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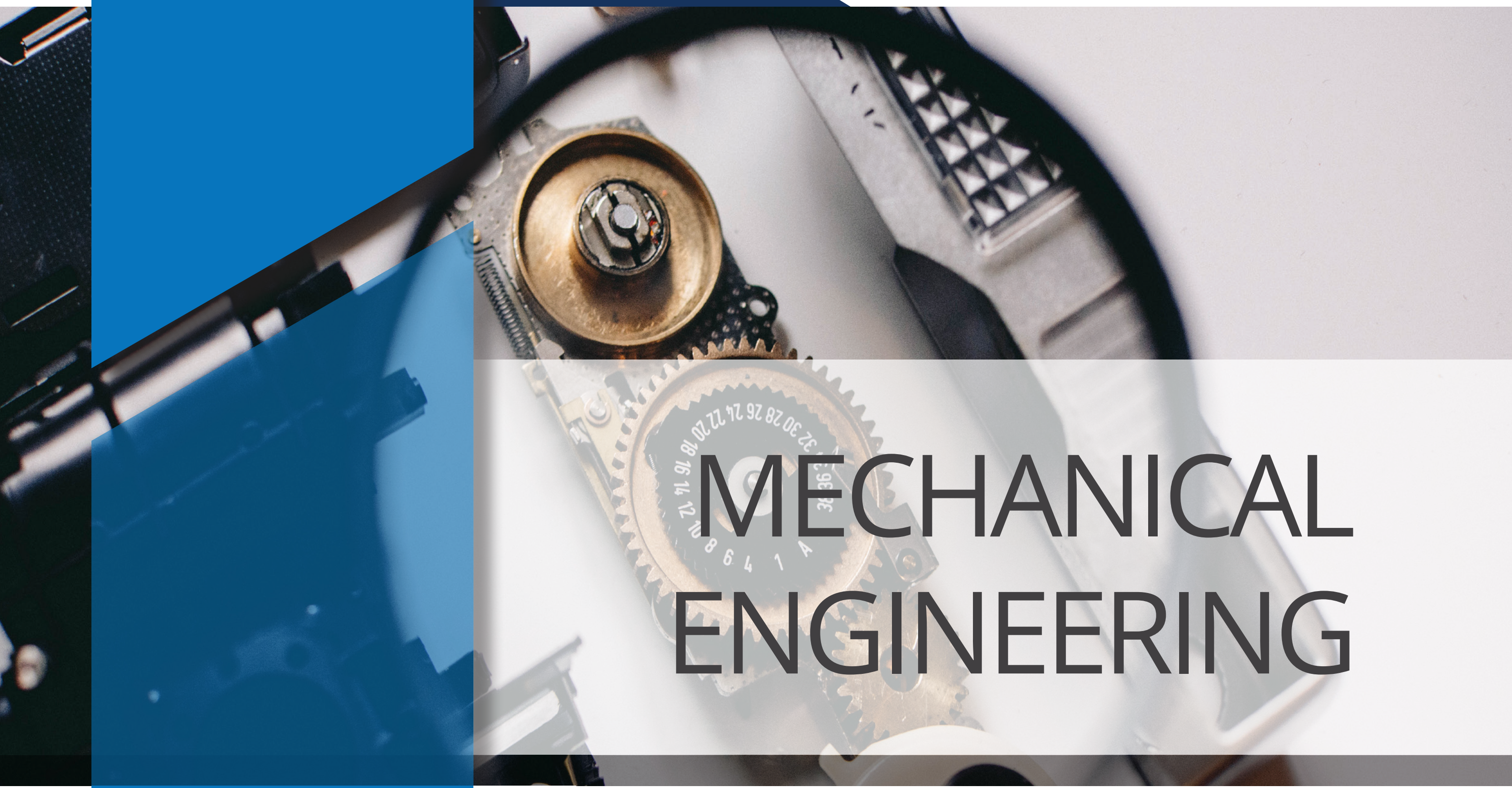

MECHANICAL ENGINEERING

Moulds and casting

UNIVERSITY
OF APPLIED SCIENCES
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Contents

1. MANUFACTURING MOULDS AND CORES

1.1. Manufacturing of moulds and cores

Forming

- **Manual forming**
- **Machine forming**

For manufacturing of a disposable mould, moulding boxes are used of a circular, square or rectangular shape, with perforated walls and mesh on the sides.

Manual forming uses the following patterns:

- planar – transverse and longitudinal
- rotational

Pattern is a modelling device (wood), whose edge is reinforced by sheet metal in order to increase its durability. It is made of a plate and it is used as a model for manufacturing large-size regular castings.

- advantages: low material demands, little production waste
- disadvantage: strenuous work

In manual forming, we distinguish between a split pattern forming or solid pattern forming.

Machine forming

A split pattern is always used. Bottom board is used. Unlike bottom board, pattern plate has pins which are used for fixing the flask, which ensures a 100% reproducibility of the casting cavity position to the flask. Each part of the mould is manufactured separately.

- Compression moulding – the problem is that the mixture around the model is not evenly reinforced. The smallest reinforcement is at the point of the highest column. For this reason, press board is used.
- Jolt moulding – the mould material is fixed around the bottom part of the model. Strengthening is given by the kinetic energy of the column of the mould material,

while the stroke height is 10-100mm and the number of strokes per 1 min is 120 - 150.

- Slinger moulding – it is used for large-size product manufacturing
- Blow moulding – for cores production – core box is filled by gradual setting of core mixture (not frequently used)
- Injection moulding – used also for cores production – core mixture is relocated to the core box in a second

Flask-less moulding

Injection and pressing
It is possible to manufacture up to 300 moulds per hour – Figure 1.1

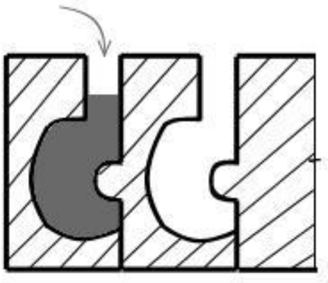


Figure 1.1 Flask-less moulding

Manufacturing shell moulds for a metal pattern

Metal pattern is pre-heated and sprayed with silicone oil. Then it is placed in the container, flipped (2 times), the shell is put in the furnace (approx. 450 °C), then another one is made and formed – Figure 1.2.

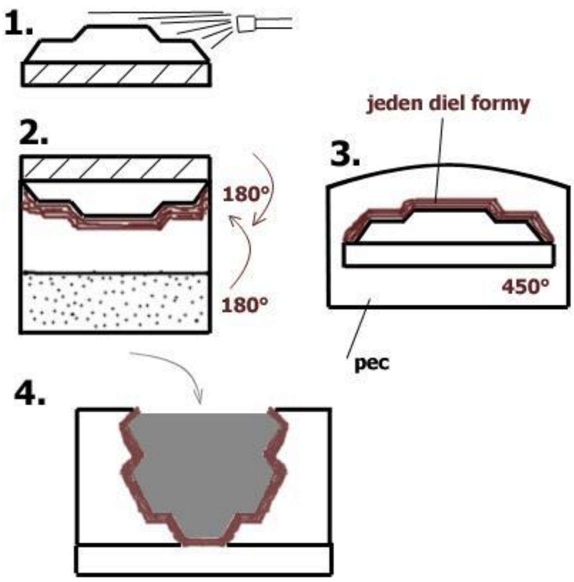


Figure 1.2 Shell moulds for metal model

Manufacturing shells for lost-wax pattern casting

Waxy tree model is immersed into a liquid binder, then sprinkled with high-silica sand. This is repeated until a shell of sufficient thickness is created. The tree is immersed in hot water in the inverted position, the wax melts and leaks, the shell is made red-hot. This method is used for making very precise products.

Manufacturing shells for burnt-pattern casting

It is a polystyrene pattern – polystyrene is burnt at the temperature of 100 °C, generating H_2O+CO_2, binding high-silica sand and thus creating a thin shell. Figure 1.3.

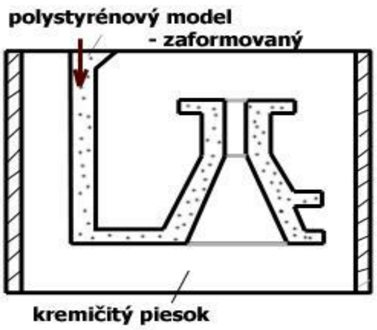


Figure 1.3 Shell mould with burnt-pattern
Legend: polystyrénový model polystyrene pattern, zaformovaný – formed, křemičitý piesok – high-silica sand

Cores hardening

- in hot core boxes - HOT-BOX – high-silica sand +binder (bitumen) – metal core box – Figure 1.4.

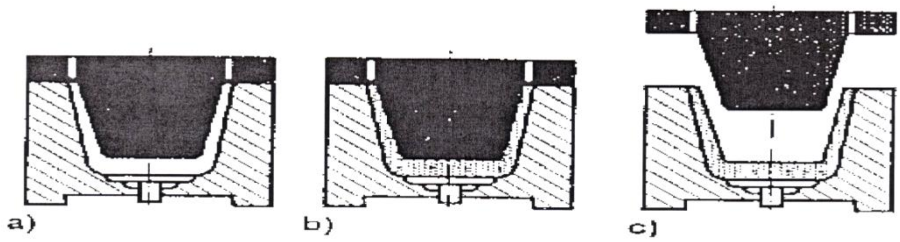


Figure 1.4 Manufacturing hollow core using Hot – Box method

a) *heated core box; b) hardening moulding mixture by core heat;*
b) *dismantling core box and removal of core*

- in cold core boxes - COLD-BOX – chemical reactions – gaseous hardener – Figure 1. 5.

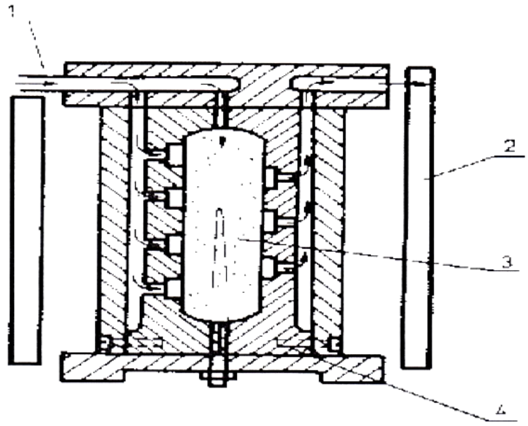
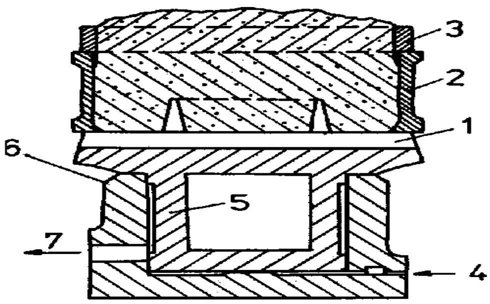


Figure 1.5 Core box for Cold – Box method
1 – gaseous catalyst inlet; 2 – extraction; 3 – core; 4 – core box

