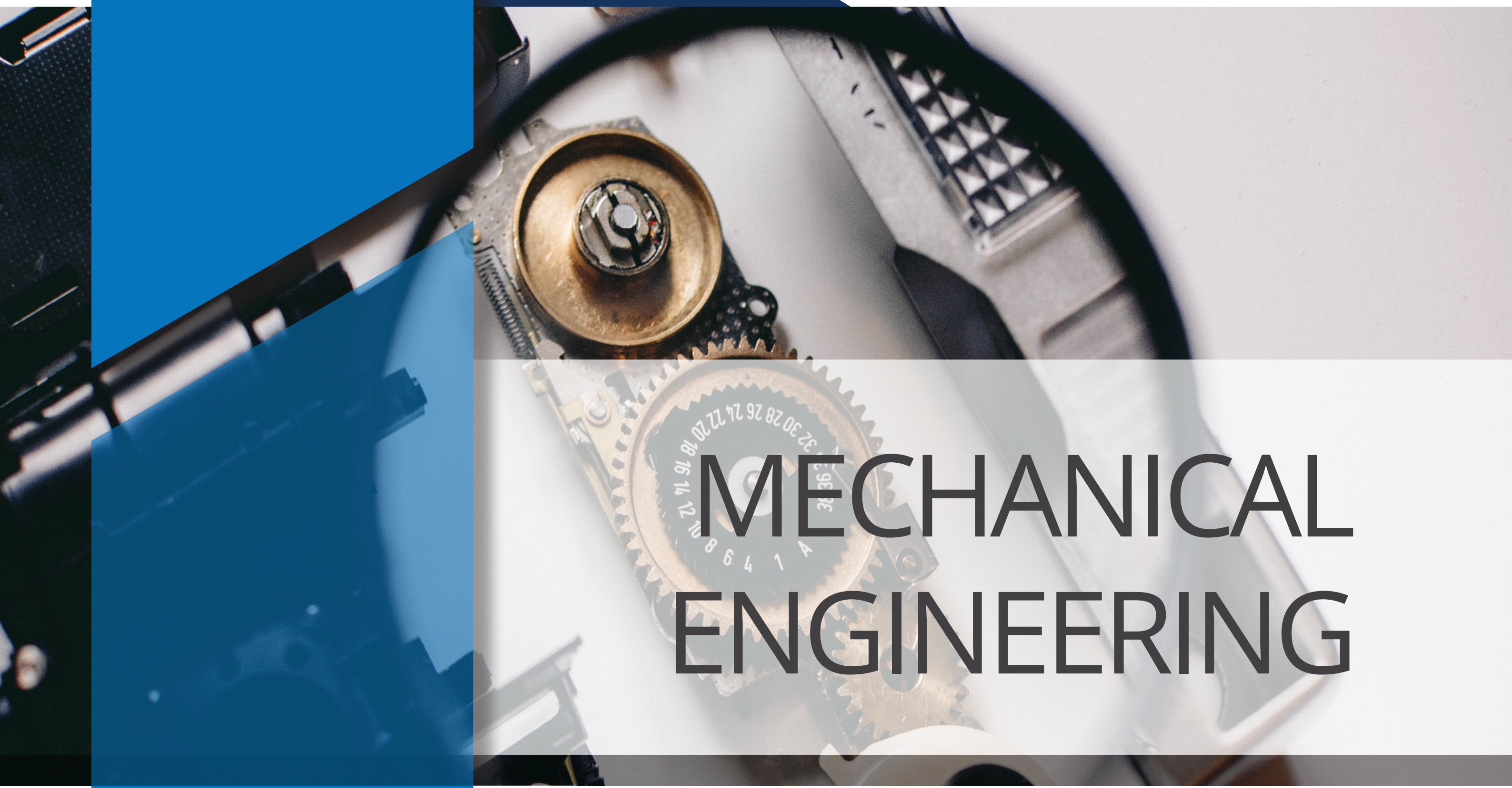
Interreg
EUROPEAN UNION
Austria-Czech Republic
European Regional Development Fund



MECHANICAL ENGINEERING

Technology of die-casting of metals

UNIVERSITY OF APPLIED SCIENCES UPPER AUSTRIA

VŠTE

EUROPEAN UNION

CONTENTS

1. DIE CASTING CHARACTERISTICS

1.1. The principle of die casting

Die-casting is a foundry industry technology in which molten metal is transported by high speed and pressure from the shot chamber into the blocker where the final casting solidifies.

The speed of the piston forcing the liquid alloy up and down operates in m/s. The liquid alloy is in this way transported from the shot chamber to the blocker by a gating system. The transition between the gating system and blocker constitutes a notching. The speed of the liquid alloy flow increases to several tens of metres per second in the notching. The high speed of the flow enables the liquid alloy to fill the shot chamber in the time that is equal to units or tens of millisecondes. This method of cavity filling enables the production of thin-walled, complex-shape castings with a high-dimensional accuracy and with a precise copies of the superficial relief of the mold cavity.

1.2. Technical and economic aspects of die casting

Advantages

- A possible production of castings in short intervals,
- A large number of castings produced from one mold
- A possible production of complex-shape and thin-walled castings
- A smooth surface of castings
- A low waste production and, therefore, lower costs of the input material
- Possible pre-die casting of openings of small diameters with low machining
- Light casting of inserts from other metals or materials
- A fine-grained structure of castings ensures good mechanical properties.

Disadvantages

- High costs of mold manufacturing,
- Enormous investment in machines and relevant devices,
- The maximum size of castings is limited by the size of the respective machine
- Die-cast alloys are less ductile.
- Castings are porous to some extent; however, their porosity may be limited,
- Die-casting technology requires previous professional experience; therefore, it requires a qualified staff

2. DIE-CASTING MACHINES

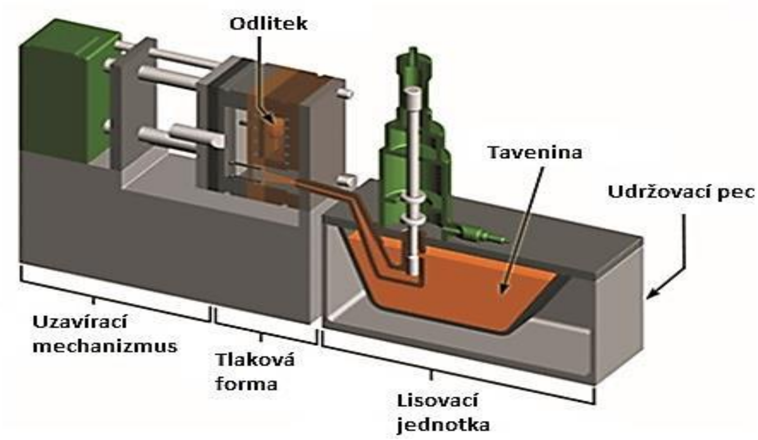
Die-casting of metals is carried out on die-casting machines that are from the technological point of view divided into:

- Hot-chamber die-casting machines:
  - Piston-based
  - Air-based

- Cold-chamber die-casting machines:
  - With vertical die equipment
  - With horizontal die equipment

2.1. Hot-chamber die casting

Low-melting-point alloys i.e. tin, lead and zinc alloys are processed in hot-chamber machines. When using this type of machines, the furnace constitutes an integral part of the machine and molten metal is directly forced out of the cup into the mold by a piston or air-based compression molding 2 – 7 MPa. In both cases the chamber gets narrow in the goose neck and ends up with a nozzle. This nozzle is pressed to the fixed die half, i.e. its opening. The piston in its upper, default position does not overlap the inlet hole of the chamber and the molten metal flows through this inlet hole from the cup to the chamber. Molten metal is pressed through the nozzle into the mold. Then follows a time period which lasts a few seconds and within which the metal in the mold cavity solidifies to a casting. After this time period the piston goes back to its default position while the chamber inlet hole re-opens. The chamber is simultaneously filled by another portion of molten metal and liquid metal from the goose neck. The movable die half, which also takes over the casting, opens within this activity. The casting is released from the grasp of the clamps and a service attendant takes it by pliers or another tool and puts it down on a palette. If the mold is open, its cavity is sprayed with a lubricant. Then closing of the mold follows and the device goes back to its default position and the whole cycle repeats.



Hot-chamber die-casting machine
Upper row from left to right: casting, molten metal, furnace
Lower row from left to right: clamping unit, die assembly, injection unit

2.2. Cold-chamber die-casting

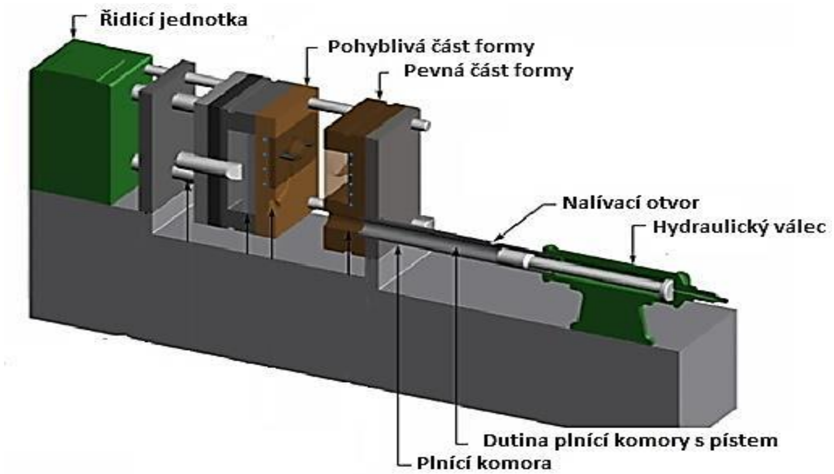
High-melting-point alloys, i.e. aluminium, magnesium, brass and iron alloys are processed in cold-chamber die-casting machines. In this case, the furnace with molten metal is not a part of the machine. Instead, it is separate and molten metal is injected into the machine chamber before the compression molding process takes place.

Vertical cold chamber die-casting machines

They consist of a vertical-positioned cylinder, nozzle, hydraulic piston and a bottom piston with a spring. The piston is in its default position, i.e. it overlaps from over the chamber to which liquid metal is poured. The hydraulic piston moves down and causes that molten metal is pressed by the bottom piston which means that the nozzle is exposed and liquid metal is run through it to the mold cavity. Then follows a time period in which metal in the mold cavity solidifies. After the metal has solidified, the hydraulic piston goes back to its default position. The force of the compressed spring that is placed under the bottom piston causes that the piston moves, clips the metal plates which arise from metal solidification in the chamber and throws the plates out of the chamber. Then the chamber opens, the casting is thrown out and, eventually, the mold cavity is sprayed with a lubricant. The mold cavitiy closes and the cycle repeats.

Die-casting machines with a horizontal cold chamber

The process is based on the following principle: the chamber in its horizontal position has a pouring hole into which molten metal is poured. A hydraulic piston moves in this chamber. The inner hole of the shot chamber should run through the fixed die half as far as the dividing plane is situated. When the metal is being poured, the hydraulic piston is in its back position in order for the pouring hole to be released. The movement of the piston forces the molten metal out into the mold cavity. After the compression molding process has been finished, the mold cavity starts to open while the piston pushes the metal plate out of the shot chamber. After the opening has been finished, the piston returns to its back position. When the mold cavity is open, the casting is removed and the cavity is sprayed with a lubricant. Then the cavity closes and the cycle repeats.



