, $\alpha < 75°$; $R = r + m$, $m = a + c$. The values of h are taken for cast iron as $h \approx 8c$ and for steel as $h \approx 10c$. The values of c are selected according to the following ratios:

$A:a$ . . .	$>2,5$	$1,8-2,5$	$1,25-1,8$
c	$0,7A-a$	$0,8A-a$	$A-a$

In aluminum alloy weldings the ratios of the design elements given in Fig.47 at the intersection of two or three casting walls are recommended. In this diagram, $h = 2(A + a)$; $h_1 = 2.5(A + b)$; $c = 0.75A$; $d = r = 0.5A + \alpha$; $l = 0.5(A + a)$.

The correctness of the proportions of adjoining cross sections may be verified by the method of inscribed circles (Fig.48). With this method a large diameter of the inscribed ~~circle characterizes maximum concentration of metal plus slowest cooling.~~

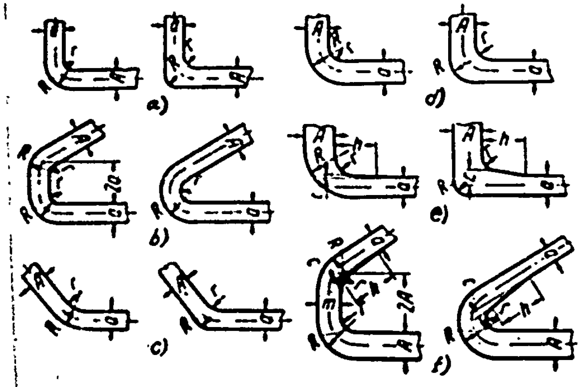

Fig.44 - Design of Junctions of Two Walls: Recommended, Left; Allowable, Right

~~The diameters of the tangents to the circle should, if possible, differ by not~~

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more than 20-25%.

Gradual transitions are particularly important in designs subjected to fatigue. In these designs acute interior angles, which are a focus for the accumulation of local stresses, should be avoided as much as possible.

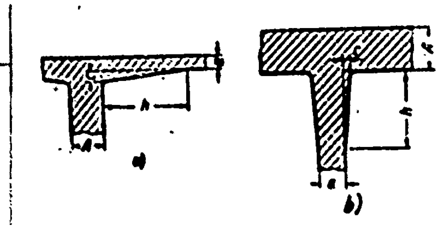

Fig.45 - Junction of Three Walls

The number of elements making a junction at a single point must be reduced to a minimum, thus X-shaped cross sections should if possible be changed into Y-shaped sections, in which only three walls come together. In this case the acute angle should be rounded by fillets in such a way that the cross section at the point of contact is somewhat less than each of the cross sections of the elements connected. Figure 49 gives schemes of intersections. In a number of cases, to avoid the accumulation of metal at the points of intersection of the walls, special openings are made (Fig.49,1).

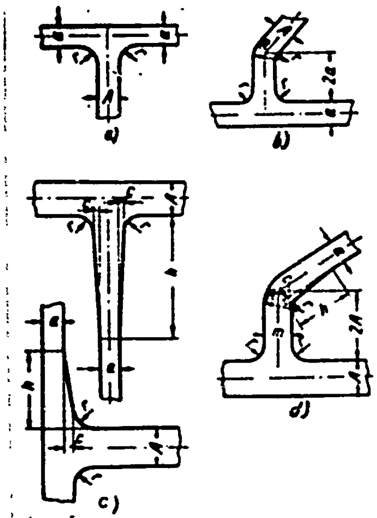

Fig.46 - Design of Various Junctions of Three Walls

No local accumulations of metal should be allowed at the junction points of the casting walls, where it is not possible to assure an uninterrupted feed of liquid metal during solidification. Thus, in malleable iron castings, depending on the purpose of the casting and the conditions of feeding the points of wall junctions, the ratios of dimensions given in Table6, Chapter V, Section "Malleable cast iron", are recommended.

In designing casting corners it is necessary to take into consideration that

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the rate of solidification of the outside corners is higher than that of the inside corners. The heat fluxes, moving perpendicularly to the casting walls, intersect at the outside corners and form a kind of hot spot, which retards solidification. At the vertex of the corner, the thickness should be 20-25% less than in the side walls (Fig.50).