1.2. Special methods of casting manufacturing

Jolt moulding – Figure 1. 6



Compression moulding – Figure 1.7

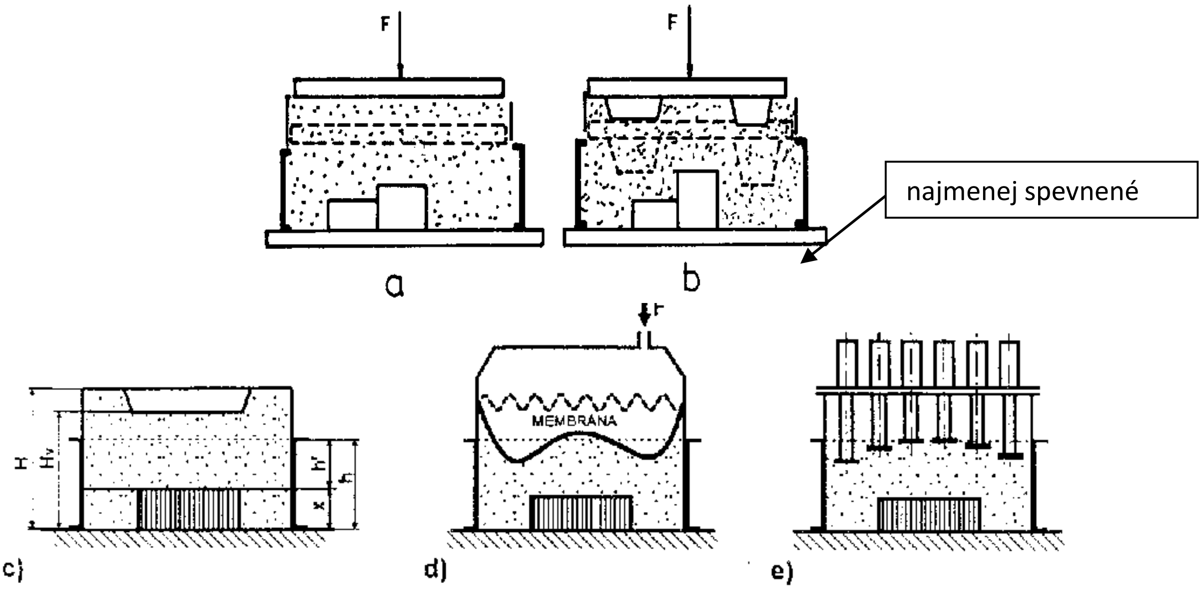


Figure 1.7 Compression moulding

Slinger moulding – Figure 1.8

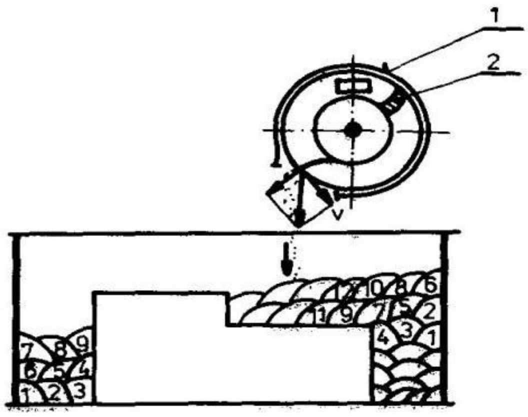


Figure 1.8 Slinger moulding

Vacuum forming – Figure 1.9

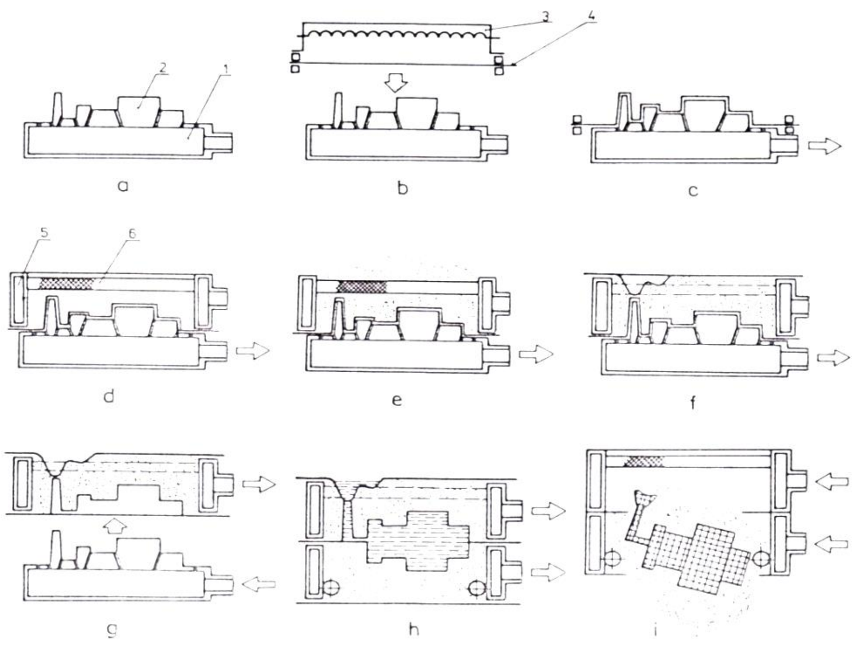


Figure 1.9 Vacuum forming

1 – bottom board, 2–pattern, 3- heating body, 4- foil, 5- cope box,
6- intake

*Initial position of pattern, **b-** foil heating, **c-** stretching softened foil onto pattern due to vacuum acting in flask, **d-** placement of flask on pattern, **e-** filling flask with dry sand, **f-** covering pouring basin of the flask with second foil, **g-** bottom board air intake, removing flask, **h-** joining mould halves and filling the mould with metal, **i-** removing vacuum in both flasks, removal of casting*

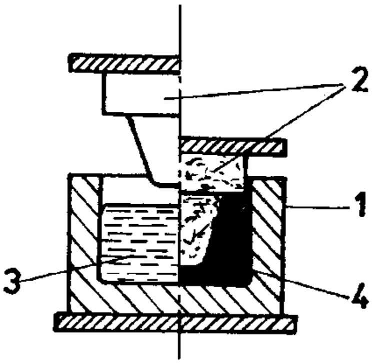


Figure 1.10. Casting and compression method

1- mould, 2- pressing piston,3- pressed liquid metal, 4- casting

Manufacturing castings by extruding melt from mould – Figure 1.11

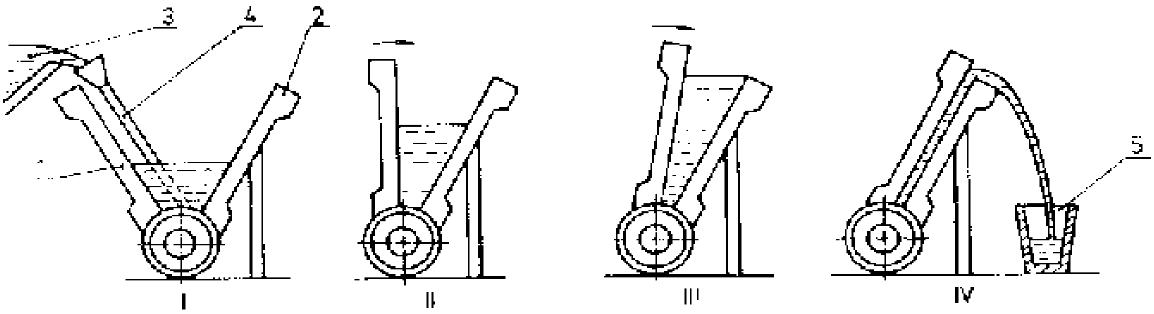


Figure 1.11 Manufacturing castings by extruding melt from mould

1,2- movable parts of mould, 3- pouring ladle, 4- runner, 5- ladle
I- *filling the mould with metal,* ***II***- *forming castings using punch,*
III- *ejection of casting from mould,* ***IV***- *pins casting*

1.3. Casting mould – gravity casting and special casting methods

Gravity casting using tilting ladle – Figure 1.12

Gravity casting is usually carried out by two methods:

- principle of gravity casting in expendable sand mould,
- principle of gravity casting in permanent metal mould.

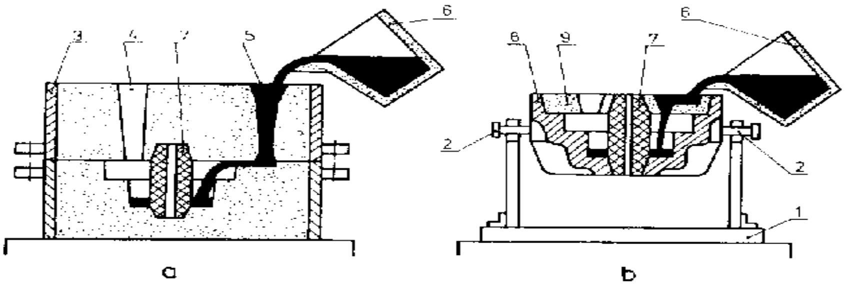


Figure 1.12 Gravity casting using tilting ladle
1- Base plate, 2- swivels, 3- flask, 4- feeder, 5- runner, 6- ladle,
7- core, 8- metal mould, 9- core
a) casting in expendable sand mould, b) casting in permanent combined metal mould

Centrifugal casting – Figure 1.13, Figure 1.14

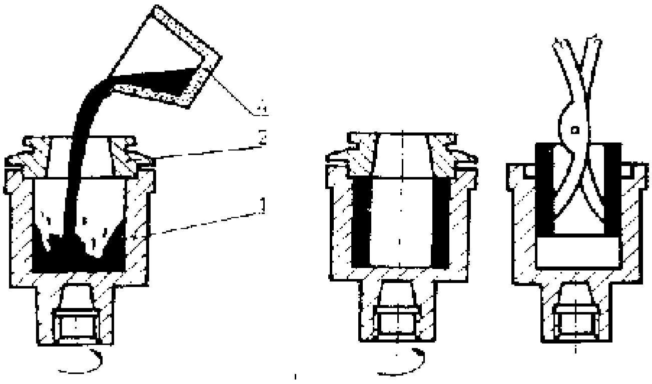


Figure 1.13 Centrifugal casting with vertical rotating axis
1- metal mould, 2- lid, 4- ladle

Continuous casting – Figure 1.15

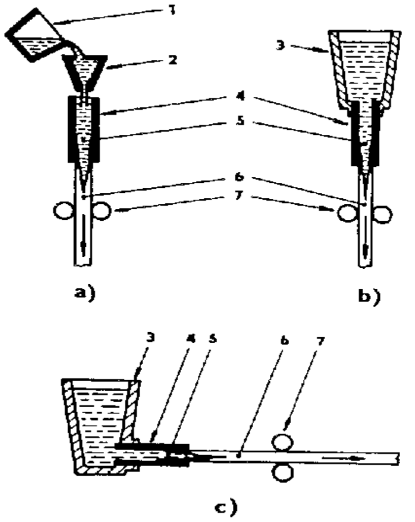


Figure 1.15 Continuous casting

1- ladle, 2- funnel, 3- melting pot, 4- mould, 5- liquid metal, 6- solidified material, 7- drawing cylinder

a- vertical open system

b- vertical closed system, c- horizontal closed system

2. MOULDS STRESS IN CASTING

2.1. Moulding box

Choosing moulding box depends on the placement of the pattern in the mould, while the directional distance of the pattern from the moulding box are kept as seen in Figure 2.1.

Moulding box: is a solid and compact mould cover enabling its handling. It can be of different shapes (mostly rectangular or square cross section). Frames with holes for folding moulds with folding pins are located on the frames, ensuring accurate and constant position of the mould parts after its dismounting and re-assembling.

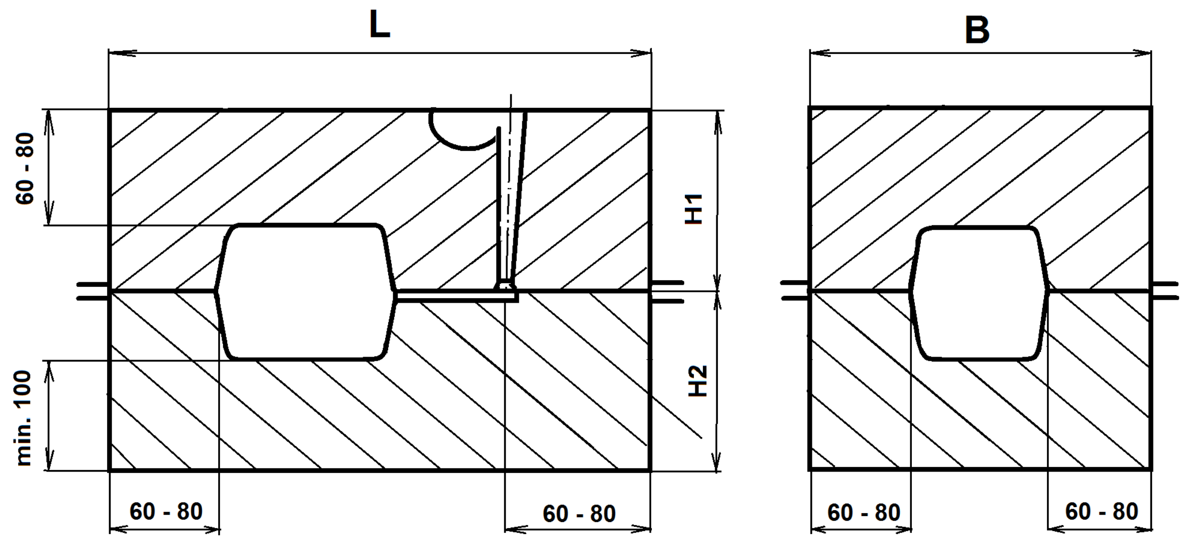


Fig. 2.1 Distance between pattern and moulding box

Gating system

Gating system is a system of gates that are used to fill the mould with melted metal (Fig. 2.2). In the gating system, the melted metal must not be cooled too much so that it could fill the mould reliably; it must not be gassed, foamed, etc. The melted metal also must not damage the mould walls. The gating system must capture as much impurities as possible. The melted metal distribution should enable guided solidification and prevent shrinkage.

a) b)

Fig. 2.2 Gating system
a) for casting cast iron b) for casting steel

Basic components of gating system:

a) pouring basin – it serves to capture the metal flow from the foundry ladle and its directing to the runner,
b) runner – serves to supply melted metal from pouring basin to the distribution channel,
c) distribution channel – supplies melted metal from the runner to the gate and captures slug and dirt tore off,
d) gates – connect the distribution channel and mould cavity,
e) overflow funnel – conducts gases and steam generated during casting.

2.2. Forming

Determining the quantity of moulding sand for forming

Net sand consumption is given by the difference between the volume of all frames used for forming and the volume of the pattern. It is also necessary to add the volume of the core. To calculate the mass of moulding materials, the specific weight of the sand is $1.7.10^3$ kg/m^3.

Composition of moulding mixture for smaller castings:

Grey cast	sand used	75 – 90 %,
	Pure sand	22 – 8 %,
	coal	3 – 2 %,

core components:

Grey cast	fresh sand	98 – 99 %,
	Sulphite lye	1 – 3 %,

For particularly thin-walled cores, 1.5% linseed oil is used.

Calculation of forces acting on the cope of the mould during casting

During casting, the mould cope is lifted by a considerable force that results from the core lift in the prints and the pressure of the melted metal on the cope of the mould. In casting of smaller castings, it is sufficient to fasten the frames to each other, thus creating a single unit. In the case of bigger castings, it is necessary to use a weight specially designed for this purpose, with lugs for crane.

Determining the place and volume of rising gate and coolers

Due to shrinking, shrinkage is created, which degrades the casting. Therefore, the casting is increased by feeder, which is removed after solidification. Feeders are most often used for steel castings (steel has the greatest shrinkage). Determining the volume of the feeder (the most suitable cross-section is circular) is based on the volume of the shrinkage, which is about 3.8 % of the initial volume. Feeder must be sized so that the draw fits in it. For this reason, the ration of draw volume to feeder volume is 1:5, while the height of the feeder is:

$$h = (1{,}5 \div 2).d \qquad \text{[mm]} \qquad (2.1)$$

where: d – diameter of feeder in mm.

If it is not possible to place the feeder, coolers are used, which will cause the metal to cool faster and thus prevent the shrinkage.