Horizontal cold-chamber die-casting machine
Upper row from left to right: clamping unit, movable die half, fixed die half, pouring hole, hydraulic cylinder
Lower row from left to right: shot chamber, shot sleeve

3.MAIN CONSTRUCTION NODES OF DIE-CASTING MACHINES

Die-casting machines must be able to perform:

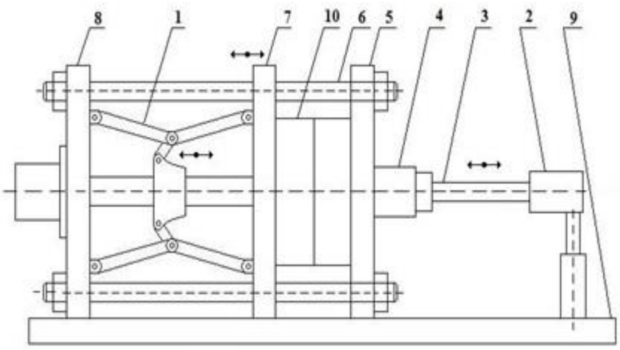
- Safe closing of the mold
- Compression molding of metal
- Solidification of castings
- Opening of the mold
- Removal of cores
- Removal of castings from the mold

In order to carry out these operations safely, die-casting machines are composed of these main parts:

- Machine fuel
- Clamping unit
- Compression molding mechanism
- Machine frame
- Hydraulic grids
- Machine bonnet
- Control system

Main construction nodes of horizontal cold-chamber die-casting machines

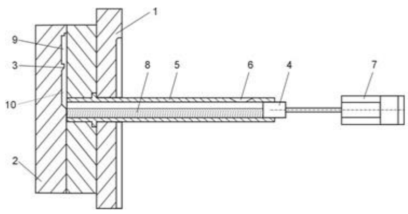
1. Clamping unit
2. Compression molding mechanism
3. Compression molding piston with cylinder
4. Shot chamber
5. Front clamp
6. Guide rod
7. Movable clamp
8. Back clamp
9. Stationary section
10. Mold



3.1. Compression molding mechanism

Its main task is to deliver molten metal into a mold cavity at a highly specified speed within the solidification period while applying high pressure

1. front clamp
2. mold
3. inlet notching
4. hydraulic piston
5. shot chamber
6. pouring hole
7. hydraulic cylinder
8. liquid metal
9. mold cavity
10. sprue



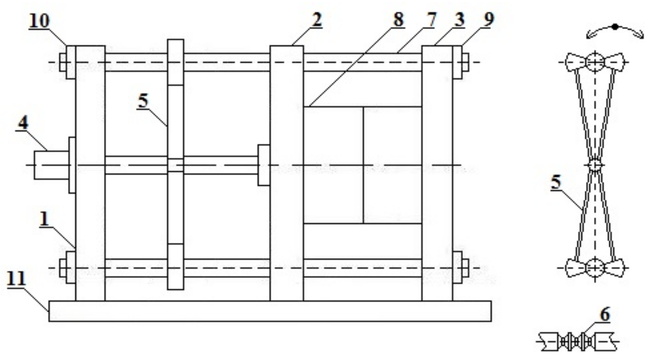
3.2. Clamping units

In regard to the construction design clamping units are divided into:

- hydraulic clamping unit
- mechanical clamping unit
- hydraulic-mechanical clamping unit
- electric clamping unit

Hydraulic-mechanical clamping units

1. back clamp
2. movable clamp
3. front clamp
4. rectilinear hydraulic motor
5. rotating clamps with modelled projections
6. notching rods
7. rod
8. mold
9. front nut
10. back nut
11. stationary section



Closing of the mold is carried out by weak-force traveling of the hydraulic cylinder. Safe closing and fastening of the mold is carried out by two rotating clamps and shape projections that fit in notchingd rods.

3.3. Die-casting machine fuel

Die-casting machines use hydraulic fuel. Older machines used water steam to generate pressure energy; nowadays, it is mineral oil, i.e. water-based liquid – glycol, that is most commonly used. The fuel is run by a pump operating in a pressure mode up to 4.5 Mpa.

In regard to construction, the pumps are divided as follows:

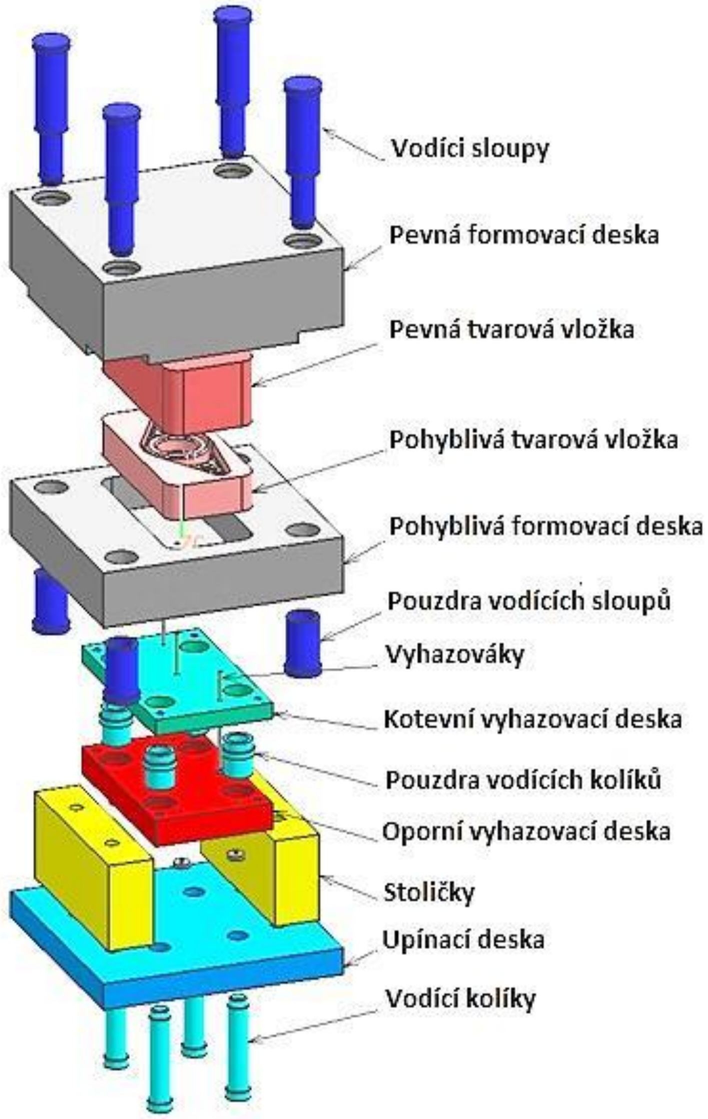
- Piston control pump
- Blade control pump
- Screw control pump

4. DIE-CASTING MOLDS

4.1. Main parts of a mold

The mold is responsible for producing the processed material in the required shape and for cooling it down to such a temperature that makes the casting solid enough to be removed from the mold without its deformation. Molds must be resistant to high pressure, be able to manufacture products with precise dimensions and enable the removal of the casting.

Picture (from up to down): guide rods, fixed die half, fixed modelling insert, movable modelling insert, movable die half, guide rod bushes, ejector pins, core ejector plate, guide bush, core back plate, spacer blocks, clamping plate, guide pins



The mold consists of these main parts:

- components modelling the mold cavity
- cooling, i.e. temperature system
- gating system
- ejection system
- vent system
- Clamping and guiding elements

Basically, main parts of the mold can be divided into construction and functional components. Construction parts are responsible for smooth functioning of the mold and functional ones ensure processing and modelling of the material.

The mold cavity

The mold cavity is vital for smooth functioning of the mold. The mold cavity is identical with the shape of the required casting; however, the mold cavity differs in proportions, which must be higher by one shrinkage value of the material. The mold cavity causes that the material there cools down. In regard to its properties, it would be applicable that the cooling effect should affect all parts of the casting at the equal speed. In order to arrange that, it is necessary to ensure the that the temperature area of the cavity is homogenous. The consequence of unequal cooling is the premature solidification of the material in colder places. As a result, these places create a thicker surface layer on the solidified material which means a significant decrease in its cross-section through which the molten material runs into other parts of the cavity. Furthermore, the mold is filled in different places with different technological conditions which results in different properties of the casting in the specific place. The unequal cooling thereby results in inner tension that may damage the final product.

Temperature system

Temperature system means a system of runners and cavities through which a cooling medium runs. This system controls the mold temperature at a designated value.

Temperature system is divided into separate segments that are designed according to the way the casting is modelled in the mold and according to the position of the dividing plane. The design of the deployment of temperature runners and their proportions must consider the overall design of the mold and its deployment must correspond to the equal solidification of the casting throughout its volume. The cross-section of runners is usually circular; however, there are also runners with a rectangular cross-section.

The mold temperature and thermal equilibrium of die-casting molds significantly influences the quality of castings and, also, extends the lifespan of the mold. The cooling system of molds must be designed in the way that prevents defects caused by unfavourable temperature. Therefore, in regard to temperature system, special runners must be made in the mold. The runner diameter depends on the thickness of the wall of the casting.

Gating system

Gating system is composed of simple or complex runners that connect mold cavities with shot chambers. The gating system controls appropriate filling of the mold cavity, clear separation or removal of the remaining material. The gating system is designed in accordance with mold cavities and their deployment. The sprue extends the flow course of molten metal into the mold which results in reducing the temperature and decreasing the compressive strength. For that reason, when constructing molds, it is necessary to make runners as short as possible and their cross-sections to be as large as possible.

The gating system should be designed in order to meet following requirements:

appropriate filling of the mold cavity
To direct the metal flow in the mold cavity so that its walls do not prematurely wear off.
To limit the local temperature increase, which would result in excessive wearing off and deterioration of the surface cleanness of the casting
To prevent whirlpools in the metal flow as much as possible; whirlpools result in gas production in the casting
The required shape and surface quality of the casting.

Ejection system

Since castings tend to shrink during the cooling process, they remain glued to the modelling parts of the mold cavity; therefore, it is necessary to provide an ejection system to eject the casting. Such a system is usually mechanical, but pneumatic and hydraulic systems can also be used. By and large, different ejection systems are often used in combinations.

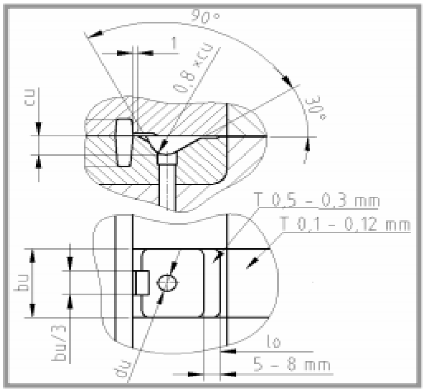
Ejection forces are derived from calculations of specific pressure between the mold and casting; furthermore, they can be calculated from thermal dependence on the friction coefficient between both mold halves and from the proportions of the casting.

Clamping and guiding elements

These refer to a construction part of machines that provide and and ensure that mold parts fit together and that they are movable.

Vent system

To vent a modelling cavity is of a major importance. Since the compression molding period is relatively short and the compression molding process runs at a high speed and pressure, it would be impossible for the air in the mold cavity to leak through mold leakages in the dividing plane. That would result in an incomplete filling of the mold cavity and in a critical pressure increase in the cavity. It is thereby necessary to ensure that the air is effectivelly drained from the mold cavity by implementing a system of vent channels. However, these channels must not cause burrs occurring on the casting.