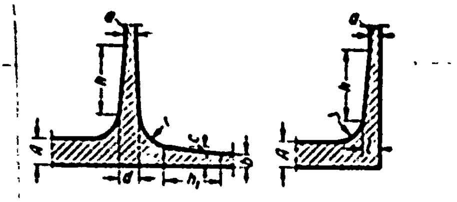

Fig.47 - Design of Junctions in Aluminum Alloy Castings

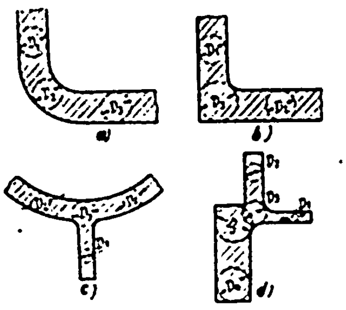

Fig.48 - Application of the Method of Inscribed Circles:
a) $D_1 = D_2 = D_3$; b) $D_1 = D_2 < D_3$;
c) $D_1 < D_2 < D_3$; d) $D_1 < D_2 < D_3$
$D_4 < D_5$

The rounding of the walls at the points of contact between the surfaces depends on the size of these surfaces and on the angles of contact (Table 66). In this case (Fig.51) the basic dimension of the surface is the dimension P perpendicular to the genartrix of the cylindrical surface of the rounding. In steel castings the radii given in Table 67 are used.

Construction of inside cavities and openings. In the design of cast details we must avoid as much as possible internal cavities which, owing to their configuration, require the use of cores. The ratios in the dimensions of the inner cavities formed without the use of cores depends on the position of these cavities in the mold (Fig.52). The cavities formed by parts of the mold located in the drag and standing on its base may have the height H, reaching to the dimensions of the base, the diameter d, i.e., $H \leq D$; the cavities formed by parts of the mold located in the copes and suspended downwards, must have the dimensions $h \leq 0.3d$*.

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* These standards of allowable ratios have been established with reference to machine-molding; for hand molding they should be about halved.

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When there are a large number of cavities formed by cores in castings, for example in the cylinders of air-cooled engines, provision should be made for their unification. The design of cavities must allow for the possibility of molding the cores on machines.

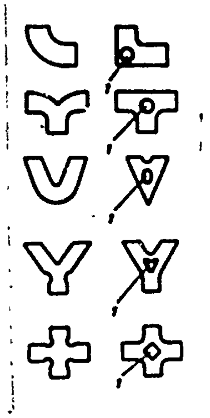

Fig.49 - Scheme of Lightened Intersections

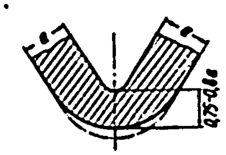

Fig.50 - Design of Corner Casting

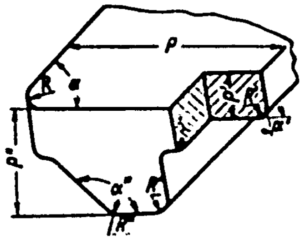

Fig.51 - Scheme of Roundings of Walls

The inner cavities of castings must be such that the configurations and the core prints shall assure reliable reinforcement and accuracy of installation. The exit openings for the core prints must be, as far as possible, continuations of the casting cavity. If the length of the core is twice its diameter, or more, the form of the cavity should provide the structural means for attaching the core at both ends.

The thickness of the cavities formed by the cores must be such that the cores shall allow the use of cast or wire frames for their reinforcement, that they shall

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Table 66

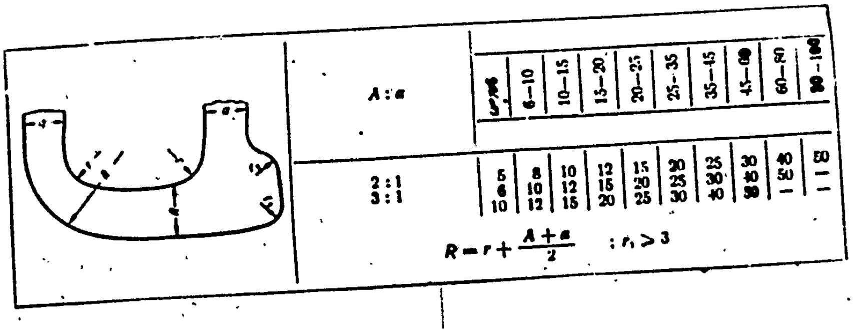
Radius R of the Rounding of the Meeting Surfaces, in mm

Dimension P in mm	Angle of Contact Up to 50	50–75	75–105	105–135	135–165	Over 165
25	2	2	2	4	6	8
26–50	2	4	4	6	10	16
51–150	4	4	6	8	16	25
151–250	4	6	8	12	20	30
251–400	6	8	10	16	25	40
401–600	6	8	12	20	30	50
601–1000	8	12	16	25	40	60
1001–1600	10	16	20	30	50	80
1601–2500	12	20	25	40	60	100
	16	25	30	50	80	120

2500

Table 67

Radii of Roundings in Steel Castings



A:a	[illegible]	6–10	10–15	15–20	20–25	25–35	35–45	45–60	60–80	80–100
 2:1 3:1	5 6 10	8 10 12	10 12 15	12 15 20	15 20 25	20 25 30	25 30 40	30 40 50	40 50 —	50 — —

$$R = r + \frac{A+a}{2} \quad ; r_1 > 3$$

a) Dimension a in mm; b) Dimension r in mm

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not break during transportation, and shall also withstand the pressure head of the liquid-metal when the mold is poured.