2.3. Casting

Calculation of metal utilization

It is necessary to determine the **level of metal utilization, which is the ratio of the weight of the rough casting to the weight of the raw casting.**

Rough casting weight is the weight of casting cleaned from auxiliary casting additives.

Raw casting weight is the weight of pure metal solidified in mould.

Casting process

Melted metal is cast into a mould from a ladle transported to the mould by crane or trolley. For grey casting, a hinged ladle is used, while for casting steel a bottom-drain ladle is used.

For a quality casting, casting speed is very important. The temperature of the metal cast should be so high that the metal perfectly filled the mould even in the thinnest walls. The casting temperature affects the quality of the casting. The speed of casting must be so high that the inlet is filled with the melt metal during casting and filled up to the edge after casting. This way the impurities, slug, and washed sand float on the melt metal surface and will not appear in the mould. It is also important not to interrupt the casting process, otherwise the same risk arises; moreover, the melted metal surface is immediately covered with oxides layer that make a perfect joining of metal impossible.

Casting tools

Moulding rammer – basic tool for manual forming. Manual moulding rammers can be wooden or metal.

Trowels – are used for treatment and smoothing of mould face after casting removal (Fig. 2.6).

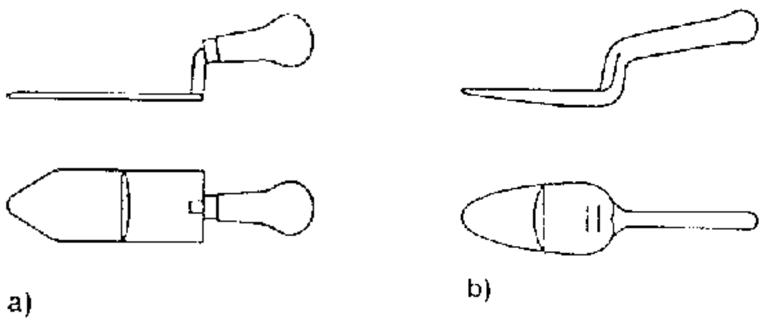


Fig. 2.6 Trowels
a) flat b) spoon

Lancets – they are used for making gates, fossas, or to correct mould defects. They are of various shapes and sizes (Fig. 2.7).

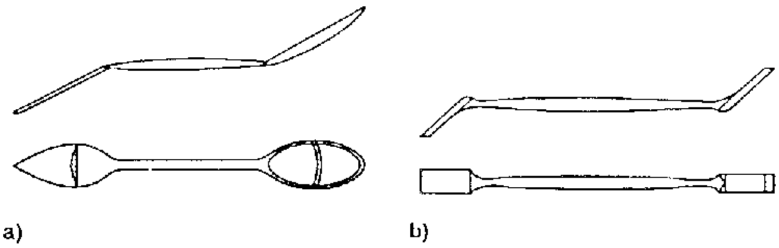


Fig. 2.7 Lancets
a) spoon   b) flat

2.4. Forming using section mould and core

Fig. 2.8 shows a gearwheel (1) manufactured by casting. It´s a casing with an inner hole manufactured by means of core. In such a case, section mould is used for creating of the hole (2) – a pattern consisting of two connected parts, centred by means of connecting pins. There are additional parts – prints (3) on both parts of the pattern, which create beds for placing the core – the core is placed in the mould by means of conical pins. Core is manufactured by means of core box (4). Wooden runner pattern (5) is identical with the pattern of whistler channel.

For this forming method, it is typical that the casting pattern creates a cavity both in the upper and lower part of the mould.

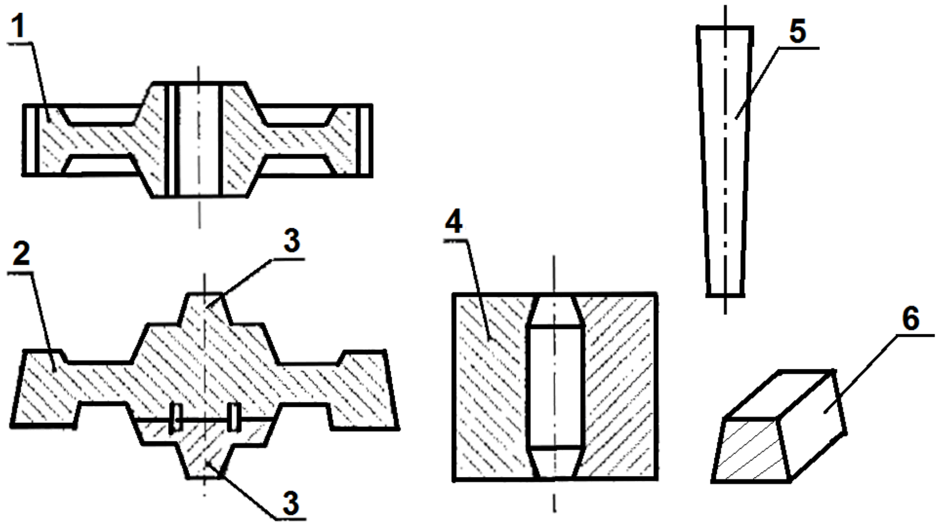


Fig. 2.8 Product with gating system

1 – component (gearwheel), 2 – section pattern, 3 – print, 4 – core box, 5 – runner mode, 6 – dirt trap pattern

Forming the mould drag

A lower moulding box (4) is placed on the cleaned pattern plate (1) and the lower casting pattern (Fig. 2.9) is suitably placed in the space. In order to enable to remove the pattern from the mould, it is dusted a powder which prevents sticking to the pattern. A layer of loosened moulding mixture of the roughness about 2 – 3 cm is sieved by means of strainer. The moulding box is filled with the moulding mixture (3) (not sieved again). The moulding mixture is condensed using a hand rammer from the outer edge to the middle. Then more layers of the moulding mixture are added until the moulding box is filled up to the cope edge. Finally, the excess mixture is cut off with a steel alignment ruler. This creates a surface on which the drag of the mould will be after its rotating.

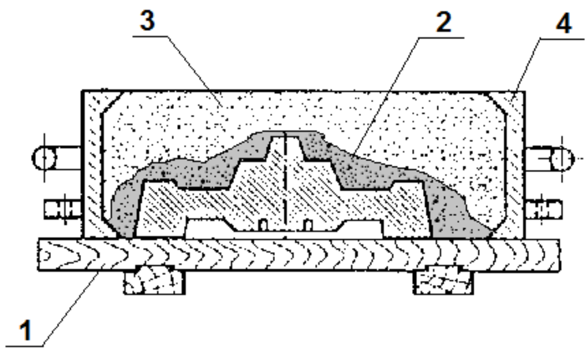


Fig. 2.9 forming the mould drag

1 – pattern plate, 2 – modelling mixture, 3 – moulding mixture, 4 – moulding box

Turning the mould drag by 180°

After forming the mould drag, the moulding box is turned together with a mat (so that the pattern does not fall out of the mould) by 180° and placed on another mat.

Forming the cope of the mould (Fig. 2.10)

The cope box (2) is placed on the lower moulding box (1) (turned by 180°) (2) by means of pins (4) inserted in the holes in the moulding box roots. The pins ensure the mutual position of the cope and the drag, which is important after dismantling and assembling the mould.

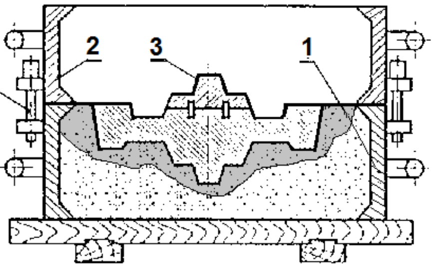


Fig. 2.10 forming the cope of the pattern and moulding box

1 – lower moulding box, 2 – cope box, 3 –upper part of pattern, 4 –pins

The upper part of the pattern is placed on the lower part of the pattern (3) (Fig. 2.11), together with the patterns of the gating system so that they are not close to the walls and the partitions of the frame. The cope of the mould is treated and vented in the same way as the drag of the mould. Around the runner, pouring basin is cut around in the desired shape. If the pouring basin is made by means of the pattern, we release it by shaking it and pull it out of the mould, including the patterns of the runner and whistler.

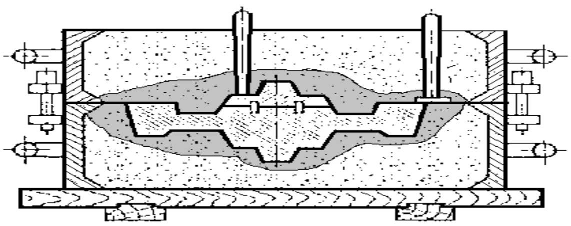


Fig. 2.11 Forming the cope of the mould

Dismantling the mould and pulling out the pattern

With a wood hammer, we tap on the corners of the cope box so that the contact surface between the cope and the drag as well as between the pattern and the moulding mixture is released. The pins are loosened but not pulled out. First the cope box with the loosened pins is raised, then the pins are pulled out. The cope of the mould is turned by 180° and placed on a wooden mat. Using foundry brush we moisten the edge of the moulding material around the mould so that the water does not reach the pattern. The pattern of the casting as well as the pattern of the distribution channel is released by shaking and pulled out by means of hooks, a stick in the form of a square pyramid or screwing the hoists. The cuts are in the drag of the mould, if they were not made by means of pattern. Possible errors are repaired manually and the remainders of the moulding mixture are blown off.

Assembling the mould and preparation for casting

After removing the individual parts of the pattern, core (manufactured by means of core box) is inserted in the mould. The core (1) is placed in the drag of the mould – the core pin must fit into the bed created by the print on the pattern. The upper part is placed on the lower part, and their mutual position is ensured by pins. The mould is placed on the field (Fig. 2.12). The cope of the mould is loaded with a weight in order to prevent it from being lifted during the casting as a result of the upthrust forces.

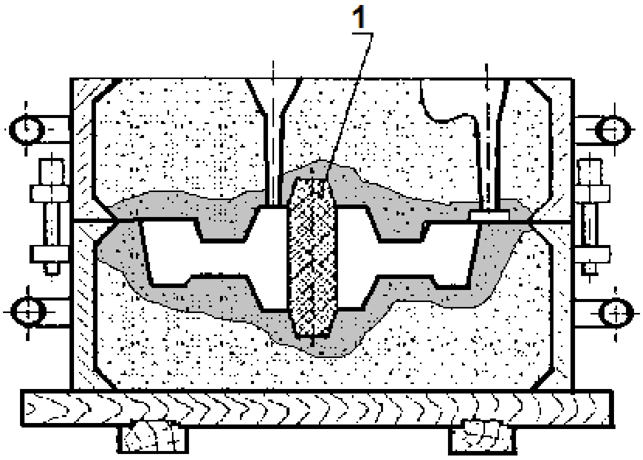
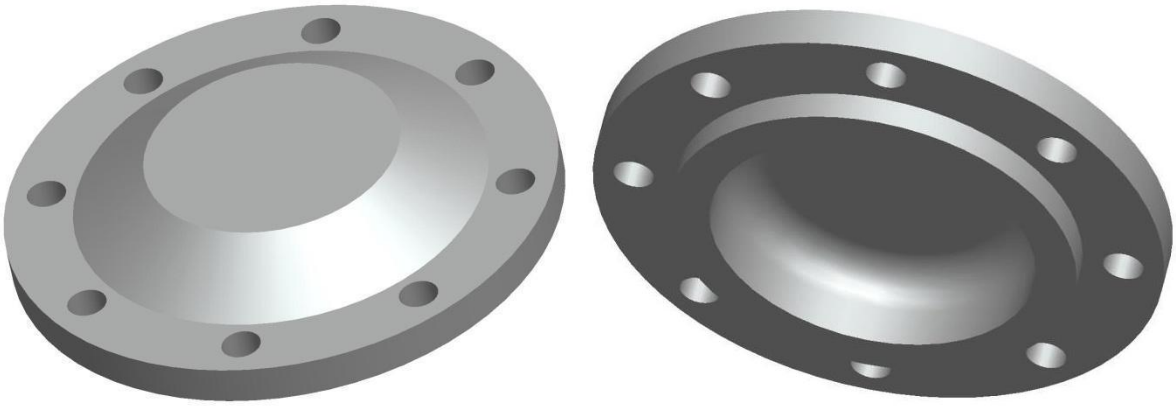


Fig. 2.12 assembled mould with a core

1 – sand core



a) b)

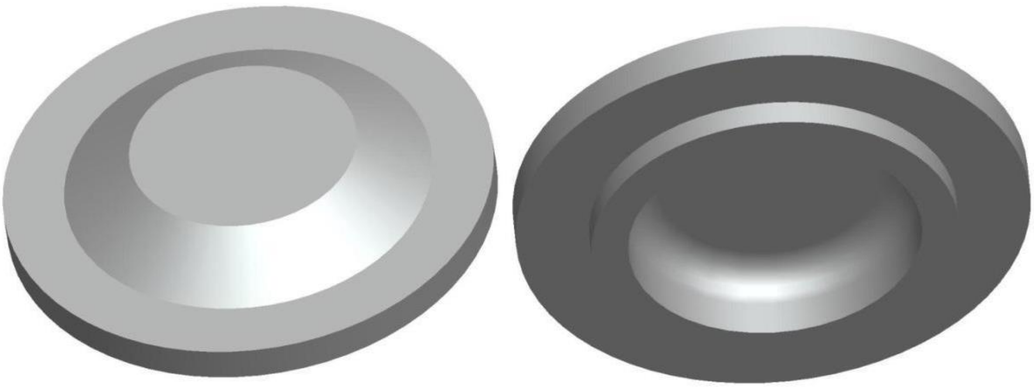
Fig. 2.13 Component made by means of casting in axonometry

Pattern device design

Choosing the material of the pattern:

Due to the one-off production, a suitable material for manufacturing the pattern is wood. According to STN 04 2008, for the castings made of grey cast, a split wooden pattern will be used, whose surface will be red.