5. METHODOLOGY OF DEVELOPING GATING SYSTEMS

Design of gating systems of a mold cavity consists of following steps:

Analysis of the liquid metal flow

- Choice of the most suitable place for situating the inlet notching and vent system
- Calculation of the maximum time for mold cavity filling and the metal flow speed in the inlet notching
- Division of the casting into gating part segments
- Determination of the volume of overflows
- Calculation of the total area of the inlet notching and the choice of notching height
- PQ^2 analysis and the closing force of the machine
- Mold cavity filling time and the area of the notching calculated regarding separate segments
- Choice of the notching type, type of the sprue and their shape

Analysis of the liquid metal flow

The ideal shape of a casting allows that liquid metal may flow in the mold cavity through clearly defined and direct paths. However, only rarely is possible to design such an ideal shape to meet these requirements, sprues and notchings in particular. As a matter of fact, real conditions require compromise. Designers should consider not only technological, but also foundry-industry aspect. The process of gating system design requires consulting and discussions with workers who are experienced in the issue of die-casting, and who consider also the practical aspect of the process of designing. As a result, designers need to find an acceptable compromise between the required shape, ideal shape and experts' observations and thereby find the most convenient way of liquid metal flowing. It is mainly this way (method) that determines the position of the inlet notching.

Choice of the most suitable place for the inlet and vent notching

All so-far-known alloys used in foundry industry tend to shrink during the solidification and cooling process. If this issue is not properly tackled, i.e. not considered while designing the mold, final castings will manifest various defects caused by shrinking during the solidification process. These defects will be demonstrated as cavities in the casting (higher porosity) and as hollows of different proportions.

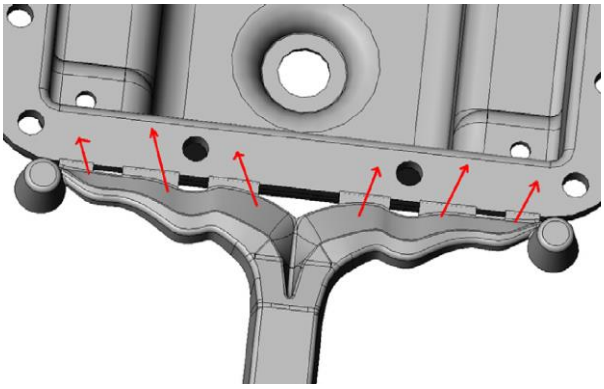
While carrying out sand-casting, gravity die-casting, low-pressure die-casting and investment casting, mold shrinking is set off with a volume of the mold increased by a value that corresponds to the shrink. The result is that the final casting demonstrates required proportional properties even after the shrink. This increase in volume is demonstrated by so called feeder-heads. Feeder-heads are cone-shaped projections located over the section that is the hardest to access and in which the casting completes its solidification.

Die-casting is an exception amongst foundry-industry technologies since feeder-heads are not present in the blocker. In fact, the shrink is eliminated by injection; for that reason, it is necessary to design the gating system in the way that molten metal should be able to transmit the pressure at minimal losses as long as possible. Designers must take into account the pressure gradient and processes taking place in the mold cavity from the inlet notching and to exhaustions.
What is convenient and implemented in practice is to design a gating system so that the notching is situated in the dividing plane of the mold while the vent system is situated opposite. An effective solution is to place the sprue and exhaustions so that the liquid metal in the blocker should flow through as-short-as-possible paths.

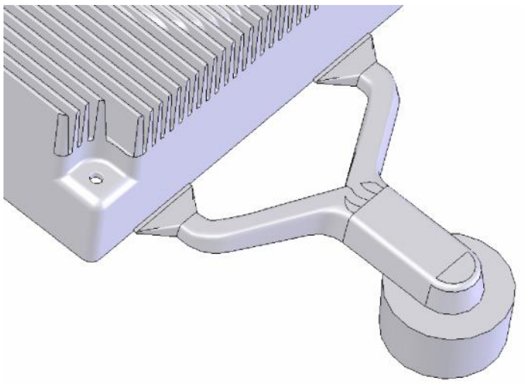
Tangential gating system enables a direct liquid metal flowing, while the fan-shaped inlet mouth allows only small or no possibilities of control.

Both types of gating systems may be used with a multiple or divided sprue. If the casting is divided into several sections with different wall thickness, each section may be provided with a notching.

If possible, when designing a gating system, it is convenient to avoid the situation in which two different flows of injected metal meet before inlet notchings. This situation is highly unfavourable, but it cannot be always avoided. In such a situation, the inlet notching should be placed from the inner part of the casting. The weak points when constructing a central gating system are particularly the absence of multiple cavities and too long a construction of gating systems causes that the speed of liquid metal flow decreases before it has flowed into the mold cavity.



Tangential gating system



Fan-shaped gating system

6. TECHNOLOGICAL FACTORS OF DIE-CASTING

The quality of die-cast castings is influenced by a large number of factors. From the construction point of view, it is particularly a good design of the die mold, its gating system, vent system, temperature system and choice of a suitable pressing machine that influences the quality of castings. Moreover, a specific type of die-cast alloy, its metallurgical processing, maintenance, condition and lubrication of mold cavities and, last but not least, machine service also play an important role. A separate group of factors are technological parameters of die-casting. These may be divided into three groups as follows:

- Parameters of the compression molding system
- Temperature parameters of the die-casting process
- Parameters arising from the properties of the liquid alloy

Parameters of the compression molding system

The main task of the compression molding mechanism is transporting and molding the liquid alloy into the mold cavity in accordance with technological parameters in order to enable a smooth and complete filling of the mold cavity. These parameters are as follows:

- Compression molding speed in the shot chamber
- Specific pressure on the liquid alloy and injection
- Time period of mold cavity filling

Temperature parameters of the die-casting process

Temperature parameters significantly influence the liquid alloy from when running through the compression molding machine and the batching period until the casting solidifies and is removed from the mold cavity. These parameters are as follows:

- Temperature of molten alloy
- Temperature in the shot chamber
- Temperature of the mold

Denis McQuail

In 1999, he distinguished four phases of the research of media effects:

- Unlitmited power of media (1900 – 1940): a profound influence of media; their contents evoke identical effects in recipients
- Ineffectiveness of media (1940 – 1965): differences between separate personality traits; individualized reception of media contents is to be dealt with

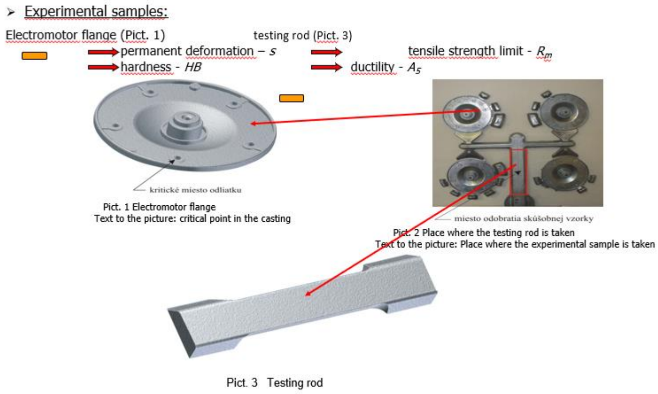
- A new deeply held belief that media have strong effects (1965 – 1980): recipients adopt an active attitude towards media
- Transactional ideas about media effects (since 1980): media have achieved a strong position; on the other hand, the same applies to the position of the audience

Parameters arising from properties of liquid alloy

Properties of liquid alloy and the method of its preparation considerably influence the quality of the casting. Basic technological parameters arising from properties of liquid alloy are as follows:

- tendency to gasification
- Tendency to contractions

7. TECHNOLOGICAL FACTORS INFLUENCING MECHANICAL PROPERTIES OF CASTINGS



Characteristics of the considered factors:

The influence of two factors was considered based on mechanical properties:

1. factor – speed of the hydraulic piston: $v_1 = 1.9\ m.s^{-1}$ $v_4 = 2.9\ m.s^{-1}$
$v_2 = 2.3\ m.s^{-1}$ $v_5 = 3.2\ m.s^{-1}$
$v_3 = 2.6\ m.s^{-1}$

2. factor – injection: $p_1 = 13$ MPa
$p_2 = 22$ MPa
$p_3 = 25$ MPa

Constant factors:	liquid alloy temperature	- 708 °C
	temperature of the mold	- 199 °C
	time period of mold cavity filling	- 0.019 s

Analysis of the speed of liquid alloy in the sprue and inlet notching:

Tab. 2 The speed of liquid alloy in the sprue and inlet notching is determined by the continuity equation

Speed of the hydraulic piston [$m.s^{-1}$]	Speed of liquid alloy in the sprue [$m.s^{-1}$]	Speed of liquid alloy in the inlet notching [$m.s^{-1}$]
1.9	14.78	36.58
2.3	17.89	44.28
2.6	20.23	50.05
2.9	22.56	55.83
3.2	24.9	61.60

ANALYSIS OF MECHANICAL PROPERTIES

Evaluation of the tensile strength limit:

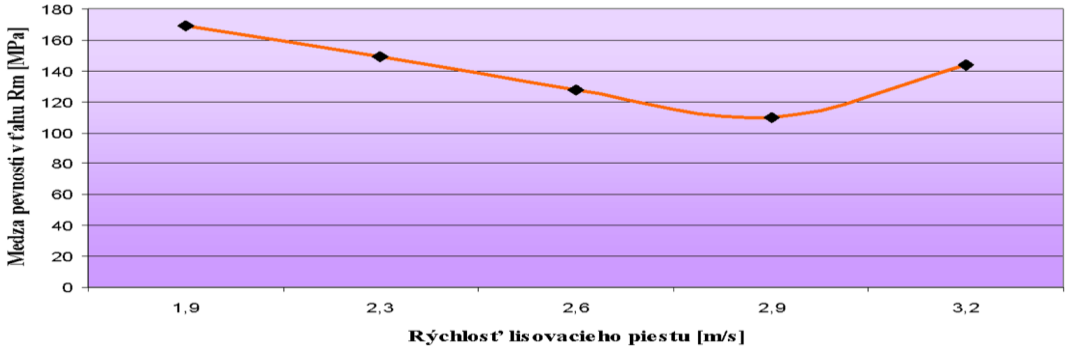


Fig. 4 Dependence of the tensile strength limit R_m
on the change in the compression molding speed of the piston
Vertical text: tensile strength limit Rm MPa
Horizontal text: speed of the hydraulic piston (m/s)

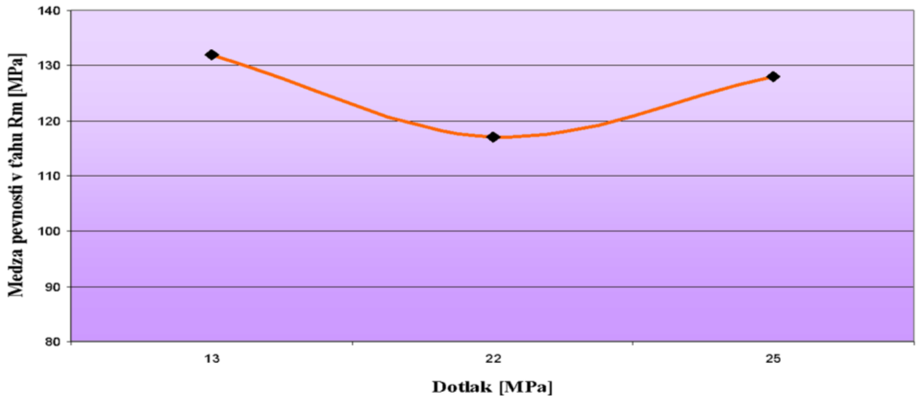


Fig. 5 Dependence of the tensile strength limit R_m
on the change in injection
Vertical text: tensile strength limit Rm Mpa
Horizontal text: injection