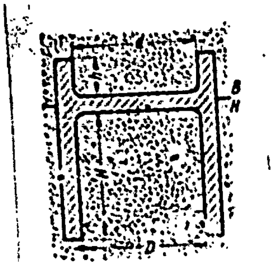


Fig.52 - Dimensions of Inner Cavities Formed by the "Blocks" of the Mold

The design of the details must as far as possible provide for the escape of gases from the core to the top of the casting.

The decision whether the opening shall be cast or not must be taken in accordance with the character of the detail and of the technology of its production. Table 68 gives the recommended minimum diameters of the cast openings formed by the cores, as related to the thickness of the walls.

Table 68

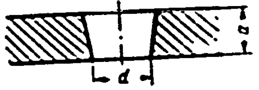
Minimum Diameters of Cast Openings in mm

b)	a)							
	25	26–50	51–80	81–125	126–180	181–205	206–300	300
25	25	25	25	25	25	25	25	30
26–50	28	32	33	33	33	33	33	40
51–100	32	38	40	40	40	40	40	50
101–150	38	42	50	50	50	50	50	60
151–200	—	48	55	60	60	60	60	70
251–400	—	54	65	80	80	80	80	90
401–600	—	—	72	90	100	100	100	110
601–800	—	—	76	95	105	110	110	115
801–1000	—	—	80	100	110	120	120	125
1000	—	—	—	110	120	132	145	150

a) Thickness of wall surrounding opening in mm; b) Length or Height of opening in mm

Table 69

Dimensions of Openings Formed by Green Parts of Mold, in mm



a	d*	a	d
4–6	8	12–14	16
6–8	10	14–16	18
8–10	12	16–18	20
10–12	14	18–20	22

---

*Taper of walls of openings 1:10.

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In large castings, cast openings are made when their diameter is not less than 50 mm, under the condition that the thickness of the walls shall be not more than 5 times the diameter of the opening.

Table 70

Machining Allowances of Adjoining Openings (by GOST 1855-45)

a)	b)		
	1	2	3
100	3	4	5
101–200	4	5	6
201–300	5	6	7
301–500	6	7	8
501–800	7	8	9
801–1200	8	9	10
1201–1800	10	10	12
1801–2800	–	12	14
2801–3800	–	14	16
3801–5000	–	16	18
5000	–	18	20

---

* With openings longer than 5 diameters, the allowances for Groups 1-2 are taken according to the next group (2-3), while the allowances for Group 3 are increased in accordance with the casting process.

a) Greatest Diameter of Casting, in mm;

b) Maximum Machining Allowance in mm, for Group*

In the case where the opening is formed in the wall of the casting by means of a green part of the mold, the ratio of the diameter to the thickness are recommended according to the data of Table 69.

The machining allowances for the openings directly affect the question of openings in castings. Table 70 gives the machining allowances for meeting walls. The allowances for machining noncontaguous openings, whose position on the casting is determined by the free dimensions, will be found in Chapter VI.

A casting design should provide for the removal of the core mix, frames, etc. from the inner cavities, and for the careful cleaning of the cavities left by the cores. If, owing to its function, an inner cavity of a detail is to be a blind closed passage, then special openings must be provided during casting for the removal of the core mix, frames, etc., followed by complete closure.

Reinforcing the walls of castings by crimps at the places of cast openings is

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recommended. Figures 53 and 54 give the recommended ratios of the dimensions of the crimps.

Recesses and grooves are cast if their width is over 25 mm and their depth over 6 mm (on small and medium castings).

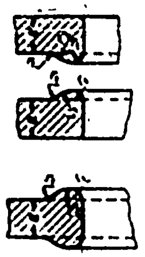

Fig.53 - Design of Edges of Unmachined openings:

a) Two-wall; b) One-wall; $r_1 = 0.25a$: $r_2 = 0.75a$

Design of ribs, flanges, lugs and bosses. The design of ribs should not cause dangerous local stresses at the outer edges and corners, which could lead to breakage of the metal (cracks). The thickness of the ribs is usually 0.7–0.9 the wall thickness, while their height should not, it is recommended, be more than five times the wall thickness.

The contact between ribs and the cross-section of the main body of the casting, and the intersections between the ribs, must not cause local accumulations of metal.