Since 8 holes of the ø 10mm on the lid will not be precast, it is not necessary to consider them in the design (Fig. 2.15).



a) b)

Fig. 2.15 The component without precast holes in axonometry

Choosing the parting plane:

The parting plane is marked by solid green line finished by crosses and the direction of forming. For the component, the parting plane is in the widest point of the component (Fig. 2.16).

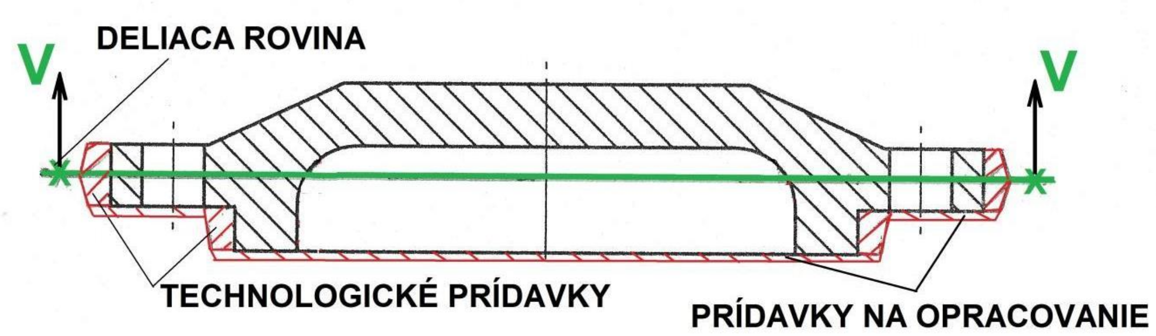


Fig. 2.16 component with parting plane and allowances

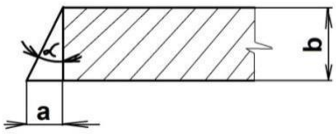
Legend: deliaca rovina – parting plane, technologické přídavky – technological allowances, přídavky na opracovanie – machining allowances

Choosing machining allowance

Machining allowances are marked in red in the drawings. The allowance is on the surfaces with established roughness which cannot be achieved by casting. These allowances are removed from the cast by chip machining.

Design of technological bevels

In order to facilitate the removal of the pattern from the mould, it is necessary to use technological bevels of C type in accordance with STN 04 2021 (Fig. 2.17).



$\alpha = 1° 30'$

Fig. 2.17 Technological bevel – C type

Deciding on the necessity of pre-casting holes

For the component in Fig. 1.16 it is necessary to pre-cast a hole, since it is a one-off production and the condition of d > 50 mm is met.

For grey cast, it holds true that:

S_L: $d < 0.3 \,.\, h + 10$ [mm] (2.3)

where : d – hole diameter,

h – height of hole,

holes for screws (Fig. 2.14):

$10 < 0.3 \,.\, 10 + 10$

$10 < 13$ => it results that the holes are not pre-cast

Lid cavity (Fig. 2.15b):
80 < 0.3 . 20 + 10
80 > 16 => the hole must be pre-cast

Choosing moulding box:

Moulding box dimensions are determined based on the pattern and gating system dimensions. The pattern distance from the edges of the moulding box is shown in Fig. 2.18.

Moulding box lid dimensions:

Upper part HR LxBxH1: 400x300x100 [mm]
Lower part DR LxBxH2: 400x300x140 [mm]

Gate length is 100mm.

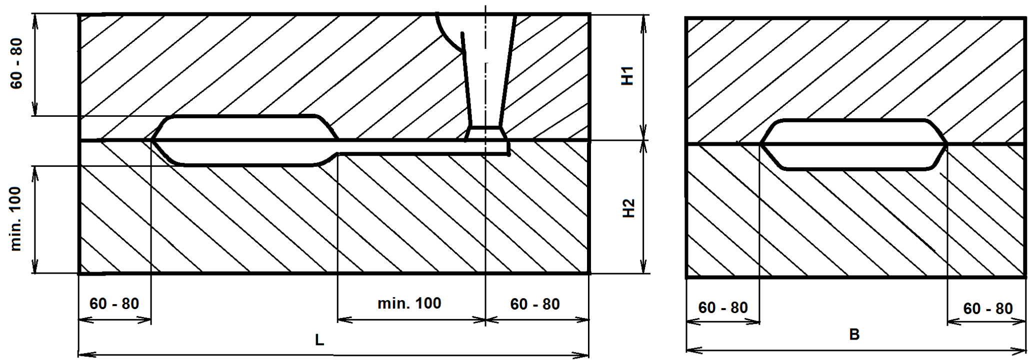


Fig. 2.18 Recommended moulding box dimensions

Calculation of gating system

Calculation of gating system is based on simplified hydrodynamic equation.

Calculation of the gate area Sz:

$$\sum Sz = x \cdot \frac{\sqrt{G}}{\sqrt{HP}} \quad [\mathrm{cm}^2] \qquad (2.4)$$

where: Sz – the overall gate area,
G – weight of casting,
x – coefficient considering wall thickness + complexity of casting (see Tab. 2.3.)
For the given component, x = 2.8.

Tab. 2.3 Coefficient x

	Simple castings				**Complex castings**		
Casting wall thickness [mm]	3 – 4	5 – 9	9 – 15	> 15	3 – 4	5 – 9	*9 – 15*
x	*3.8*	*3.2*	*2.8*	*2.4*	*5.8*	*4.9*	*4.3*

Calculation of casting weight with gating system:

$$G = 1{,}5.m_O \qquad \text{[kg]} \qquad (2.5)$$

where: G – casting weight with gating system for which 0.5m_o [kg],
m_o– casting weight

G = 1.92 kg

Calculation of mean ferrostatic height:

$$H_p = H - \frac{p^2}{2 \cdot C} \qquad \text{[cm]} \qquad (2.6)$$

$$H_p = 10 - \frac{1{,}8^2}{2 \cdot 3{,}0}$$

H_p = 9.46 cm

where:C – casting height [cm],
H_p – mean ferrostatic height [cm],
p – casting height above the gate [cm],
H – runner height above the gate [cm],

Calculation of gate area:

$$\sum Sz = x \frac{\sqrt{G}}{\sqrt{HP}} \qquad [\text{cm}^2] \qquad (2.7)$$

$$\sum Sz = 2{,}8 \frac{\sqrt{1{,}92}}{\sqrt{9{,}46}} = 1{,}26 \text{ cm}^2$$

For the area of one gate, it holds true that:

$$Sz = \frac{\sum Sz}{n} = \frac{1,26}{2} = 0,63 cm^2 \qquad (2.8)$$

where: n – number of gates

For calculating the gate and trap area of simple castings, it holds true that:

$$S_K > S_L > \sum Sz = 1.4 : 1.2 : 1 \qquad (2.9)$$

$S_K = 1.4 . \sum Sz$ $S_L = 1.2 . \sum Sz$
$S_K = 1.76\ cm^2$ $S_L = 1.51\ cm^2$

where: S_K – runner area [cm^2]
S_L – dirt trap area [cm^2]
Runner has a circular cross-section, therefore it is calculated as follows:

$$S_K = \frac{\pi . d^2}{4}, \text{ then } d = \sqrt{\frac{4S_K}{\pi}} \quad [cm] \qquad (2.10)$$

$$d = \sqrt{\frac{4.1,54}{\pi}} = 1.4\ cm$$

In practice, vacuum runners of a conical shape with a peak angle of 3 – 5° are used. For calculating the dirt trap dimensions (Fig. 2.19) it holds true that:

$$S_L = 0.935 . a^2 \quad [cm^2] \qquad (2.11)$$

$$a = \sqrt{\frac{S_L}{0,935}} \quad [cm] \qquad (2.12)$$

$$a = \sqrt{\frac{1,51}{0,935}} = 1.27\ cm$$

In gating system design it is necessary to ensure that the lower diameter of the gating system is identical with the width of the dirt trap on the upper part. The dirt trap dimensions will be calculated as follows:

$0.7a = d_{runner} = 1.4$ cm

(2.13)

$a = 2$ cm.

Height of a trapezium dirt trap is calculated as:

$$S_L = \frac{0{,}7a + a}{2}.v \qquad [cm^2] \qquad (2.14)$$

$$v = \frac{2.S_L}{0{,}7a + a} \qquad [cm] \qquad (2.15)$$

$$v = \frac{2.1{,}51}{1{,}4 + 2} = 0{,}89 \text{ cm}$$

where: v – dirt trap height

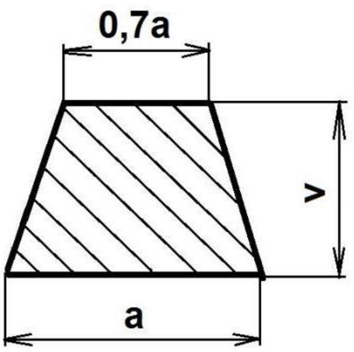


Fig. 2.19 Dirt trap cross-section

For calculating gates dimensions in Fig. 2.20 it holds true that:

$$S_z = 0.285 \, . \, R^2 \qquad [cm^2] \qquad (2.16)$$

$$R = \sqrt{\frac{S_Z}{0{,}285}} \qquad [cm] \qquad (2.17)$$

$$R = \sqrt{\frac{0{,}63}{0{,}285}} = \underline{1{,}48 \text{ cm}}$$

where: R – gate radius

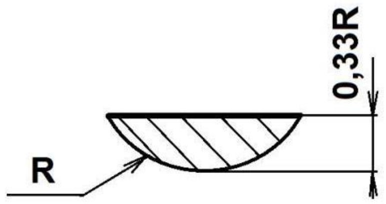


Fig. 2.20 Gate cross-section

Whistler, which is mostly situated on the highest surface of the component cast has a conical shape (as well as the runner). The peak angle of the cone is 2 – 4 º.

Based on the calculation, it is possible to make a wooden pattern of the component and gating system. The bottom of the component and core pattern can be formed in the drag (as shown in Fig. 2.21).

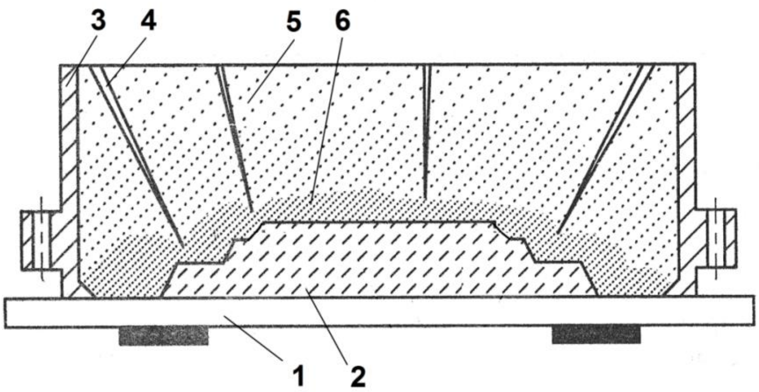


Fig. 2.21 Forming of the pattern bottom
1 – plate, 2 – lower part of wooden split pattern, 3 – lower mould frame, 4 – air channels, 5 – backing moulding sand, 6 – modelling mixture

After forming the bottom of the pattern, the bottom frame is turned and attached with the top (Fig. 2.22). At the distance of at least 100 mm from the pattern, dirt trap is placed.

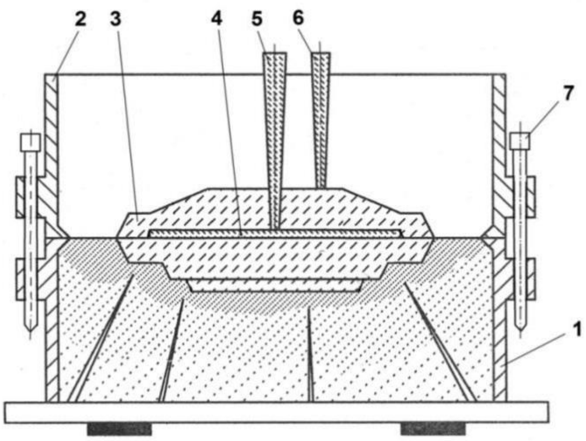


Fig. 2.22 Forming upper part of pattern

1 – lower mould frame, 2 – upper mould frame, 3 – upper part of wooden split pattern, 4 – slag channel, 5 – runner, 6 – whistler, 7 – distance pins

On dirt trap, a pattern of runner is moulded into facing and then backing sand. Similarly, a whistler pattern is formed, as well (Fig. 2.23). The length of both patterns exceeds the upper part of the moulding box in order to facilitate their removal from the mould. After forming, the moulding sand is stamped e.g. by pneumatic stamper, and air channels are created in the moulding sand. Besides the runner, pouring basin is created in the moulding mixture.