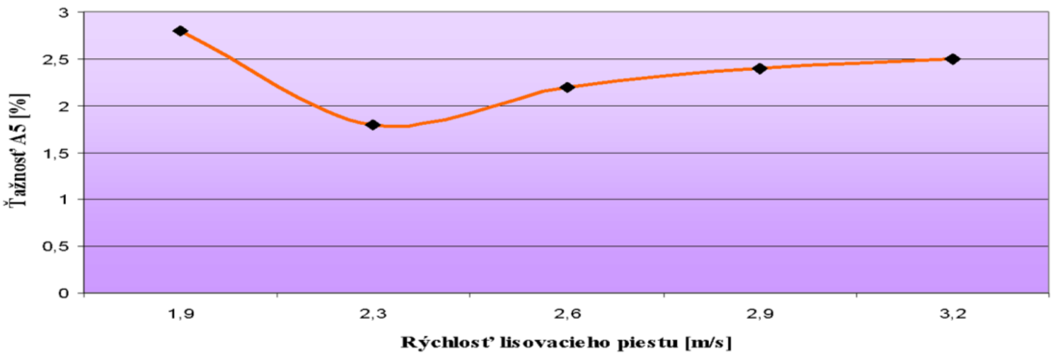


Fig. 6 Dependence of the ductility A_5 on the change in the speed of the hydraulic piston
Vertical text: ductility A5 (%)
Horizontal text: speed of the hydraulic piston (m/s)

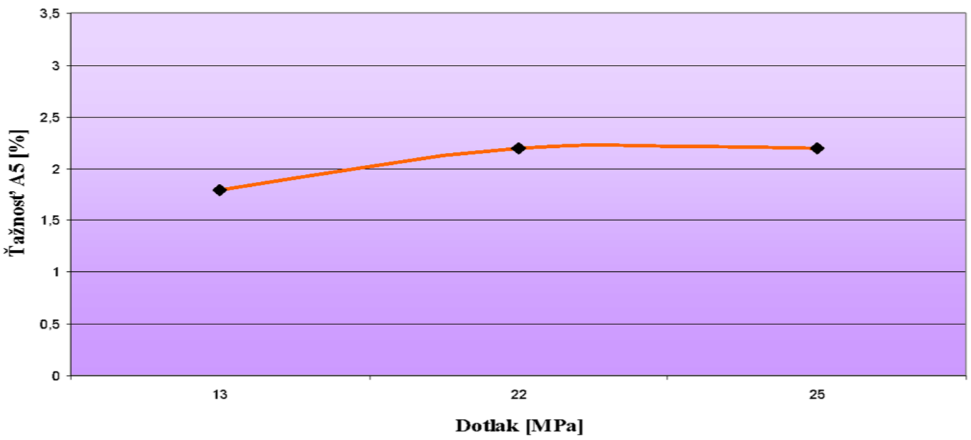


Fig. 7 Dependence of the ductility A_5 on the change in injection
Vertical text: ductility A5 (%)
Horizontal text: injection (Mpa)

Evaluation of hardness:

Carried out according to Brinell on measuring equipment HPO 250 (Pict. 8)

measuring conditions:

- marble diameter D = 2.5 mm
- load force F = 613 N
- load time t = 10 s

Fig. 8 Measuring equipment HPO 250

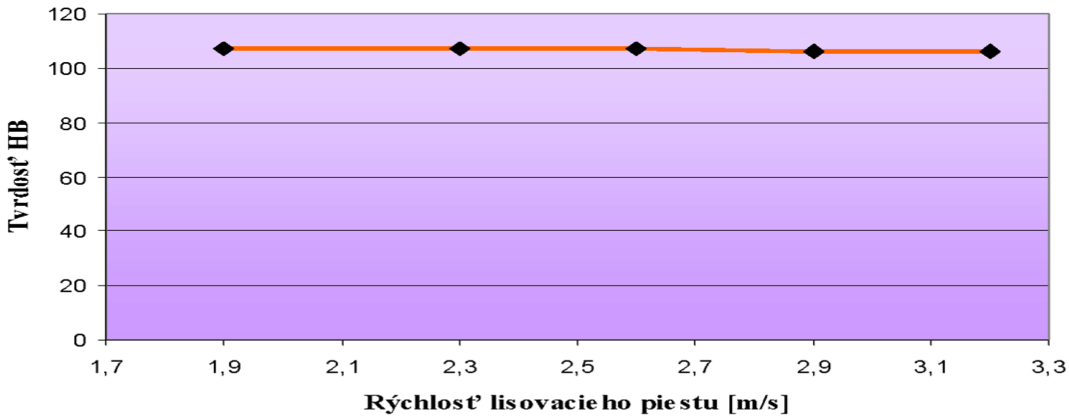


Fig.9 Dependence of the hardness HB on the change in the hydraulic piston speed
Vertical text: hardness HB
Horizontal text: hydraulic piston speed (m/s)

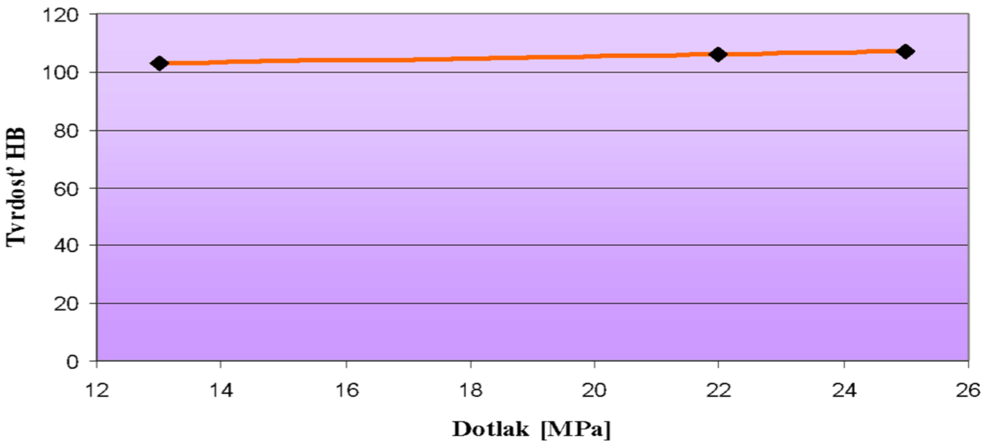


Fig. 10 Dependence of the hardness HB on the change in injection
Vertical text: hardness HB
Horizontal text: injection (MPa)

Evaluation of permanent deformation

Static test in pressure was measured on equipment TIRAtest 28200 (Pict.11).

Fig. 11 Measuring equipment TIRAtest 28200

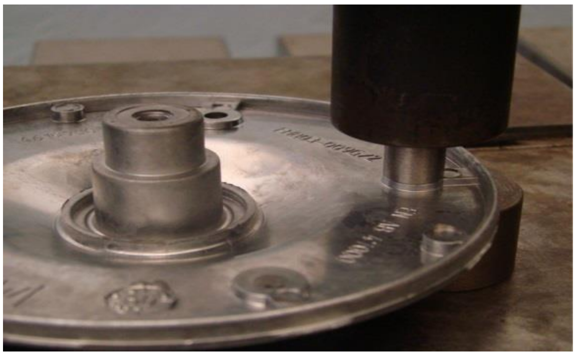


Fig. 12 Loading of the testing place in the casting

Measuring conditions:

- load force $F_a = 16$ kN
- force after relief $F_m = 8$ kN
- load speed $v = 10$ mm.min^{-1}

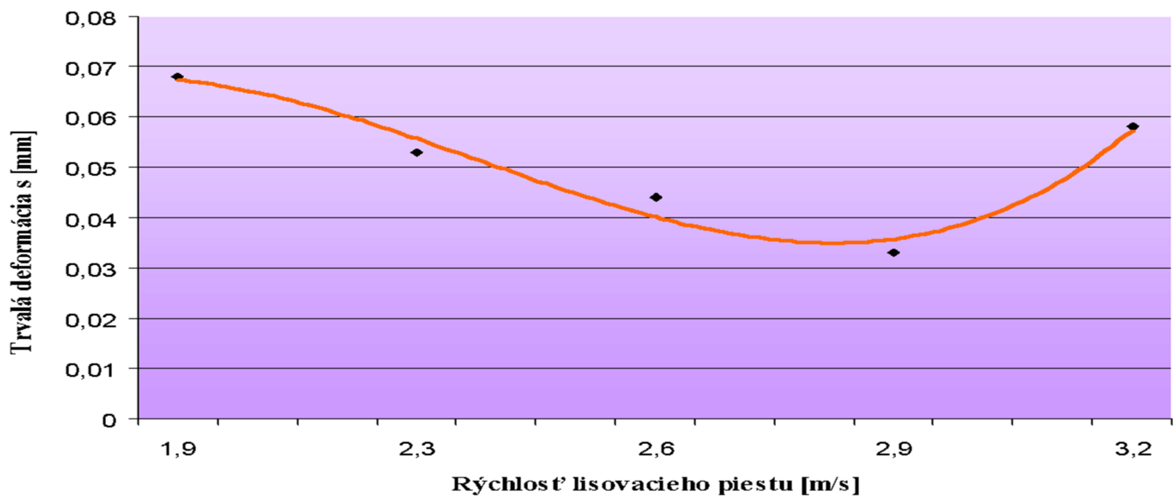


Fig. 13 Dependence of the permanent deformation s on the change in the hydraulic piston speed

Vertical text: permanent deformation

Horizontal text: hydraulic piston speed (m/s)

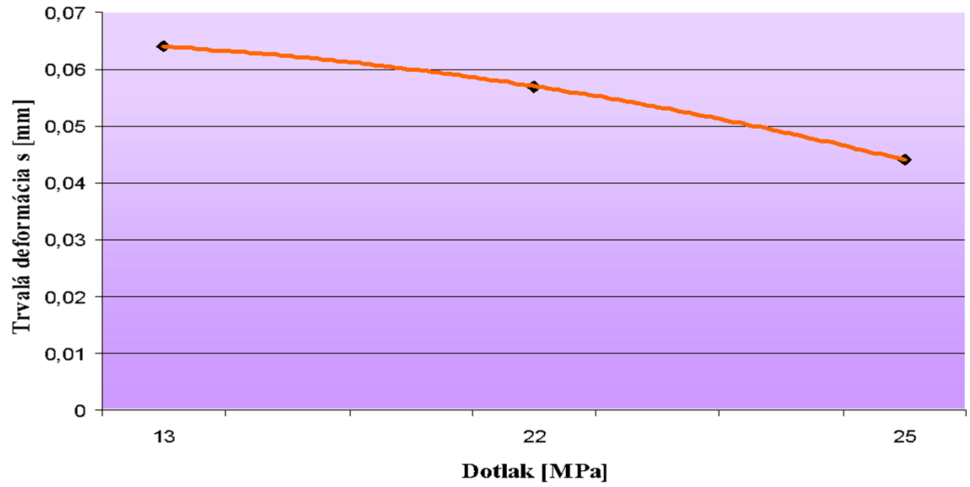
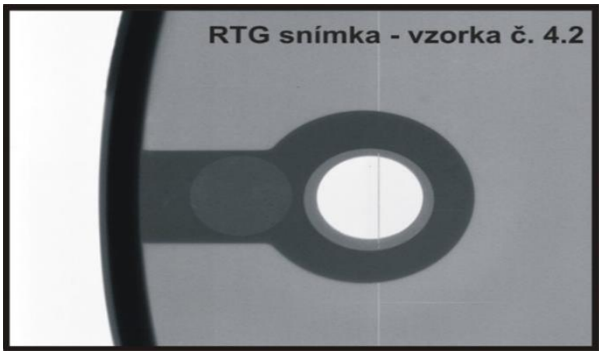


Fig. 14 Dependence of the permanent deformation s on the change in injection
Vertical text: permanent deformation
Horizontal text: injection (MPa)

ANALYSIS OF THE INNER HOMOGENEITY

Inner homogeneity in castings occurred in selected castings on places where permanent deformation had been measured in order to compare received results of the permanent deformation with X-ray images – equipment RTG VX1000D.