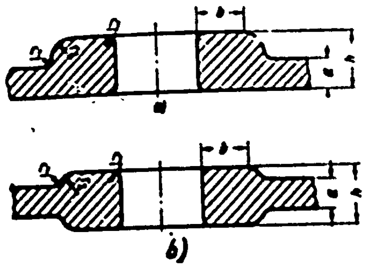

Fig.54 - Design of Beads in Machined Openings.

a) Two-walled castings (recommended design); b) single-walled: $r_1 = 0.25a$; [redacted]

Figure 55 shows the design of a wall with a rib located in its central portion. The recommended dimensional ratios are as follows:

H	a	S	r	r_1	R
≤ 5A	0.8A	1.25A	0.5A	0.25A	1.5A

Figure 56 gives the design of a casting with ribs located along the edges of the wall. The following dimensional ratios are observed in this case:

H	a	r	r_1	S
≤ 5A	A	0.3A	0.25A	1.25A

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Considerable accumulations of metal should not be formed at the points of intersection of the ribs. Accordingly, a checkerboard design or rib networks for small and medium castings, and a ring design of such networks for large castings, is recommended, with c ≤ 2a (Fig.57a) and d ≥ 4a (Fig.57b).

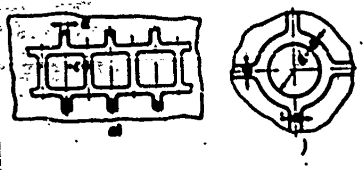

Fig.57 - Metting or ribs:
a) Checkerboard; b) Ring

To reduce the accumulation of metal at those corners where a perpendicular strength rib makes contact with two walls, it is desirable to provide a cast opening in that strength rib, which, without weakening the structure, will still favor the production of a sound casting.

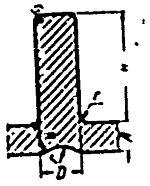

Fig.58

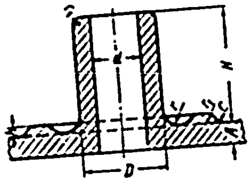

Fig.59

Figure 68 shows the joint between a massive pin and thin walls. In this case:

H	D	R	r	r_1
≤ 4A	≤ 1.5A	1.5A	0.5A	0.25A

With pins of larger size, they are made hollow (Fig.59). For D = 3A, d = 1.5A, so that (d-d)/2 ≥ 6 mm.

Figures 60-62 show the construction of various types of bushings. Figure 60 shows a flanged bushing, where H and d are selected for designs considerations; r = 0.5A; r_1 = 0.25A; S ≤ 1.4A.

Figure 61 shows a bushing with unmachined opening. The ribs are symmetrically located, and recesses are provided opposite them to prevent local accumulations of metal; R = 1.5A; r = 0.25A; S = 1.25A.

For bushings with machined openings and asymmetrically located ribs, the design shown on Fig.62 is recommended, with the following dimensional ratio: $l = 1.2A$; $l_1 = 0.3A$; $R = 0.5A$; $r = 0.25A$; $S = 1.25A$.

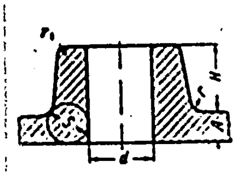

Fig.60

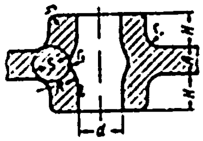

Fig.61

When the thickness of the beads differs greatly from that of the main body of the casting, a smooth transition with a taper of 1:4 or 1:5 is necessary.

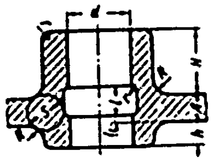

Fig.62

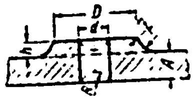

Fig.63

When two beads meet, one of them must be wider than the other by 6–8 mm at the plane of contact.

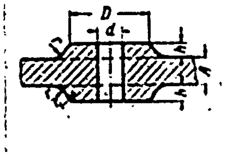

Fig.64

Fig.65

Bosses, lugs, brackets and other projecting elements of cast details should be designed for the unhindered removal of the casting from the casting mold.

The thickness of lugs and bosses should not differ considerably from the thick-

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ness of the main body of the casting; as a rule, the height of bosses should not exceed 0175 to 1 wall-thickness.

In occasional cases lugs may be lightened by forming openings or recesses in them.

Figure 63 shows such a design of a single-sided lug, where d is not less than 8 mm. For $d < 8$ mm, the opening is replaced by recesses with $R = 0.15 D$; $r = A$; $r_1 = 0.25A$; h is chosen on the basis of design considerations. The following ratios are recommended for D; d; D = 25; 35; 80; 170; 260 mm; d = 10; 20; 50; 120; 200 mm. Figure 64 shows the analogous lightening of a two-sided lug with the same dimensional ratio.

A lug of the same cross section as the wall is shown on Fig.65, where h has been selected on the basis of design considerations; $r = h$; $R = A + h$; $r_1 = 0.25A$.

The following minimum heights are recommended for lugs:

Dimension of detail in m	Up to 0.5	0.6 - 2	Over 2
Height in mm	6	10 - 15	20 - 25

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