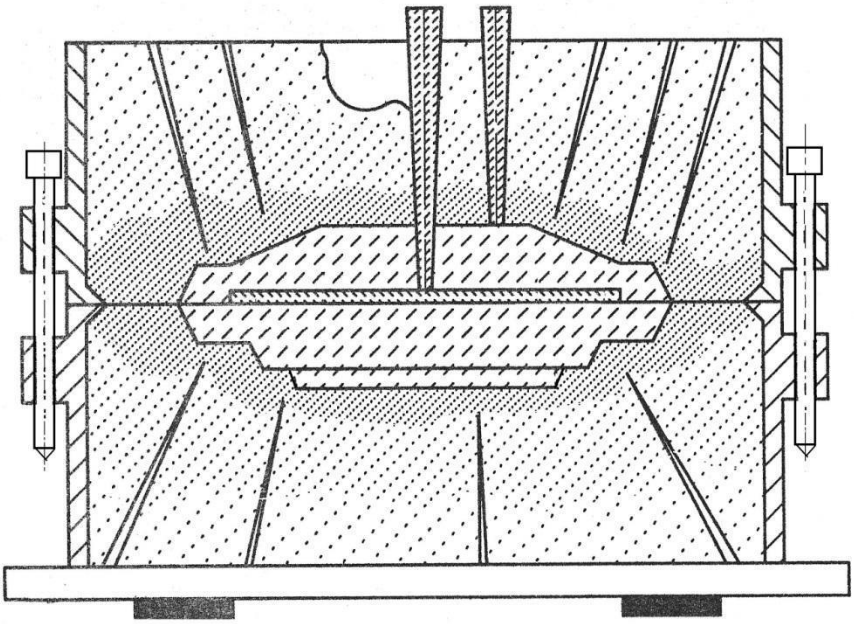


Fig. 2.23 Formed pattern with gating system in split mould

After stamping, it is necessary to remove wooden patterns from the sand mould. First the whistler and gating system patterns are removed (Fig. 2.24). Then distance pins are removed and the mould can be dismantled in the parting plane (Fig. 2.25).

From the upper and lower part of the moulding box, the wooden pattern of the component and the dirt trap is removed (Fig. 2.26). In the cavity of the lower part of the form, gates are made using forming tools (see Fig. 2.21).

The upper and lower part of the mould are connected using distance pins and its edges are loaded with a weight that prevents mould moving during the casting process (Fig. 2.27).

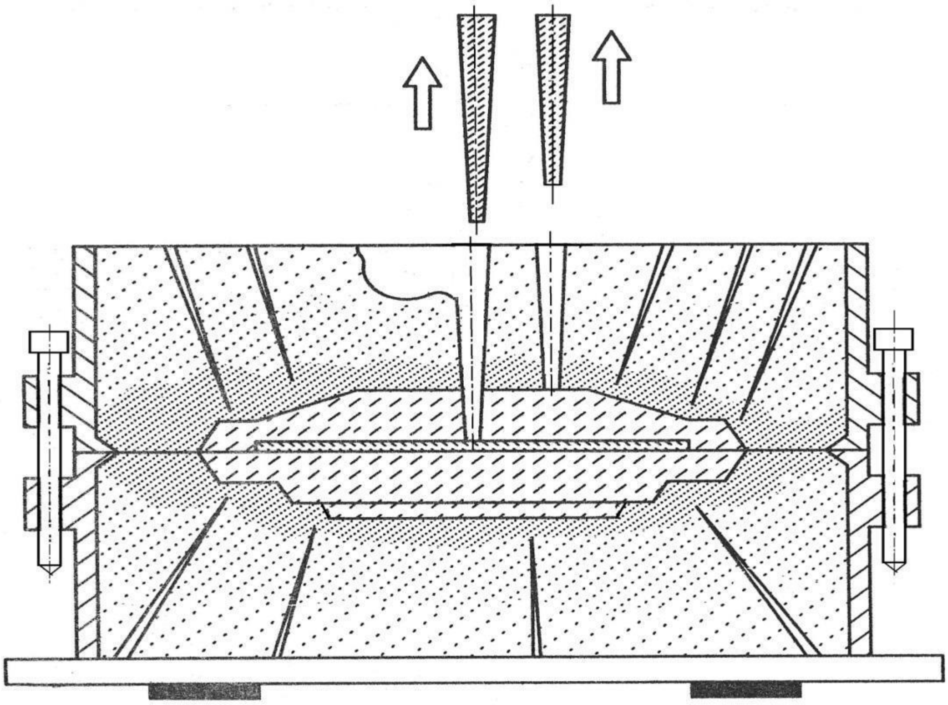


Fig. 2.24 Removing gate and whistler before mould dismantling

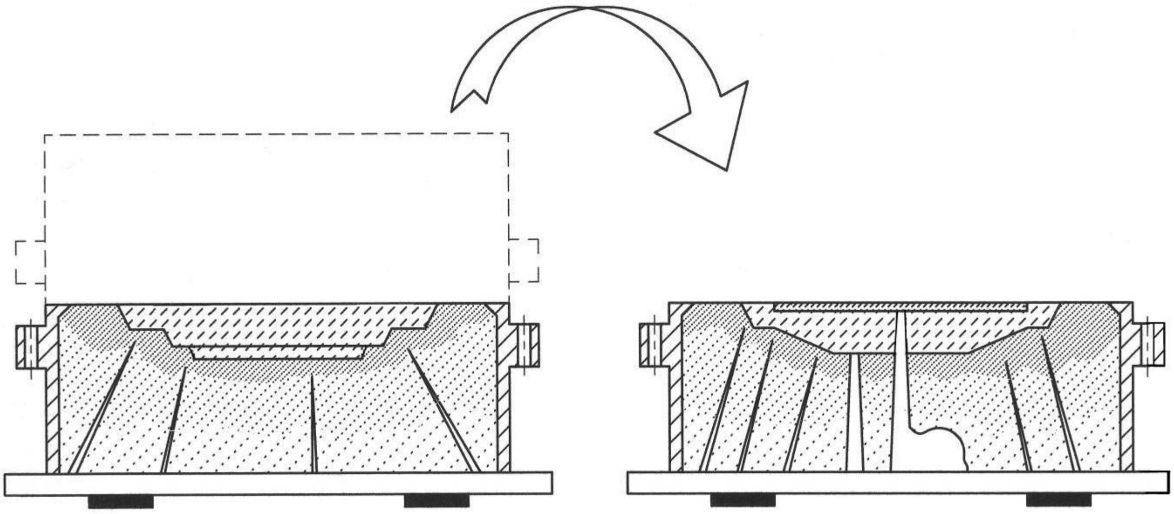


Fig. 2.25 mould dismantling in order to remove patterns of component and gating system

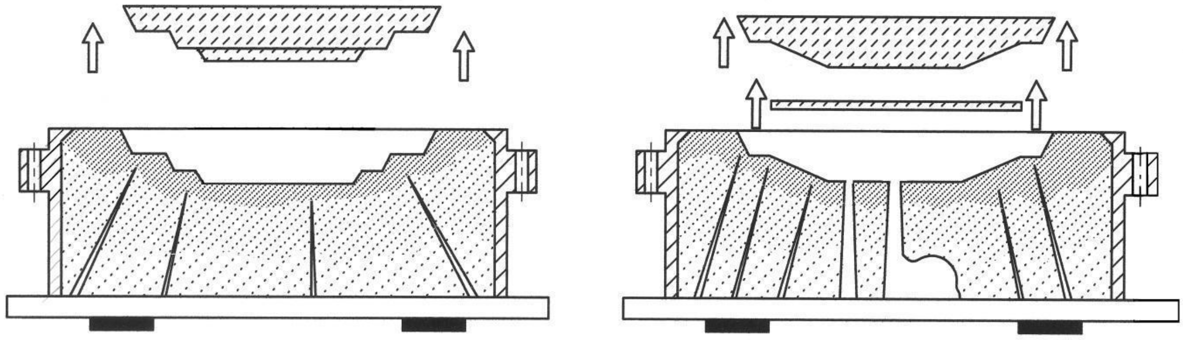


Fig. 2.26 Ejection of split pattern, gate, and dirt catcher from mould

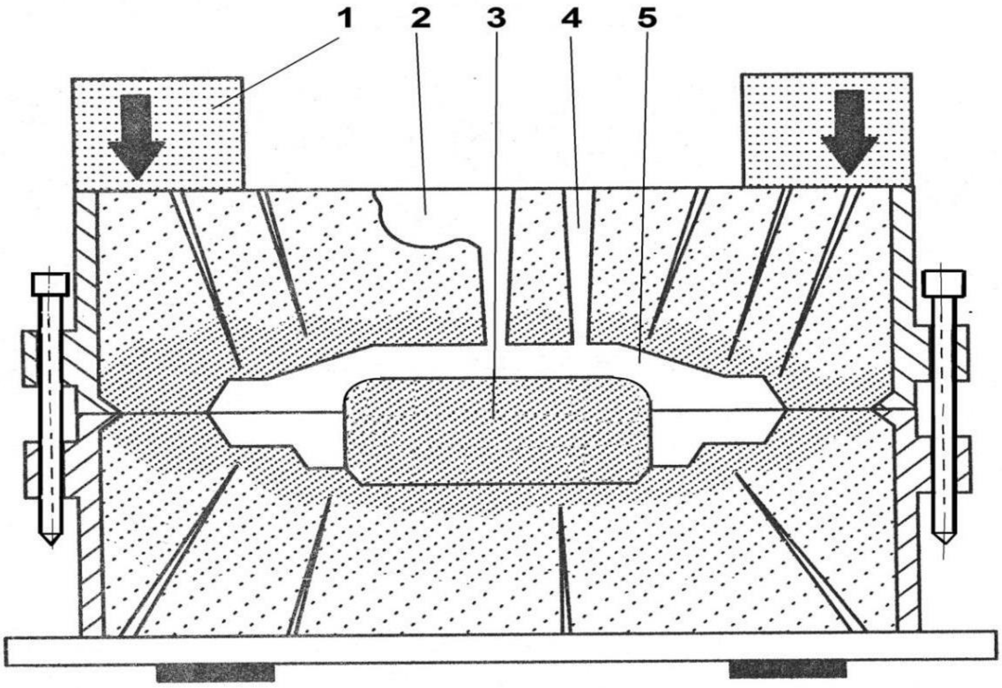


Fig. 2.27 Assembling the mould before casting
1 – loading mould with weight, 2 – cavity of pouring basin and runner, 3 – core, 4 – whistler cavity, 5 – component cavity

After assembling and loading the mould, the casting is cast from tilting ladle. Into the pouring basin, grey cast is poured, that gets into the mould cavity via runner. During the casting process, the whistler conducts air and vapours. The casting process is completed when the melted metal fills the whole whistler cavity (Fig. 2.28).

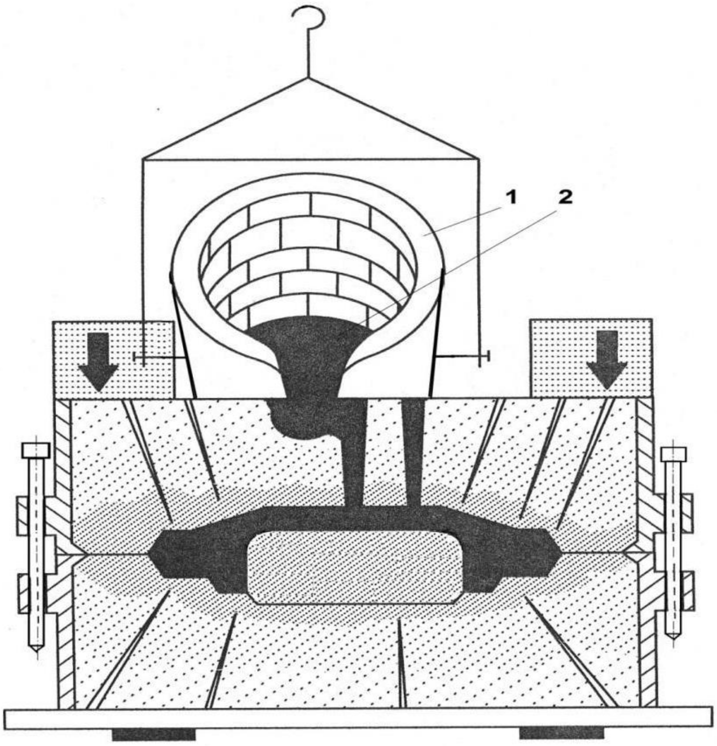


Fig. 2.28 Casting into sand mould
1 – tilting ladle, 2 – melted metal

The mould is dismantled after the casting cooling, and raw casting (Fig. 2.29) is treated with a finish and subsequent machining in order to achieve the required dimensions (see Fig. 2.14).

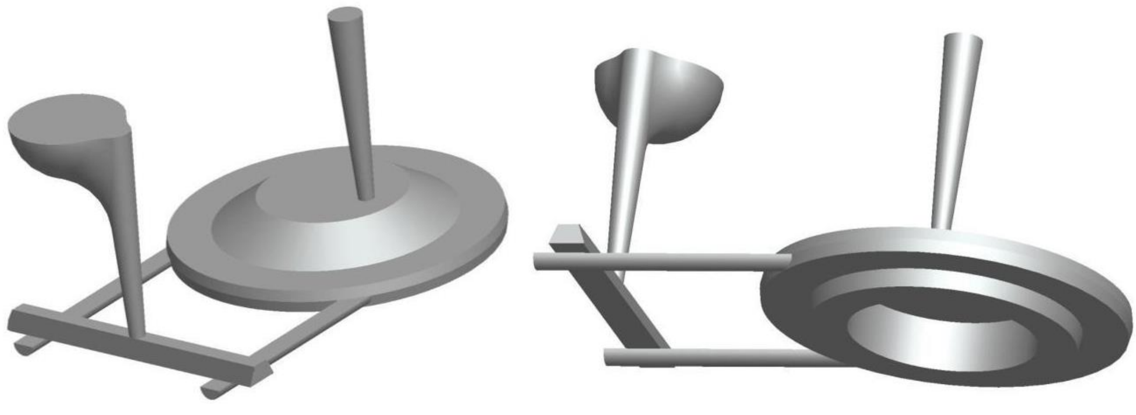


Fig. 2.29 Raw casting

3. CASTING SOLIDIFICATION AND COOLING

3.1. Casting properties of metals and alloys

Fusibility

Fusibility is the ability of material to pass from solid to liquid state while maintaining its chemical composition and purity.