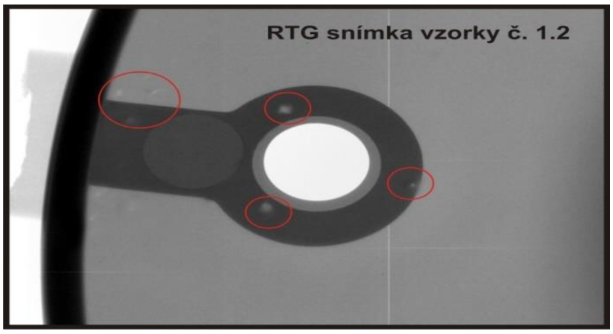


Fig. 15 X-ray image sample No. 4.2, v = 2.9 $m.s^{-1}$ *Fig. 16 X-ray image sample No. 1.2, v = 1.9 $m.s^{-1}$*

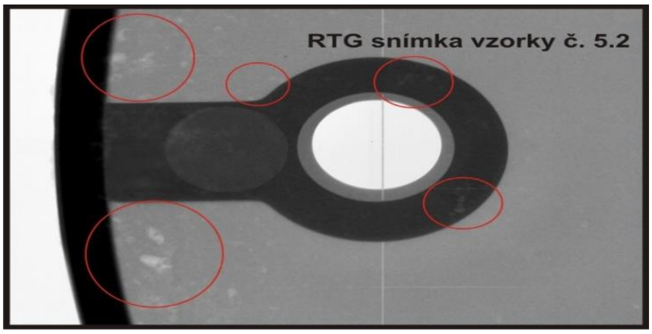
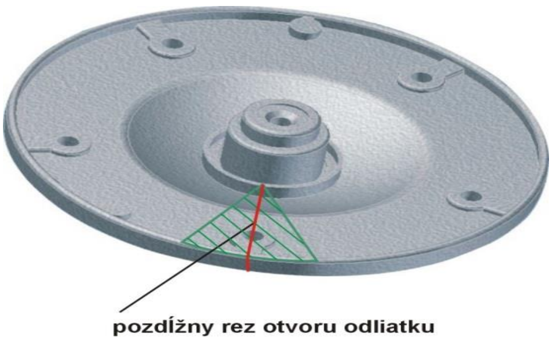


Fig. 17 X-ray image sample No. 5.2, v = 3.2 m.s⁻¹

MACRO AND MICROSKOPIC ANALYSIS

Microscopic and metallographic analysis was applied for the purpose of the examination of the inhomogeneity of mechanical qualities.



The oblong cut in the close proximity of fracture The oblong cut of the hole of cast-
ing
The space of fracture *Fig. 19 The scheme of sampling for*
the
Fig. 18 The scheme of sampling for the evaluation evaluation of the porosity of casting
of the porosity of testing bar

The analysis of the porosity of the metellographic cuts obtained from the samples was carried out in the OLYMPUS GX51 microscope at the rate of zoom of 100 and it was processed by the ImageJ computer program (Fig. 20).

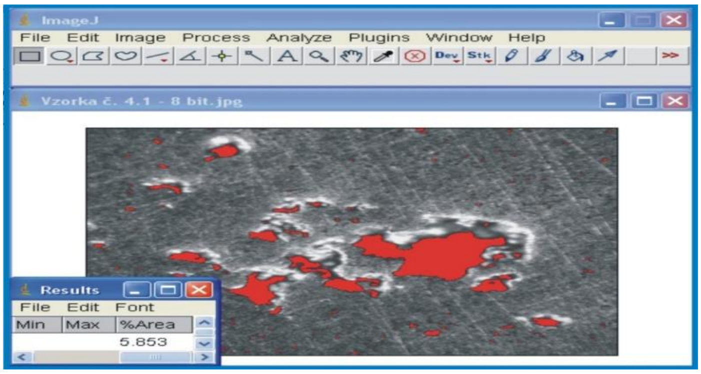
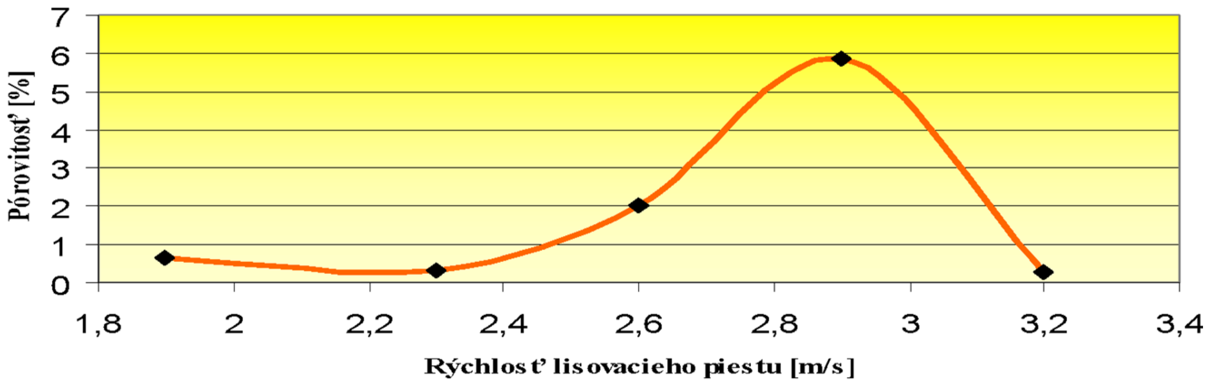
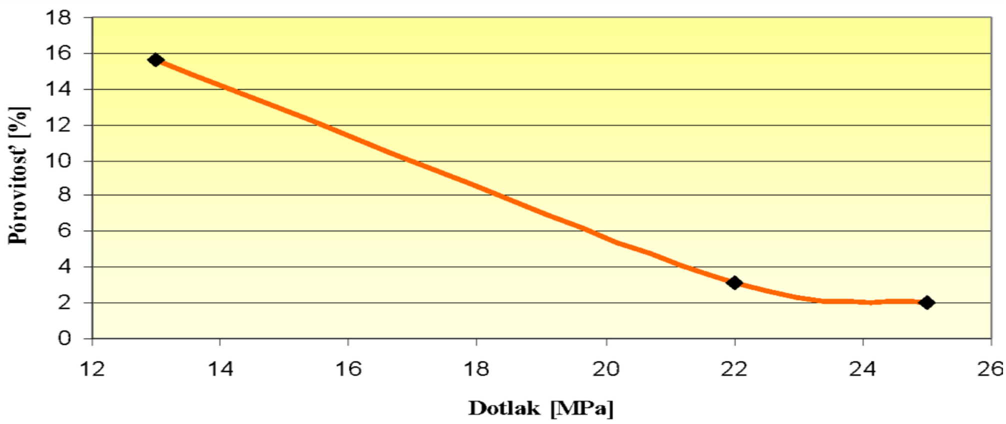


Fig. 20 Computer program ImageJ

The evaluation of the porosity of samples obtained from the testing bars



Porosity [%]
The velocity of pressing piston
Fig. 21 The dependence of porosity on the velocity of pressing piston



Porosity [%]
Holding pressure[Mpa]
Fig. 22 The dependence of the porosity on the change of holding pressure

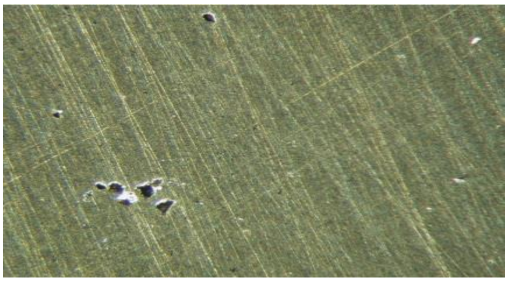


Fig. 23 Porosity 0.33 %
v = 2,3 m.s^{-1}

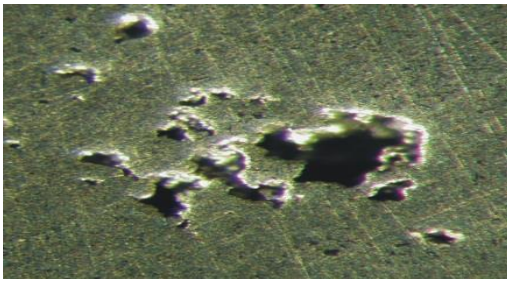


Fig. 24 Porosity 5.85 %
v = 2,9 m.s^{-1}

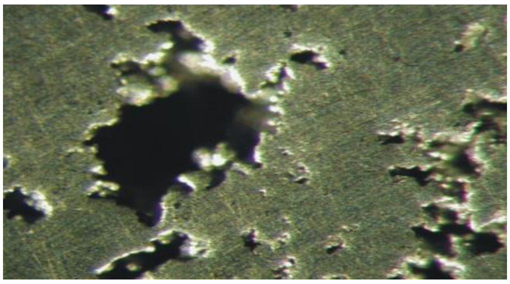


Fig. 25 Porosity 15.59 %
p = 13 MPa

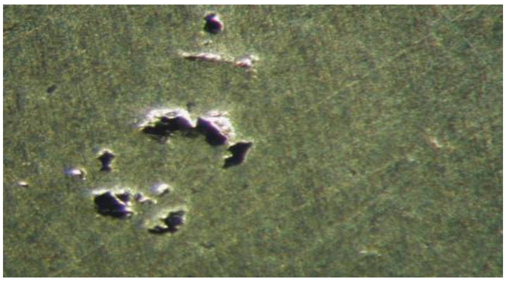
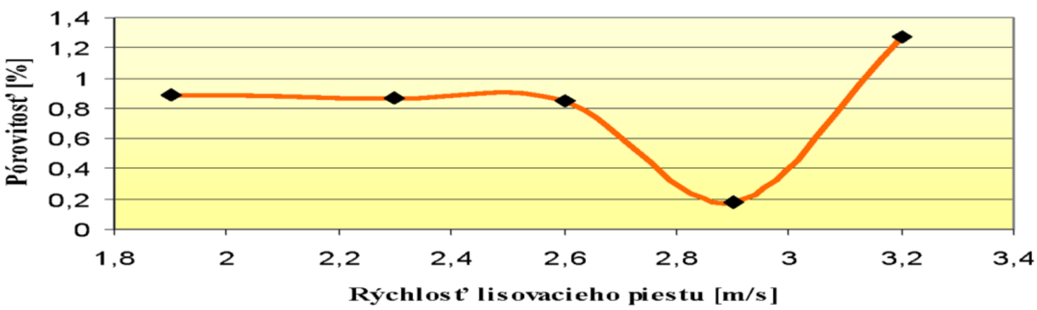
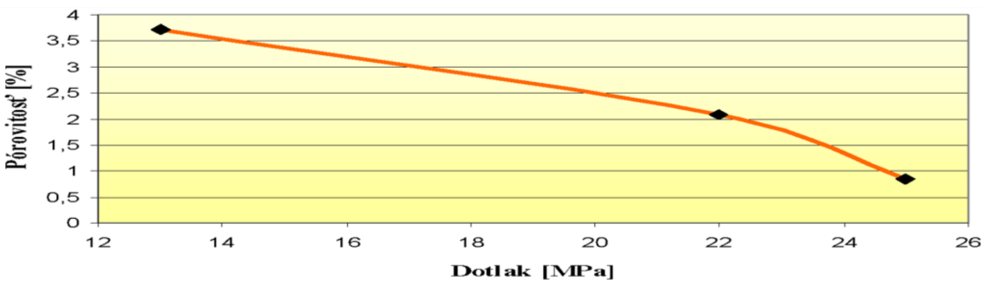