Fig. 3.1 and 3.2 show the heat consumption for melting and heating the cast

Amount of heat:

$$Q=c_s(t_L-20)m+m.l_T+c_s'(t_p-t_L)m \qquad (3.1)$$

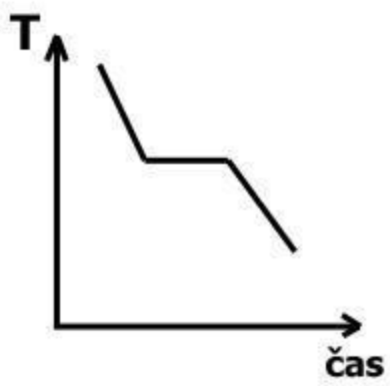


Fig. 3.1 Cooling pure metal

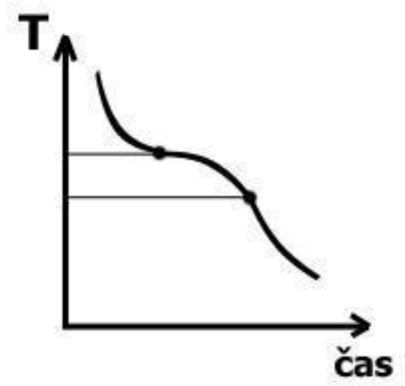


Fig. 3.2 Cooling alloy

Fluidity

Fluidity is the inverse value of dynamic viscosity.
$\varphi=1/\eta$, where η is dynamic viscosity.

- fluidity is measured as filling the mould before the melt solidifies. The cast fluidity is increased by phosphorus (grey cast). Phosphorus is a negative element, acting positively only in the case of increasing melt fluidity.
- Segregation is separating individual components during solidification. It is caused by partial or complete insolubility of two metals or alloys, e.g. leaded bronze (Cu-Pb); T_{TAV-Cu}=1083°C and T_{TAV-Pb}=327°C
- The ability to absorb gases is the solubility of gases in metals. It increases with increasing temperature + vice versa.

Shrinking

Shrinking is a property showing in changing volume / dimensions; dimensions diminish with decreasing temperature (Fig. 3.3 and Fig. 3.4).

Specific weight

Solid steel ρ=7.8 kg.dm^{-3}, molten steel ρ=6.8 kg.dm^{-3}
Solid grey cast ρ=7.25 kg.dm^{-3}, liquid grey cast ρ=6.9 kg.dm^{-3}

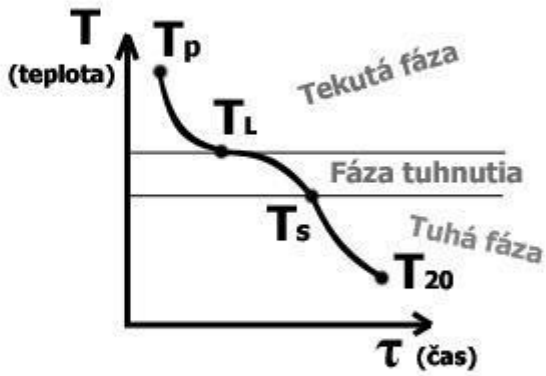


Fig. 3.3 Shrinking in liquid state, during solidification, solid state

Tp - TL – shrinking in liquid state – solved by pouring, reservoir of liquid metal
TL-Ts – shrinking during solidification – solved by feeding or chill
Ts-T20 – shrinking in solid state – model is manufactured bigger by shrinking

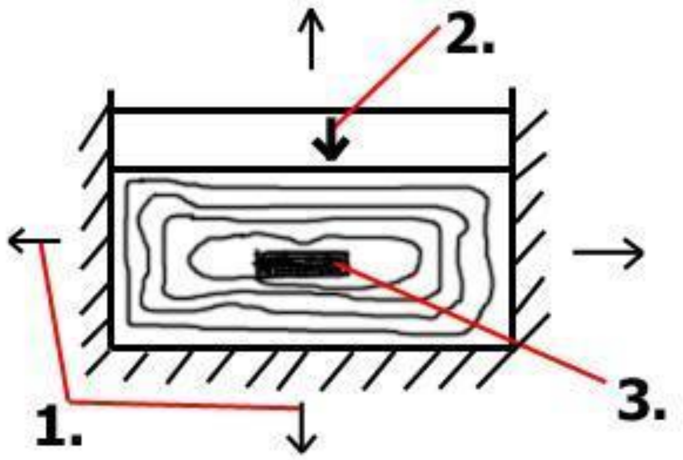
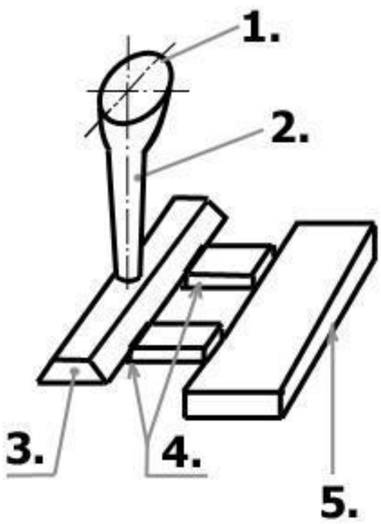


Fig. 3.4 Shrinking

1. *Conducting heat away, 2. Drop of surface, 3. Shrinking – formation of shrinkage*

3.2. Foundry forming materials and gating system of casting

Gating system – Fig. 3.5



1. Gating system
2. runner
3. dirt trap
4. gates
5. casting

Fig. 3.5 Gating system

Runner is narrowed by 2-4°.
For pouring melt, two basic types of ladle are used:

- Tilting ladle
- Bottom pour ladle – more expensive, complicated maintenance; used for steel; impurities are captured on the surface of melt, therefore dirt trap is not necessary

Dirt trap is not used for steel.

Gates can be of various cross-sections – square, triangle, semi-circle. Gates in the mould cavity must be placed so that the melted metal does not strike the face of the mould or does not fall from higher distance to the mould bottom.

Whistler conducts gases and vapours away, signals filling of the mould, dampens the strike of liquid metal at the moment of cavity filling. For its manufacturing, model (pin) is used (Fig. 3.6).

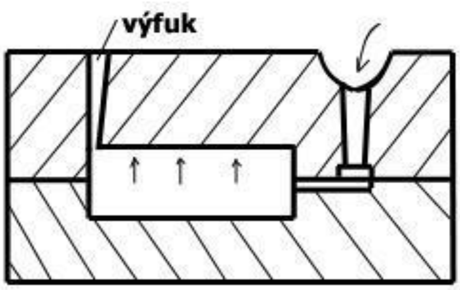


Fig. 3.6 Filling the mould cavity. Výfuk – whistler

Castings:

- Raw casting - vypadne z formy
- Rough casting – machined, without a whistler and gating system
- Finished casting – abrased, completely machined

<u>Moulding sand</u>

It is used for manufacturing expendable moulds. They consist of binder and sand. Binder is used for creating a compact mixture by wrapping and bonding the sand grains.

Moulding sands are:

- Natural: SAND – silica and siliceous sands on the basis of SiO2 - BINDER – using binder, medium-strong sand, strong sand, very strong sand
- Synthetic: SAND - natural (silica sand) and artificial (fireclay, magnesite) - BINDER - anorganic (cement, gypsum, water glass, clay) and organic (oils, bitumen, carbohydrates)- binder with natural or artificial sands.

Moulding mixtures properties:

- physical (conductivity, expansion)
- chemical (low reactivity with melt metal)
- technological
    - in forming: adhesion, fluidity, durability, dimensions accuracy
    - in casting: mechanical
    - breathability
    - properties during removal of mould

Manufacturing of moulds and cores is conditioned with moulding mixture properties:

- Formability – the ability to receive a shape of a model, thereby enabling to create a mould corresponding to the shape of the casting
- boundedness – the ability to retain the shape given by forming and transmit force resistance so that the mould retains the same dimensions
- breathability – the ability to release gases and vapours generated during casting
- strength after drying – raw binding is not enough, so complicated forms and cores the boundedness values are increased by drying
- Refractoriness – depends on chemical composition and presence of harmful fluxes
- Granularity – conditioned by the size of sand grains and the type of the metal cast – size of casting and required surface quality

- Chemical resistance – affects the quality of the casting surface; chemical effect is manifested by the reaction of acid oxides with bases
- disintegration – the ability to lose strength after casting; the casting can shrink after the casting process. This is due to the fact that some binders are burnt by acting of melt and stop binding sands

Unwanted properties:

- Stickiness – makes removing of the model difficult, damages the mould faces, model has to be covered with a special substance
- hygroscopicity – the ability to absorb moisture from the air
- Friability – lowers the boundedness during mould drying

<u>Crystallization of metals – cooling curve – PURE METAL</u> (Fig. 3.7)

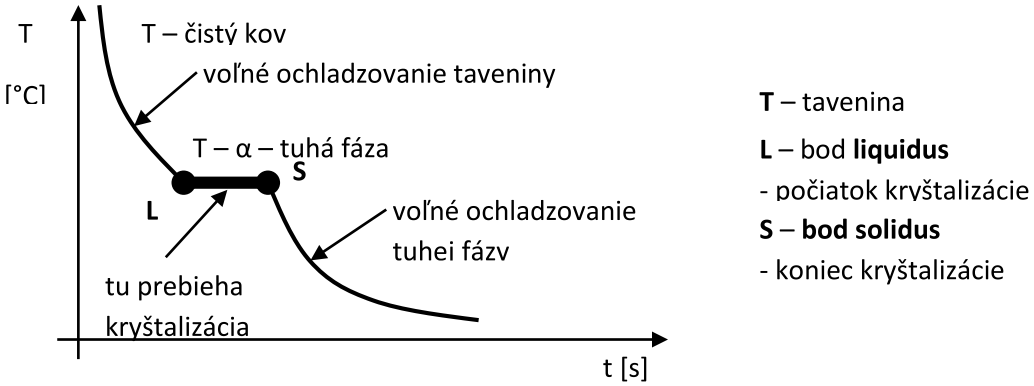


Fig. 3.7 Pure metal crystallization curve

Legend: čistý kov – pure metal, volné ochlazovanie taveniny – free melt cooling, tuhá fáze –solid phase, voľné ochladzovanie tuhej fázy – free cooling of solid phase, tu prebieha kryštalizácia – process of crystallization, tavenina – melt, bod liquidus – liquidus point, počiatok kryštalizácie – start of crystallization, bod solidus – solidus point, koniec kryštalizácie – end of crystallization

Crystallization of metals – cooling curve - ALLOYS (Fig.3.8)

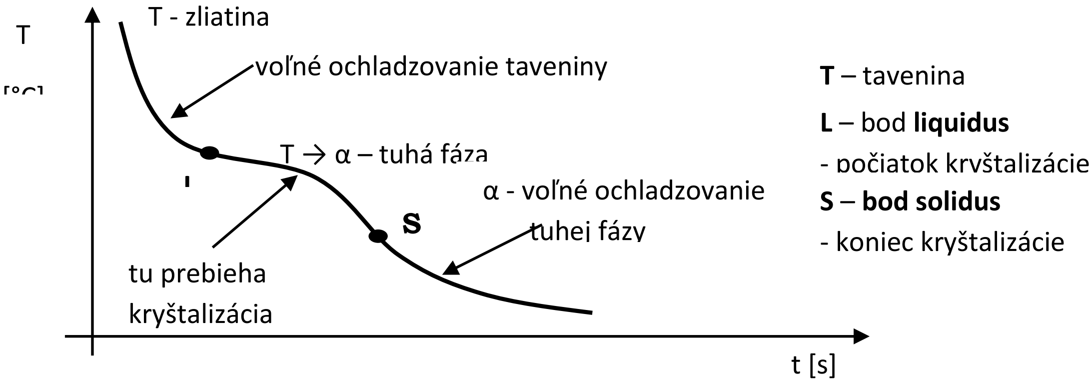


Fig. 3.8 Alloy crystallization curve

Recrystallization of metals – cooling curve

Recrystallization of metals: a change in a crystalline arrangement. A change of structure in solid state during the process of metal (alloy) cooling, e.g. Fe, Be, Sn, Ce, Ti etc.
Recrystallization: a change of crystal lattice in solid state
Cooling curve: function of temperature in dependence over time
Polymorphism: the ability of metal to crystallize in different structures in dependence over temperature
Allotropism: the ability of alloys to crystallize in various forms/ structures.

Process of transformation of metal structure in solid state – change of crystal lattice.

Metals crystallization - transformation of **liquid state into solid state.** It is related to the atoms arrangement in crystal lattice.

It consists of two stages:

- Formation of crystallization nuclei
- Nuclei growth

Nuclei:

- stable (when they reach a certain size)
- unstable

Crystallizing nuclei:

- from the basic phase
- extraneous (Al_2O_3, TiO_2)

Crystallization course is influenced by two factors:

- ability to crystallize – the speed of nuclei formation at 1 cm^{-2} per sec.
- Speed of crystallization – nuclei growth speed is changeable

In casting, the mould top is lifted by a considerable force that results from the upward lift of the core and the pressure of the melted metal on the top of the mould. In the case of smaller castings, it is sufficient to attach the boxes to each other to form a single unit. In the case of bigger castings, a weight specifically created for this purpose must be used.

The casting process consists of pouring melted metal from the ladle transported to the mould by crane or trolley. For grey cast tilting ladle (Fig. 3.9) is used, while for steel for castings, bottom pouring ladle.

For the quality of the casting, casting speed is very important. The temperature of cast metal must be high enough so that the metal perfectly filled the mould even in the thinnest walls. The cast temperature affects the casting quality. The casting speed must be so high that the inlet is filled with melted metal during casting and filled up to the edge when casting is finished. This way the dirt, slag, and washed sand float on the surface and are not drawn into the mould. At the same time, it is necessary not to interrupt the casting process, otherwise there is a risk that the melted metal is covered with a layer of oxides that prevent perfect merge of metals.

Legend: tekutý kov – melted metal, ocelové teleso pánvy – steel body of ladle, výlevka - drain, závesné panty - hinges, sklopný mechanismus – tilting mechanism, viacvrstvová výmurovka – multi-layer lining, laity betón – cast concrete, šamot - grog, izolačná vrstva – insulation layer

4. FUSING

Fusing is a heat-metallurgical process during which the material (batch) changes its physical state from solid (solidus) to liquid (liquidus) as a result of adding or generating heat.

A certain amount of heat is required for this transition. The heat consists of heat Q_1 necessary for heating the whole batch volume from the normal temperature of the environment (T_0) to the temperature of melting metal (or the liquidus temperature T_L), heat Q_2 necessary for melting the whole volume of the batch, and heat Q_3, necessary for heating the melt to certain temperature T_{pr}.

Pure metals melt and solidify at the same temperature (liquidus temperature = solidus temperature), alloys melt and solidify at a certain temperature interval (liquidus temperature is higher than solidus temperature).

Metal melting takes place in melting aggregates (furnaces).

4.1. Basic terms

Alloy is materials consisting at least of two elements, out of which at least one is metal, forming a solid unit in solid form. Alloy is formed by dissolving additives in basic liquid metal.

For castings production, binary, ternary, and multicomponent or poly-component alloys are used, where we can identify:

- Basic element (main alloying element), whose content is greater than 50% and is used for naming the alloy (zinc alloys, aluminium alloys, copper alloys, etc.)
- Alloying element (alloying additive), whose content in alloy is significantly lower compared to the basic element content.

The content of all alloy elements is defined by the relevant standard.

Alloying is a process in the production of alloy in which alloying elements are added in liquid metal. In alloying, the proportion of one or more elements is increased, which improves some properties of the casting.

The opposite of alloying is dilution – a certain alloying element is diluted if its concentration is too high in the melt, that is, if it exceeds the maximum permissible concentration limit. Usually, a pure metal is added, which increases the proportion of the basic metal and also the reduction of the alloying elements proportion.

Additives (impurities) – are elements whose presence in the alloy is unwanted. Mostly those are other elements except for alloying materials.

4.2. Metals melting

For metals melting, various types of melting devices are used. The decisive factors in choosing the suitable type of device are cost-effectiveness and technology requirements for production of metal or alloy. The most important technology parameters include:

- The power of melting device
- Content, design, and type of device
- Method of the melting device heating (gas, liquid or solid fuel, or electrical heating)
- Method of heat exchange
- Movement of the melt in the work area
- Work temperature range, temperature changes
- Control and regulation
- Atmosphere and pressure
- Melting process time

A very important parameter is the exchange of heat in the furnace work space, carried out by means of radiating, flowing or conducting. Depending on the work temperature and furnace design, one of the heat exchange methods is predominantly used. E.g. in the case of furnaces with a minimum temperature of 1000°C, the main heat exchange method is radiation, while in the furnaces with a temperature range above 650°C it is conducting. In the heat exchange process, inwall plays an important role, as it is heated to a higher temperature than the batch due to the lower heat conductivity. The dimensions and shape of the work space are essential for the melting process and for the furnace performance. They are the main criteria determining the amount of the molten metal.

The movement of the melt in the work space is a useful phenomenon, as it causes balancing heat and weight gradients in the volume of the liquid metal. If the melt moves correctly there is no local overheating that has a negative impact on the quality of the melt, especially in the case of aluminium alloys. For uniform heat and homogeneous melt, spontaneous flow (convection) is sufficient.

Melting devices can be divided into melting and maintenance by their use, and into fuel (gas or solid fuel) and electric (arc, inductive, and resistance) by the method of heat generation.

4.3. Melting cast iron

The most common and most suitable device for melting cast iron with graphite flakes is a cupola furnace. The main problem in the case of producing cast iron in a cupola furnace is higher-quality types of cast iron production and environmental regulations which some of the cupola furnaces ceased to meet. To achieve the required emission limits would require considerable investments; therefore, some foundry plants switched to the production of cast iron in electric induction furnaces.

Besides these two types of furnaces, it is possible (yet exceptionally) in electric arc furnaces and reverberatory furnaces.

- MELTING CAST IRON IN CUPOLA FURNACE
- MELTING CAST IRON IN FUEL – REVERBERATORY FURNACE
- MELTING CAST IRON IN ELECTRIC FURNACES (arc, induction)

4.4. Melting non-ferrous metals alloys

For melting non-ferrous metals alloys, especially aluminium alloys, the following types of furnaces are used:

- SOLID FUEL FURNACES
- ELECTRIC RESISTANCE FURNACE
- ELECTRIC INDUCTION FURNACE

Rational production in casting foundry plants requires only remelting of finished alloys (or their additional alloying) and their own returnable material. Unlike in foundry plants, in melting plants, various types of e.g. aluminium waste are re-melted. As batch material in foundry plants, finished alloys, pure metals for additional alloying, pre-alloys, metals with refining, protective, inoculation, and modification effects, own returnable material, and processing waste are used. In melting plants, aluminium scrap, pure metals, pre-alloys for additional alloying are used as a batch material.

The batch in both cases includes also non-metallic materials, salts used for:

- Additional alloying with certain elements
- Protecting the melt against oxidation and burn
- refining
- structure refining

5. PROPERTIES OF MELTED METALS AND ALLOYS

Foundry deals with the production of castings from metals and their alloys, the properties of basic and additional raw materials for their production, as well as the relevant aids and equipment.

Foundry is of key importance for mechanical engineering; in terms of production economics, it is the least expensive production methods in the case of complex casting shapes. It is the method to produce metal components, in which the melted metal is poured in a mould in whose cavity the melt solidifies and creates a raw casting.

After removing gating and boss system, a rough casting is obtained. After its machining according to drawing, clean casting is obtained. By foundry, it is possible to produce components and parts weighing between several grams to hundreds of tons.

According to subsequent processing of the casting, two basic types of castings are distinguished:

- Simple castings of circular, square or octagonal cross-section with rounded edges, intended for further processing by forming. They are called ingots or conti-castings. They are made by casting in metal moulds (chill moulds) or by continuous casting in crystallizers of square or rectangular cross-section. The solidified semi-finished product is further processed by rolling or forging. This subsequent forming changes the shape and the size of the original casting. It also significantly influences the physical and mechanical properties by removing various crystallization imperfections.

- Castings of machine parts and components – it´s about obtaining a final, often very complex shape, as similar to the future component as possible. Physical and mechanical properties of castings are influenced mainly by chemical composition and the method of casting.

5.1. Technological properties of metals and alloys

Foundry properties are technological properties derived from complex acting of physical properties of metal and mould in casting, conditions of the casting process and design of casting. This is called castability, i.e. the ability to create a quality casting.

The most important properties include:

- meltability-the ability of metal to pass from the solid state to liquid state
- fluidity- depends on the mobility of melt particles at given temperature
- fluidity- the ability of the melt to fill thin sections in the active mould cavity
- shrinking- volume and dimensional changes in the active mould cavity
- separation – separating various structural components during the melt solidification.
- gas solubility- with increasing temperature, solubility of gases in the melt increases, while it decreases when cooling.

6. METALS AND ALLOYS IN FOUNDRY AND THEIR MARKING

6.1. Materials used for casting production

The most commonly used materials for casting production include steel for castings, cast, and aluminium alloys. Physical properties of metals used for casting are shown in Table 1.

Table 1 Physical properties of metals used for casting

Metal	Melting temperature (°C)	Boiling point (°C)	Density ρ at (20 °C) ($10^3.kg.m^{-3}$)
Steel for castings	1500 - 1550	-	7.8 – 8.0
Cast	1150 - 1300	-	6.8 – 7.5
Al and its alloys	660 - 700	2519	2.70
Cu and its alloys	1083	2562	8.96
Mg and its alloys	650	1090	1.74
Zn and its alloys	419	907	7.14
Ag	961	2162	10.49
Au	1064	2856	19.3
Sn	231	2601	7.2

For casting process, the melting temperature is a decisive factor. The melting furnace type depends on the type of the metal melted. For melting individual kinds of ferrous and non-ferrous metals, the following types of furnaces can be used:

Steel

- electric induction furnaces,
- electric arc furnaces,

Cast – cupola furnaces,

- cupola furnaces with hot air,
- reverberatory furnaces,
- duplexing (cupola furnace + electric furnace),
  (cupola furnace + reverberatory furnace),

Al and its alloys – induction furnaces in which graphite-fireclay or metal tubes are located

Cu and its alloys

- bath furnaces,
- drum furnaces,
- crucible furnaces – solid, gas, and liquid fuel,
- induction crucible furnaces (most widely used) (Figure 1),
- channel furnaces,

Zn and its alloys – crucible furnaces with gas or electric resistance heating.

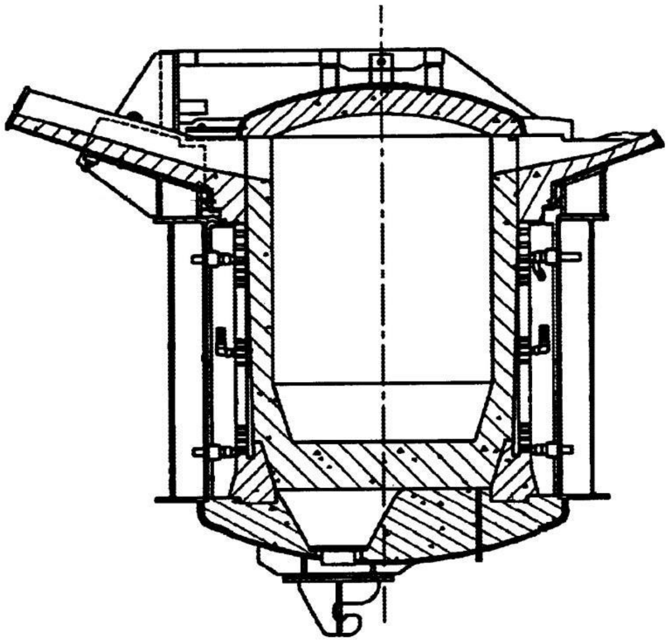


Figure 1 Induction crucible furnace

7.PRODUCTION OF CASTINGS

Technical preparation of production

The purpose of technical preparation is to ensure the necessary technological documentation for castings production.

Technological process in ensured by development office based on the drawing of clean casting.

Pattern maker determines the type of model or model equipment, splitting the model, allowances for machining and shrinking, type and splitting of core box, type of modelling sand, type and size of moulding frame, type and size of gating and feeder system, moulding technology, method of casting, cooling, and cleaning.

The design must take into account the number of castings and determine the work process accordingly.

The drawing with a pattern production process is called drawing of process / process drawing. Based on the drawing, the pattern shop makes a pattern which is sent through a pattern store to foundry plant. In the foundry plant, mould is made. After casting and cooling, the casting is removed from the mould, it is cleaned and the gating and feeder systems are removed, then it is checked and handed for dispatch. The example of making a simple casting is shown in Figure 2.

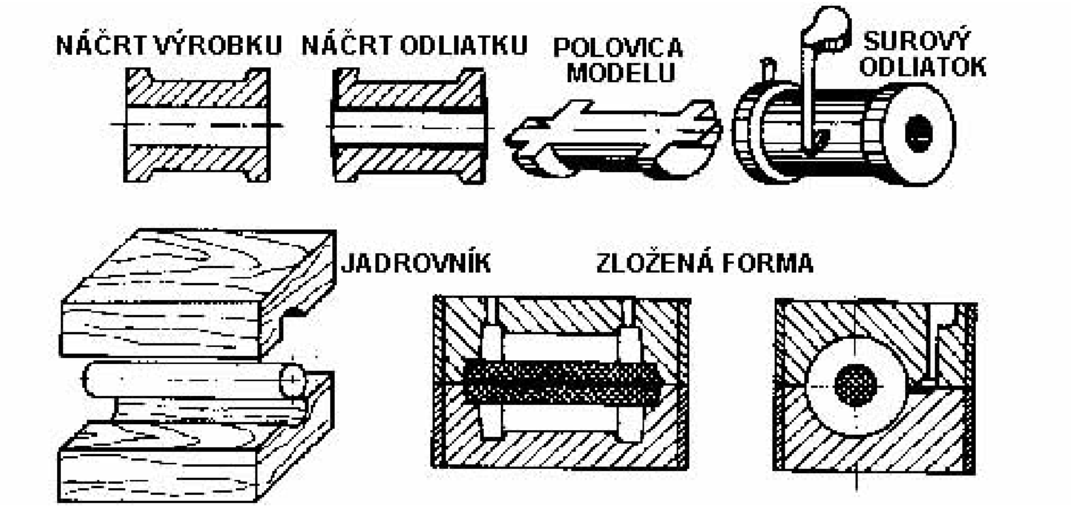


Figure 2 Production process of simple casting

Legend: náčrt výrobku – sketch of product, náčrt odliatku – sketch of casting, polovica modelu – half of pattern, surový odliatok – raw casting, jadrovník – core box, zložená forma – assembled mould

7.1. Technological process of casting production

The proposal of technological process of casting production is based on the design drawing of the machine member that is to be made by casting from a given material. Figures 3 - 6 show the proposal of components production process from the drawing to the assembled casting mould and the basic terms are explained.