Fig. 26 Porosity 2.03 %
p = 25 MPa

The evaluation of the porosity of samples obtained from the castings:



Porosity [%]
The velocity of pressing piston [m/s]
Fig. 27 The dependence on the change of the velocity of pressing piston



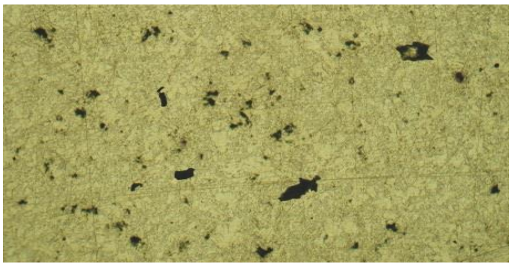
Porosity [%]

Holding pressure[Mpa]

Fig. 28 The dependence of the porosity on the change of lockout

Fig. 29 Porosity 0.18 % *Fig. 30 Porosity 1.27 %*

v = 2,9 m.s^{-1} *v = 3.2 m.s^{-1}*



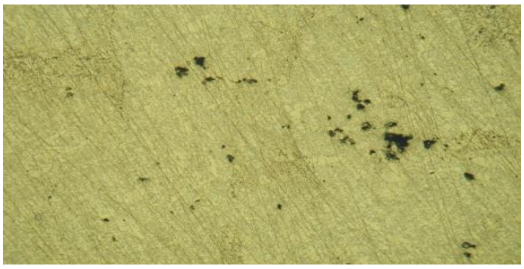


Fig. 31 Porosity 3.73 % *Fig. 32 Porosity 0.85 %*

p = 13 MPa *p = 25 MPa*

The Analysis of Structures:

The structure is formed by: α – solid solution
eutectic from the residua of α – solid solution and silicon

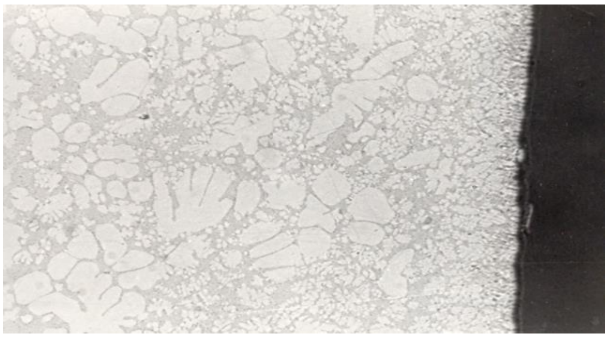


Fig. 33 The microstructure of the marginal part of sample /250x/

Fig. 34 Basic structure /2000x/

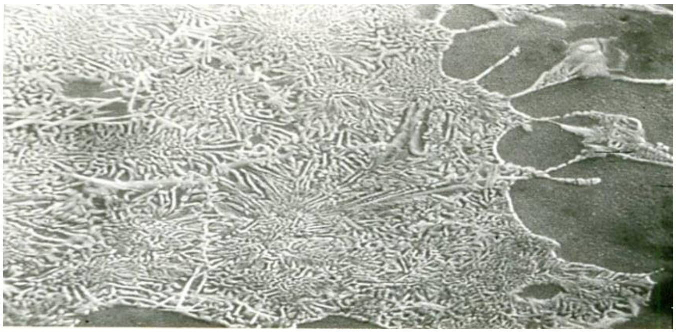


Fig. 35 The coalescence of eutectic cells

The analysis of the character of disruptions and casting failures

The fracture of the hypereutectic silumins is fragile, even and organized vertically to tensile strength

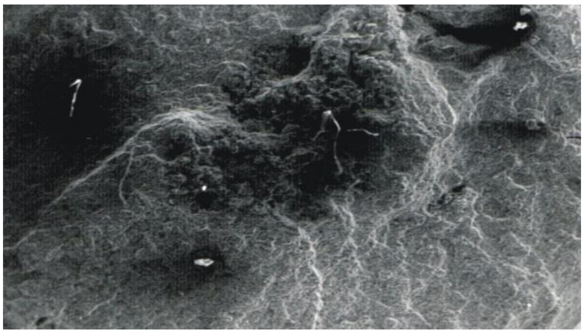


Fig. 36 The microscopic view of the fracture /10x/

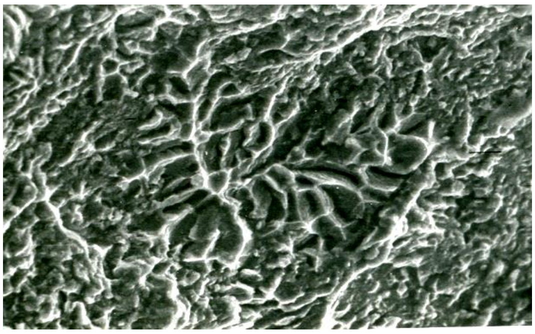


Fig. 37 The characteristic of the disruption of the α dendrites of solid solution and eutectic /250x/

There were casting failures on the following fracture surfaces:

- the cavities with the surface formed by the dendrites, in the middle of which there is a membrane of Al_2O_3 oxide
- Al_2O_3 particles

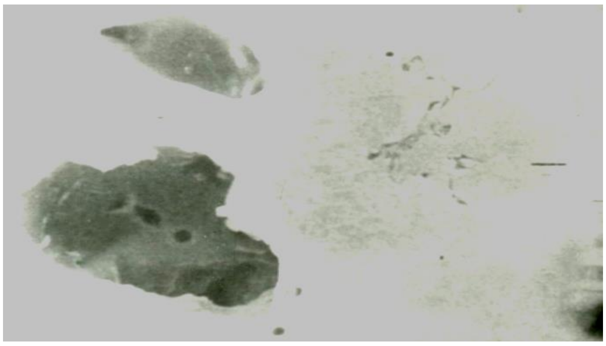


Fig. 38 Exogen bubble /250x/

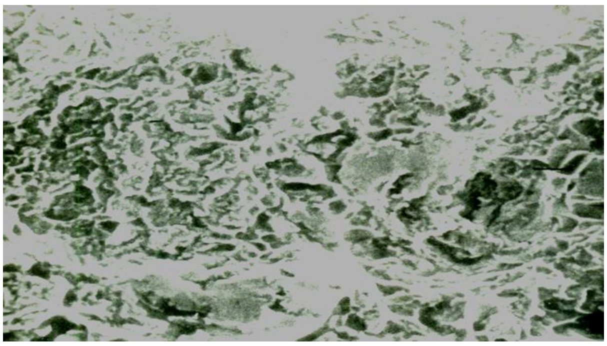


Fig. 39 Al_2O_3 particles on the fracture surface /250x/

8.CASTING FAILURES

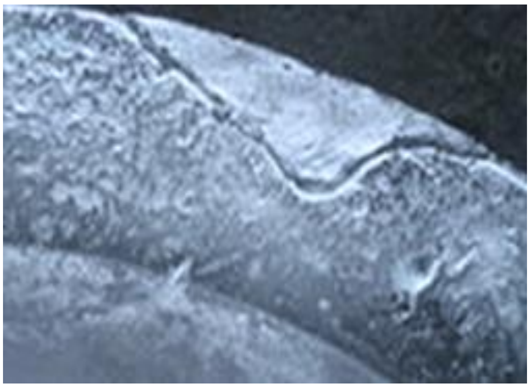
The occurrence of casting failures is affected by a number of factors, which are interconnected, and the change of one of them disrupts the setup of the others. The failure is defined as such a state of casting which prevents the formation of its utility properties. Considering the quality of product, it is defined as every deviation from the properties prescribed by technological norms or arranged conditions. The list of the links between failures and the conditions of their emergence according to their dependence on the factors of casting is described in the Savenov's diagram.

Insufficient casting

It is a state when certain spots are not filled by casting. It most frequently occurs in such places which are located the furthest from the flow notch, have the insufficient elimination of air or are stained by the remnants of lubricants, which have been brought in by flow of metal. Moreover, the overall formation of the casting and the location of the flow notch bear influence on the formation of insufficient casting. It is appropriate to construct the location of the flow notch as a prediction in such a way that the flow of melt does not hit the side, especially near the flow notch. If the design of the form is appropriate, it is possible to correct the mistake by the optimal setting of technological parameters.

Cold Joint

It occurs on the casting surface as a small pit with rounded edges. It is formed when two flows of prematurely solidified melt come together. The cause of this defect is a low pressure of the machine, low temperature of casting or uneven solidification of melt in the mold.

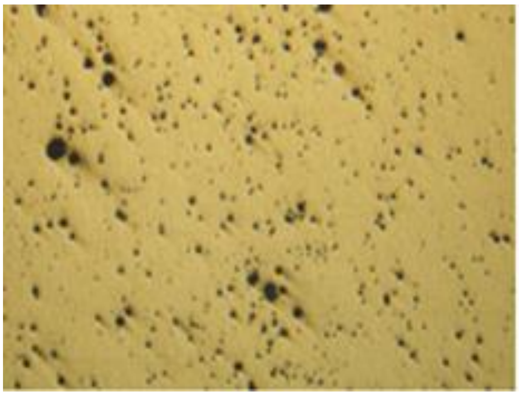


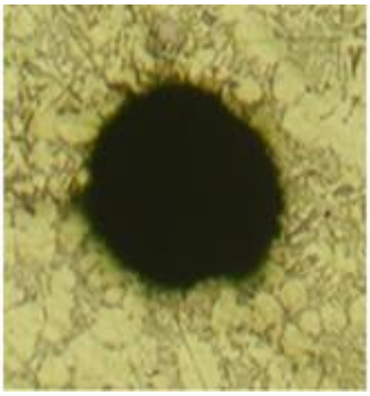
Porosity

It is caused by the shrinking of melt in the clusters and thermal joints of casting. The formation of pores is frequently caused by the differences of the width of sides and by the unguaranteed settling of melt after it is pressed down into the spots where solidification takes place last. The pores take forms of cavities with rough surface. Porosity often occurs in clusters and causes the looseness of casting. The elimination of the formation of porosity is possible by the reduction of the quantity of thermal joints, the suitable design of flow system with a large notch and the appropriate design of thermal system in such a way that the equal solidification of melt in the mold hollow is guaranteed. If such a conventional procedure is not able to solve the porosity problem, it is possible to opt for an extraordinary method of squeeze casting. The use of this method requires the appropriate equipment, i.e. the machine operating on this basis.

Bubbles

These defects are characterized by small cavities with smooth surface. They are formed by the air from the filling chamber, the mold hollow or the gas release of alloy, if the gas contained in the mold hollow is not sufficiently released by the air release system and remains locked in the casting volume. The reduction, or rather removal, of bubbles is enhanced by a fluent filling of mold hollow, which is meant to be completed in the places where an efficient air release is possible. The flow system must be designed in such a way that the air is not enclosed by melt and consequently pushed ahead of it. Therefore, it is appropriate to design the casting in such a way that the air is released from the spots where the melt is last solidified. It is also important to design the appropriate mouth of notch and the suitable location and volume of overflows.



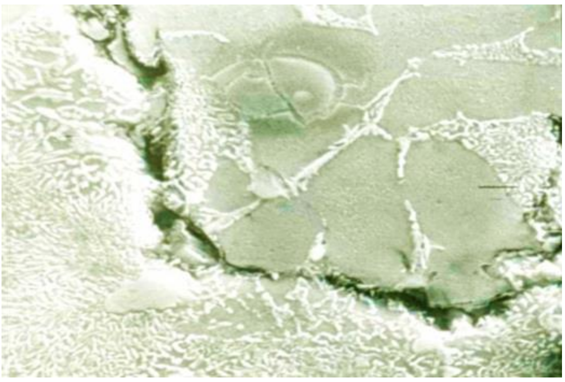


Blisters

The defect occurs when some air is enclosed slightly under the surface of casting. It is a result of high pressure in the bubble and low solidity of the side of hot casting. The cause is an insufficient air release of mold, a shape of the mouth of notch and a location of tempering channels in the body of mold. The occurrence of blisters is also enhanced by the excessive temperate of mold, the high temperature of melt on casting or the wrong start of holding pressure.