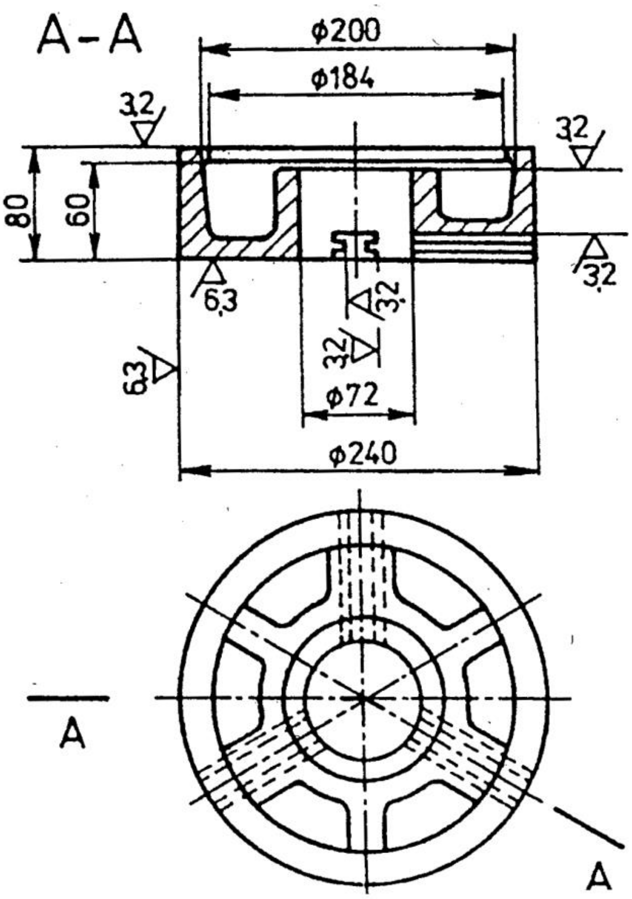
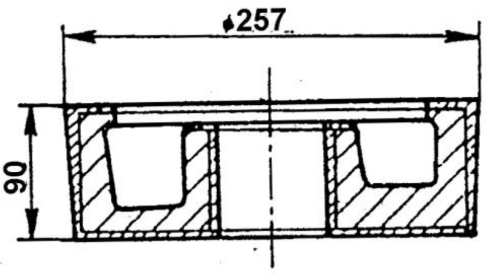


Figure 3 Sketch of finished component made of grey cast



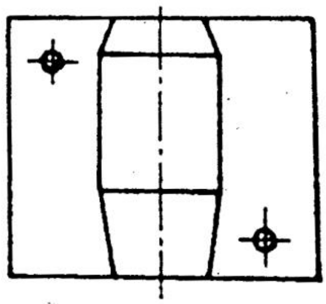


Figure 4 Sketch of raw casting half

Fig. 5 Sketch of core box

(hatched area shows allowance for machining)

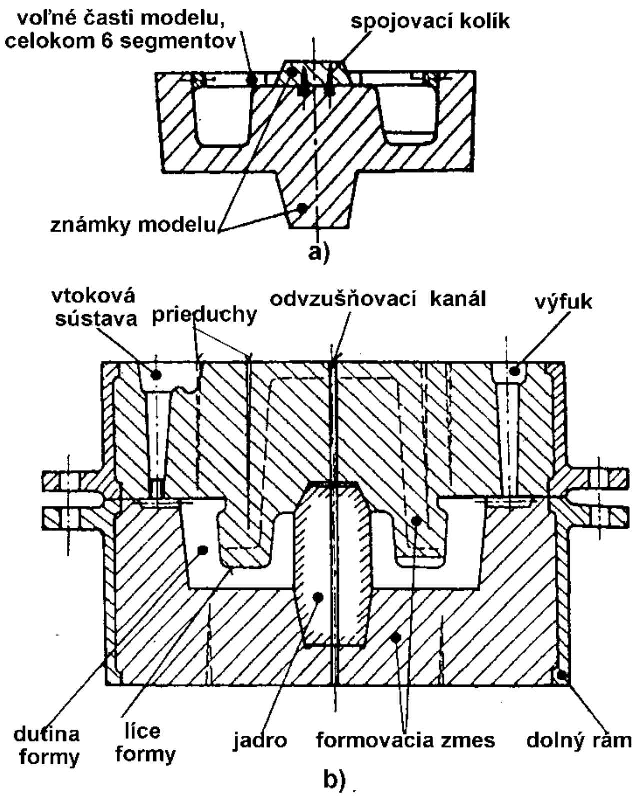


Fig. 6 a) Sketch of split pattern, b) Sketch of mould

***Le*gend: volné části modelu, celkom 6 segmentov – free parts of pattern, in total 6 segments, spojovací kolík – pin, známky modelu – pattern print, vtoková soustava – gating system, prieduch – air channel, odvzdušňovací kanál – vent channel, výfuk – whistler, dutina formy – mould cavity, líce formy – mould face, jádro – core, formovacia smes – moulding mixture, dolný rám – drag box**

Description of technological process of casting production must contain the following:

- Chosen casting position in mould.
- Chosen parting plane.
- Chosen method of mould production in terms of:
    - Moulding mixture,
    - Methods used in foundry plant (green-sand mould, dry-sand mould, etc.),
    - Size, shape, and material of casting,
    - Type of production (manual, machine forming),
    - Special shape or use of castings (shell moulds, metal moulds, etc.)
- Chosen method of core production (the same aspects as in the case of moulds).
- Determined number and shape of cores.
- Determined casting method and calculation of gating system.

- Determining casting thermal nodes, determining the places for feeders and chills, calculation of feeder size.
- Determining production aids (type and number of patterns, bottom boards, moulding boxes, etc.).
- Determining the time of cooling in the mould.
- Determining casting heat processing.
- Determining the control and handover regulations according to STN or the customer´s requirements.
- Technological data (casting temperature, casting time, loading moulds, etc.).

7.1.1. Choosing the casting position in the mould

Casting position is chosen according to:

- Directed solidification,
- Laying important areas of greater thickness in the bottom part of the mould, where there is the purest metal (in the case of grey cast castings). In the case of steel castings, the important areas of greater thickness are placed in the upper part of the mould (adding shrinking and solidifying metal from feeders),
- Reliable placement of cores,
- Placing thin walls in the bottom part at a certain angle or vertically.

7.1.2. Choosing parting plane

Parting plane is chosen according to the principle of:

- The smallest number of cores,
- Achieving minimum mould height,
- Placing the basic casting elements in one half of mould
- Placing the main cores in bottom part of mould,
- Obtaining straight parting plane.

8. PATTERN MAKING EQUIPMENT

Pattern making equipment includes:

- patterns,
- pattern making tool,
- core boxes,
- bottom boards.

Pattern making equipment is made in pattern shop. Pattern making equipment is a equipment to prepare an active mould cavity which is bounded by the mould forms and inserted core walls.

The complexity of the equipment is given by the complexity of the casting, on which also depend the number and position of parting planes, placement of cores and prints.

Wooden pattern-making equipments are color-coded on the surface depending on the casting material to be used (Table 5.2).

Table 5.2 Colour marking of the surface of pattern making equipment

Casting material	**Colour**
Grey and ductile cast iron	red
Malleable cast iron	light blue
castings steel	dark blue
copper alloys	yellow
aluminium alloys	grey
magnesium alloys	green

The shape of the pattern-making equipment is determined by the shape and the size of the casting, by the method of mould and cores production, kind of casting material, and mould.

8.1. Patterns

Patterns are tools used to create a cavity in the mould. The shape and dimensions of the pattern are based on the shape and dimensions of the components increased by allowances.

The free parts of the pattern that would not allow its ejection from the mould are made in such a way that enables them to remain in the mould and are removed afterwards.

Shrinking of cast alloys

The dimensions of the patterns and cores are increased compared to the finished casting because of the expected shrinking of the casting. The overall allowances thus consist of shrinking, machining, and technological allowances (non-precast holes, reinforcement of walls towards the feeders, bevels, etc.).

Since the metals and alloys shrink during cooling, the pattern-making equipment shall be made bigger by the shrinkage of the given material. The shrinkage during solidification is different and depends basically on the chemical composition of the given metal, casting temperature, design of the casting and type of mould. The general values of the length shrinkage of alloys are as follows:

grey cast	0.7-1.2%	bronze	1.3-2.5%
casting steel	1.3-2.1	magnesium alloys	1.1-1.4%
brass	1.7-2.2%	aluminium alloys	0.8-1.5%

At the calculation is time-consuming, patternmaking metres are used, where the scale is increased by the shrinkage value.

Machining and technological allowances

Machining allowance is a layer of material on the outer or inner surface of casting that enables to achieve precise dimension and quality of the casting by machining. It is determined by means of STN 01 4980, and depends on the component dimensions, material, the degree of precision and position of the surface.

Technological allowance is a layer of material on the outer or inner surface of the casting that enables to achieve directed solidification or facilitates the production.

Patterns and castings bevels

Bevels serve to easily remove the pattern from the mould and the core from the core box. The walls that are perpendicular to the parting line are practically bevelled to 0.5 - 20^{O}, based on the place and length to which the bevel is related. Depending on the relation of to the dimension of nominal dimension, we distinguish between bevels of the A, B or C types (Fig. 5.7).

Nominal dimension is the dimension given on the castings drawing. The deviations of the dimensions and shapes of the casting apply to it. For the areas to be machined, nominal dimension of the casting is the dimension including the machining allowance.

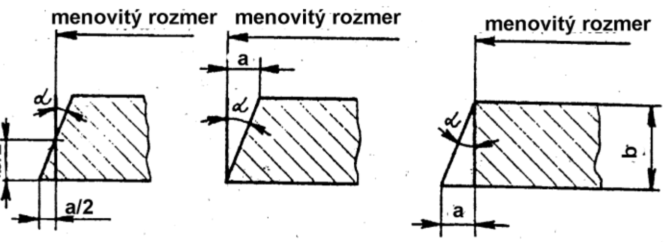


Figure 5.7 Foundry bevels – types A, B, C
Legend: menovitý rozmer – nominal size

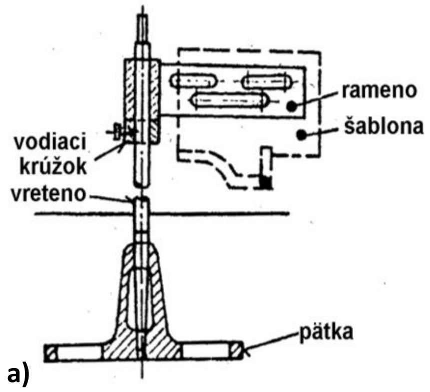
Bevel A is usually used for rough surfaces; it is the most widely used bevel type. It does not have to be a part of the drawing.

Bevel B is used if it is possible to reduce the casting dimensions (reduction of weight). It has to be a part of the drawing.

Bevel C is used on machined surfaces or if it is not possible to reduce the casting dimensions. If the casting surfaces of the C bevel are not machined, the bevel has to be a part of the drawing.

8.2. Sweeping equipment

It is equipment for making moulds and cores consisting of a gib and the sweep pattern (Fig. 5.8). We distinguish between rotational, transverse and longitudinal sweeping.



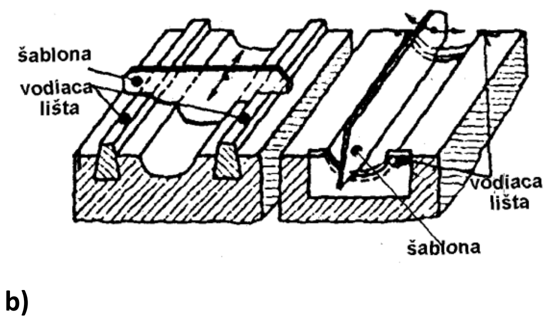


Fig 5.8 Sweeping equipment

a)- rotačná šablóna – turning sweep pattern, b)- transverse and longitudinal sweeping
Legend: rameno – arm, šablona – sweep pattern, vodiaca lišta – gib, vodiaci krúžok – guide ring, vreteno - spindle, patka – root

Core boxes

Mould cavity is created by means of a special part of the mould, called **core**, which is made in a pattern-making equipment – **core boxes** (see Figure 5.9).

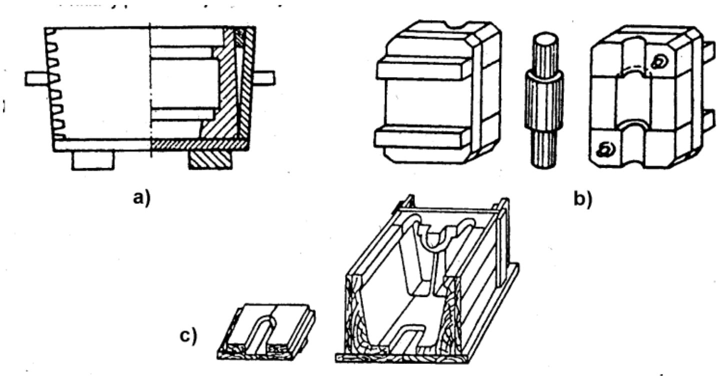


Figure 5.9 Core boxes a) case, b) – split, c) – frame core box with sleeve

To secure the position of the core and its displacement in the active cavity part, the core is placed by prints in the print beds created by the prints on the pattern (Fig. 5.9). The prints of the vertical cores have a conical shape.

8.3. Pattern boards

Pattern board is a plate on which the patterns or their parts are placed for manual forming.

In the case of machine forming (in series and mass production) pattern boards with a fixed half of the pattern, including the parts of the gating system models and pins are used. When producing a higher number of castings, especially in the case of machine forming, the production can be facilitated by placing half of the pattern on the pattern board. In the case of mass and series production, wood is not suitable.

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