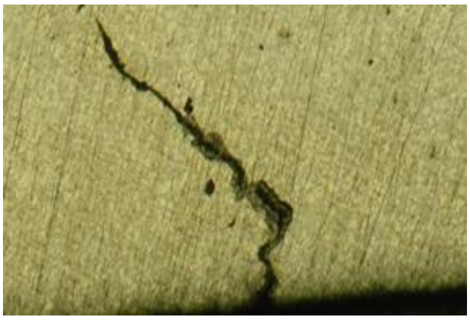
Trundles

The defect is caused by the joining of prematurely solidified flows of melt. Its cause is an insufficient pressure of casting machine, an insufficient temperature of melt or an uneven solidification of casting in the mold. A prediction is possible by the following of the technological procedure of casting, the correct setting of parameters, the right temperature of melt and the temperature of mold.



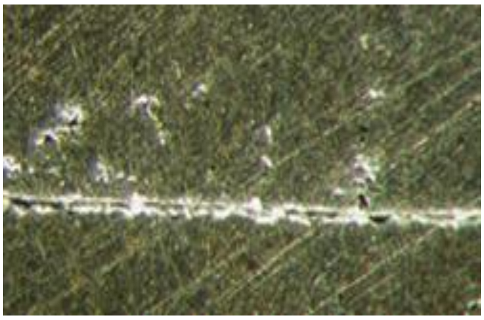
Splits

It is a defect in the cavities of the sides of casting and it is a defect based on the infringement of the fullness which goes from the surface to the volume of casting. It is a curvilinear infringement of the side which takes place in heat on a slightly oxidized surface. It starts within the process of solidification if natural course is mechanically or thermally impeded.



Cracks

They are defined as a curvilinear break of the side of casting which has occurred in cold. Their surface is clean. Their causes are a tension resulting from shrinking, an inappropriate design which causes the tension in the volume of casting after it has been cooled down, or a premature removal of casting from the mold. They run through the internal parts of cores because their edges are stronger than their cores after cooling.



Deformations

The design of mold influences the formation of deformations, which may be caused by:

- an insufficient chamfer of the shaping part of the solid part of mold
- a small chamfer of the deep shapes of casting
- a wrong location and insufficient surface of ejectors
- an insufficient supporting surface of casting on the releasing of movable cores
- a wear and tear of mold in the area of the unsuitable mouth of notch
- an inappropriate design of the cooling system of mold

Apart from the design it is the quality of mold which bears certain influence; especially the state of the surface of shaping part; the treatment of mold after the completion of casting cycle and the emergence of splits in heat.

Size Deviations

If a casting complies with the required conditions, it must comply with the obvious requirements regarding fullness, internal and external quality and mechanical properties. Apart from them it must comply with size requirements which are defined by the design documents. The requirements regarding the accuracy of sizes must be considered by a designer when he or she is projecting the completion of the mold of casting and the overall design of mold.

If we consider the size deviations from the point of view of the design of mold and the way of the completion of the mold of casting, we conclude that they are caused by the following determinants:

- the sizes which cross the dividing plane cannot be restrained within the narrow tolerance limits
- the system of the tempering of mold must also consider the influence on the size deviations of casting; the solution is an achievement of thermal balance in course of casting
- the wrong design of the value of the shrinking of casting in terms of the design of the mold in relation to the type of alloy
- The deformation of mold, i.e. deflection, overheating, caused by the insufficient sizing of the individual parts of mold

9. ADDITIONAL DEVICES TO THE DIE CASTING MACHINES

Dosing equipment

The function of the manipulators of dosing is to transfer the measured quantity of melt from the holding furnace to the pressure chamber of die casting machine.

They consist of stand, power plant, swivel arm, scoop and probes.

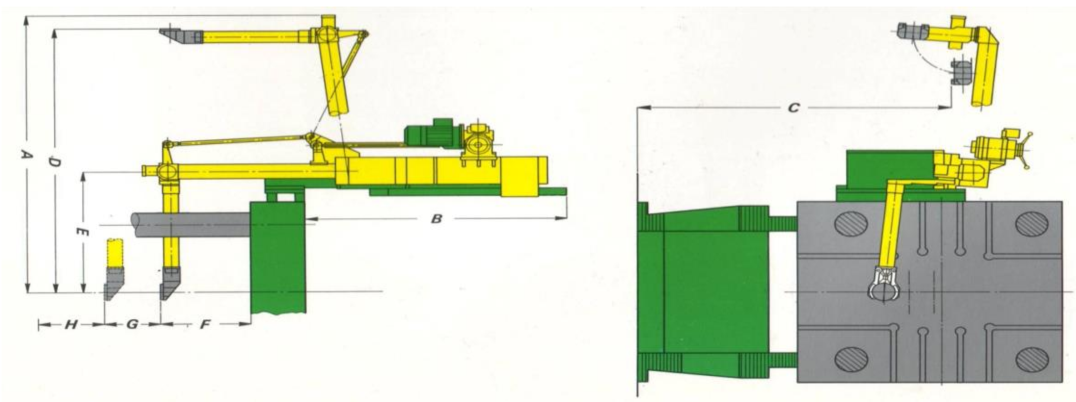
The stand is designed in such a way that it enables a vertical reposition and the manipulator to revolve. It is fixed on the ground next to the die casting machine. The power plant consists of electric engine, transmission and threaded gearbox.

The swivel arm is fixed on the output shaft of worm gear. There is a chain drive in the swivel arm. It keeps the support arm in the arranged position in the course of the moving of swivel arm. The support arm carries the scoop. It contains a device for the turning of scoop.

The scoop is mostly made of perlitic gray cast iron. Its shape is designed in such a way that when it is dived into the melt, the infringement of oxidative surface is minimal. The accuracy of dosage is about 0.8%. It is possible to empty the scoop entirely.

The machine for the collecting of castings

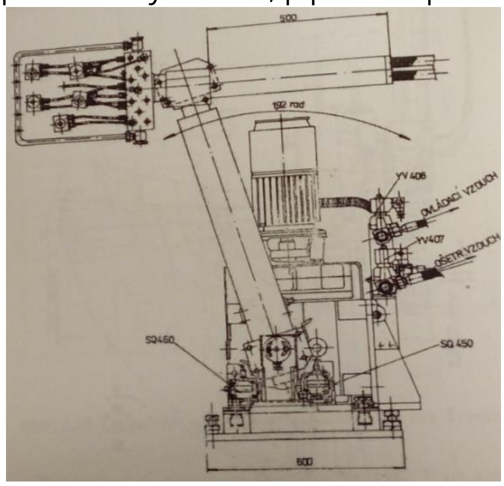
The collecting of castings is linked to some other operations such as the testing of castings. There are freely programmable industrial robots, which collect the castings.



The device for the treatment of mold

The external and the internal cleanliness of castings largely depends on the treatment of the active part of mold, which is provided by the treatment device.

It consists of reciprocator and pressure distributive system. The reciprocator is fixed on the solid caliper of pressure casting machine. It is possible to revolve it mechanically in the room of the dividing plane of mold and by the loosening of screws in the flange. The transition of treatment block to the location of mold is provided by pneumatic cylinder. The treatment of mold is done by lubricating and blowing nozzles. The supply of air and lubricant to the treatment block is provided by houses, pipes and pressure vessel.



Trimming presses

The trimming of inlets on the castings is performed on the trimming presses. The operation of the trimming presses must be automatically self-guarding. The machine contains a lot of components, such as end-switches, hand-protecting devices and control valves.

There is a security of individual lift so that the press would make only one lift even if all the buttons were pressed.

The device for the auxiliary heating of operational liquid

The machine is able to get the liquid at the operational temperature in 3 – 4 hours of operation. The auxiliary heating is used to reduce the time.

The auxiliary heating is used if the machine is turned off for a rather long period. The temperature drops by 20 ° C.

The cooling of the liquid causes the rising of viscosity. It creates a coat on the filter liner which turns on the signalization of machine defect.

The most efficient are the electric heaters of operational liquids.

10. THE MELTING OF ALLOYS

The alloys are melted in smelting furnaces with sufficient input to achieve an intensive melting and to reduce the overheating to minimum. The casting temperature depends on the type of alloy, the chemical composition, the design of casting, the complexity of design and the roughness of sides. Considering the casting temperature, it is necessary to take into account the cooling effect of mold and cores as well as the way of casting.

The excessive temperatures cause the rise of the quantity of gases, the excessive amount of oxides, the roughness of cores and the consumption of energy.

Melting is a thermo-metalurgical process. In its course the heating is added or rather created and the material (batch) changes its physical state, i.e. from solid (solidus) into liquid (likvidus).

The batch materials:

- Blocks of alloy
- Pure metals (Al, Mg, Zn, Cu, Si, etc.)
- Master alloys for doping (Al-Ti, Al-Cr, Al-Mo, etc.)
- Chemicals (ion based compounds) used for additional doping for the adjustment of structure
- Waste, which must be carefully selected according to its chemical consistence

Convertible material

Convertible material is formed by inlets, pours, remnants in the pressing chamber and defected products of die casting. Considering practical experience, the percentage of convertible material depends on the size of casting, it can be from 20% of the weight of rough casting up to 75% of the weight of large castings.

In case of casting which does not require excellent properties it is possible to use an alloy of lesser quality by the use of convertible material in the course, specifically from the second to the third melting. The content of convertible material of the second melting should not exceed the value of 40% and the content of convertible material of the third melting should be within 30%.

Convertible material is classified as pure material, i.e. from the inlet system, defected castings and polluted material, i.e. the remnants from the filling chamber and the alloy polluted by oil. In the course of melting the batches are first to melt then a new block of alloy is added. It is followed by refining.

Melting, keeping and casting

Several types of melting aggregates are used for melting. The crucial factors are the economy and technology of the preparation of metal or alloy.
The most important technological parameters include:

- The performance of melting aggregate
- The way of the heating of melting aggregate
- The way of the change of temperature
- The movement of melt in the workplace
- The range of working temperatures and the change of temperatures
- Control and regulation
- Atmosphere and pressure
- The time of melting process

11. CA TECHNOLOGIES IN FOUNDRY

The rapid introduction of computer technology into every branch of industry has opened the way to experimental and simulation modelling and the evaluation of the designs of inlet systems and pressure forms which are designed analytically and empirically. It has been proved that the use of computer technology for the simulation of processes which take place in die casting saves 40% of time which is needed for the design of casting, 30% of time needed for the evaluation of the results in laboratories and it brings an increased profitability by 25% in terms of the whole process.

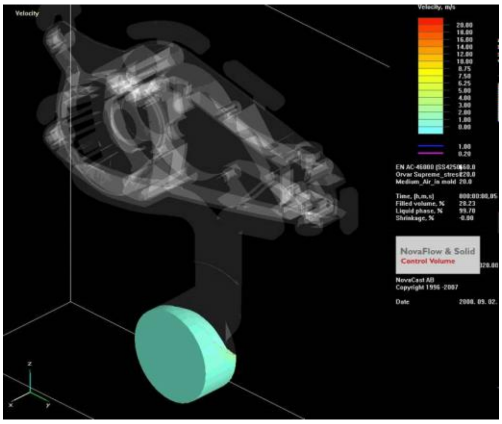
There are several dozens of simulation programs which are used for the simulation of processes taking place inside the mold. The most usual programs are the following ones:

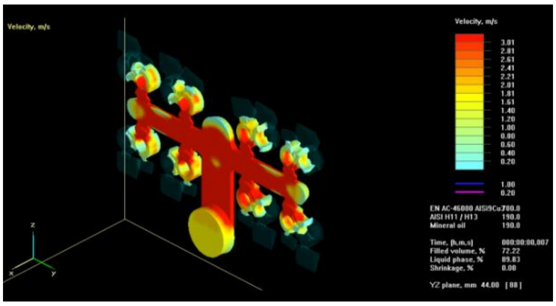
- NovaFlow & Solid,
- PamCast,
- Magmasoft,
- Simtec - Wincast.

NovaFlow & Solid

The program is developed by NovaCast, S.A., Sweden. The calculation of the course of the filling of the mold hollow takes place simultaneously with the solving of the formula which calculates the flow and the penetration of heat. The user is especially provided with the overall view on the course of filling and solidification. It provides a definition of the size and the layout of defects for any type of alloy. At the end of filling, the temperature fields of casting are subsequently used for the simulation of solidification. The flow of incompressible liquid, Reynolds number, the friction losses in the inlet system of mold, the change of the density of metal in course of solidification and the size of volume changes are taken into account in the simulation.

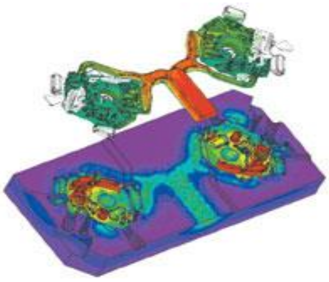
The program is equipped with a database of the thermo-physical properties of alloys and the material of molds. It is possible to alter and to add the database. The visualisation is provided in the 3D form with the possibility of the animation of the process. The program is able to display the vectors of flowing, the layout of the temperatures of liquid phase, the layout of shrinkages in 2D or 3D format and the time course of temperatures.





PamCast

This program is a product of ESI Group, France. It is more precise and detailed than NovaFlow & Solid. It can solve Navier-Stokesov formulas of the turbulent flow of metal and air together with thermal balance extremely accurately and without any approximations. The user sets the input parameters in dependence on time and temperature. It is possible to animate the movement of free metal boundary, the distribution of solid and liquid phase and to predict the layout and the occurrence of shrinkages.
A simulation enables to optimize the set up of the machine in such a way that there is no turbulent flow of the melt and the consequence of which is the reduction of the contact of the air and the melt.

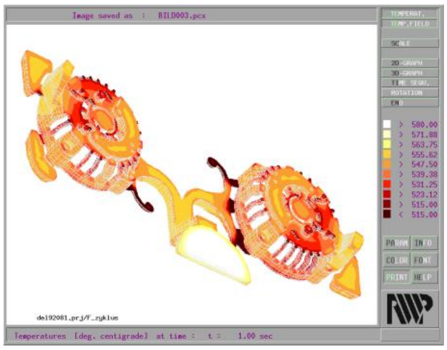


Simtec – Wincast

It is a complete and universal instrument for the optimization of the design of the production of castings and it provides a wide range of information:

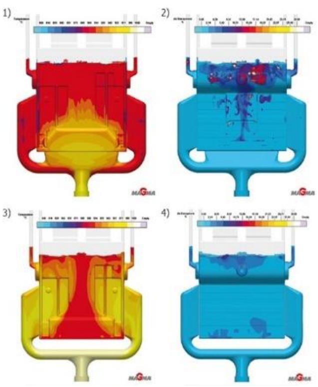
- The course of casting and cooling
- Residual stress
- Shrinking and deformation after casting
- The formation of porosity
- The microstructure of material
- The strength properties of components
- The suitability of casting system
- The course of temperatures and the design of cooling in case of metal molds

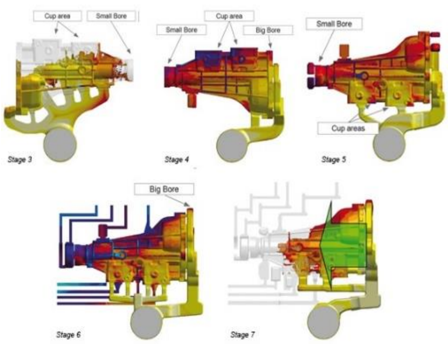
It has functions and modules which accelerate an accurate setting and evaluation of the specific parameters of the technology of die casting and the thermo-physical properties of materials. One of the advantages is a fact that the user does not have to import the shape of casting from other programs. It is possible to create and adjust it directly in the program. The possibility to import and to communicate with other programs is guaranteed by a number of interfaces, such as FEM, VDA, STL, etc.

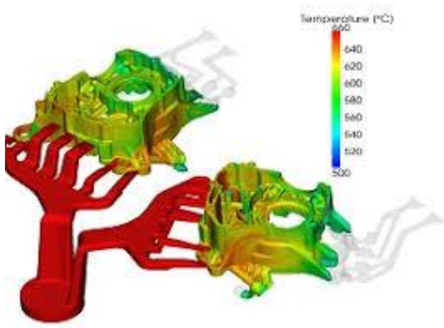


Magmasoft

It is a most popular software. It is designed for 2D and 3D simulations which deal with the filling and solidification of castings, the calculation of residual stress, thermal field and heat flow. This program is an effective instrument which enables to reduce defects or costs and which can increase the use of metal. It is characterized by a short time of calculation, high accuracy, efficiency and easy operation.







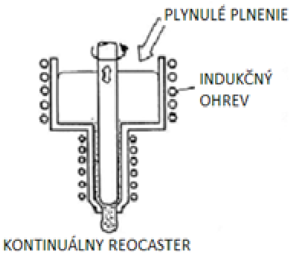
12. SPECIAL TECHNOLOGIES IN FOUNDRY

SEMI SOLID METAL (SSM) PROCESS

Semi solid metal is a casting method for metals and their alloys which are in partly solid state, i.e. the temperature is between liquid and solid. The material is similar to the consistency of plasticine, i.e. thixotropant state of material. The picture shows a semi-finished product containing 55% - 60% of crystal phase, which can be cut by a knife.

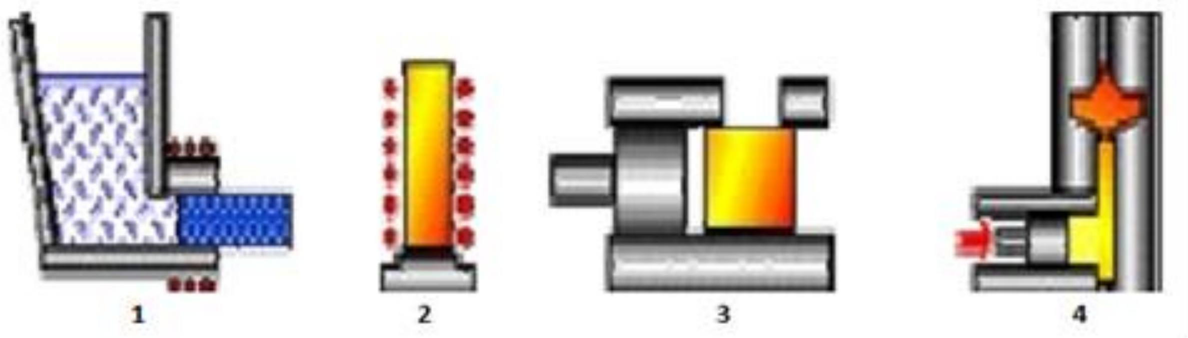
Rheocasting

Rheocasting (reoliatie)is in fact a modified method which uses a semi-liquid state of material. The term for this way is rheocasting because the principles of rheology are used for the preparation of semi-finished product. The scheme of the production of semi-finished products is in the figure. The machine is formed by two cylinders.



Thixocasting

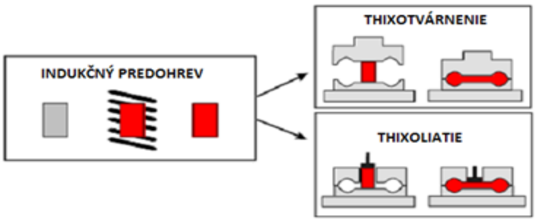
Thixocasting (thixoliatie) is essentially a modified SSM method. The base for further processing is a specifically prepared material, which is usually made by continual casting and subsequently divided into tablets. Such tablets are heated by inductive way so that the part of the solid phase is ranging approximately from 60% to 65% of volume. They are subsequently put into the horizontal chamber of pressure machine. The castings are made in a similar way to rheocasting. The duplex structure with all the positive properties is preserved as well.



Description: 1 – the production of continually cast semi-finished product which is made of specially prepared melt and which is divided into tablets, 2 – the heating of tablets by inductive heat, 3 – the insertion of tablet into the pressure machine, 4 – the injection of heated semi-finished product into the mold hollow

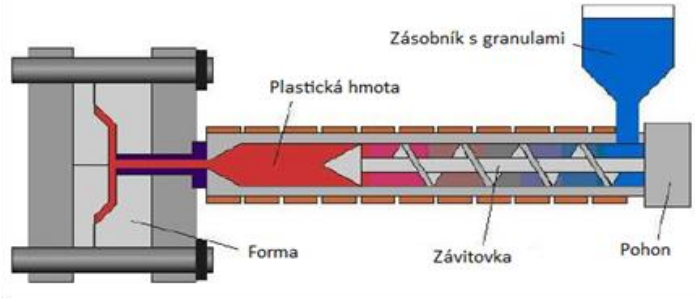
Thixoforming

Thixoforming is similar to thixocasting. It also uses the advantages of SSM or rather thixocasting. Thixoforming also uses semi-finished products which are made of continual casting and subsequently cut into tablets. The inductive heating of tablets reaches such a temperature so that the share of the solid phase of their volume is 70%. The main difference between thixocasting and thixoforming is the share of the solid phase in the tablet of material, which is put into the form. Moreover, there is a difference in the machine which is used. The heated tablets are gradually put into the special form which is fixed on the forming press. The scheme of the method is in the figure.



Thixomoulding

Thixomoulding is a casting method which is based on the heating up of metal powder or granulate on the base of magnesium or aluminum in a special pressing machine. The scheme of the principle of thixomoulding is in the figure below.


Zásobník s granulami
Plastická hmota
Forma
Závitovka
Pohon

LITERATURE

GAŠPÁR, Š., PAŠKO, J., MAJERNÍK, J. *INFLUENCE OF STRUCTURE ADJUSTMENT OF GATING SYSTEM OF CASTING MOULD UPON THE QUALITY OF DIE CAST*. 1st ed. Lüdenscheid: RAM - Verlag, 2017. 82 p. ISBN 978-3-942303-47-7.

GAŠPÁR, Š., PAŠKO, J. *Technológia výroby hliníkových odliatkov tlakovým liatím*. 1st ed. Lüdenscheid: RAM-Verlag, 2015. ISBN 978-80-553-2236-0.

MAJERNÍK, J. *Problematika návrhu vtokových soustav permanentních forem pro lití kovů pod tlakem*. 1st ed. Stalowa Wola: Wydawnictwo Sztafeta Sp. z o.o, 2019. 94 p. ISBN 978-83-63767-63-1.

PAŠKO, J., GAŠPÁR, Š. *Technological Factors of Die Casting*. 1st ed. Lüdenscheid: RAM-Verlag, 2014. 93 p. ISBN 978-3-942303-25-5.

RUŽBARSKÝ, J., PAŠKO, J., GAŠPÁR, Š. *Techniques of Die Casting*. 1st ed. Lüdenscheid: RAM-Verlag, 2014. 199p. ISBN 978-3-942303-29-3.