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The Most Common Foundry Errors of Pressure Die Castings Made from Hypoeutectic Silumin*

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Abstract: Pressure die casting is the method used for forcing molten metal into mould cavities under high pressure and at high speed (10 - 100 m.s^{-1}). Pressure die casting is a highly productive method of casting parts with low dimensions tolerance and high surface quality. From the point of view of production quality and effectiveness, special attention should be paid to the internal structural quality of die castings, which is characterised by the types and range of foundry errors (cavities, cold laps). The method of a mould cavity filling which is dependent on the input speed of melt is very important from the point of view of die castings quality. The article deals with the influence of a mould cavity filling speed as well as the occurrence of foundry errors in the pressure die castings made from hypoeutectic silumin.

Najčešće greške u odljevcima prilikom lijevanja podeutektičkog silumina pod tlakom

Izvornoznanstveni člsnak

Sažetak: Lijevanje metala pod pritiskom je metoda za proizvodnju odljevaka kojom se rastaljeni metal ubrizgava u kalup pri velikim brzinama (10 do 100 ms^{-1}) pod utjecajem visokog tlaka. To je vrlo produktivan način lijevanja odljevaka sa uskim tolerancijama i visokom kvalitetom površine. U smislu učinkovitosti i kvalitete proizvoda treba posvetiti pažnju kontroli unutarnje strukture odljevaka, koju karakteriziraju vrsta i opseg ljevačkih defekata (šupljina, unutarnjih udubljenja). Za kvalitetu odljevaka vrlo je važan način ispunjavanja šupljine kalupa tekućim metalom, što ovisi prvenstveno o ulaznoj brzini tekućeg metala u šupljinu kalupa. Ovaj rad se bavi proučavanjem utjecaja brzine ispunjavanja šupljine kalupa kvalitetnom legurom, te pojavom grešaka lijevanja u odljevcima od podeutektičkog silumina.

Keywords

pressure die casting
hypoeutectic silumin
internal quality
foundry errors

Ključne riječi

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kućište od podeutektičke legure
unutarnja kvaliteta
nedostaci lijevanja

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1. Introduction

Pressure die casting is the method of precise casting. It is the closest way to convert raw material into a product. With this technology, the molten metal is pressed into a mould cavity at high speed. The process of a mould cavity filling is not affected by gravity anymore; it is a result of transformation of pressure energy into kinetic energy. The complexity of the mould filling problem lies in the fact that factors affecting the die casting design as well as heat balance of a mould determine the real flow of the melt [3, 6]. Quality of die castings is affected by the following technological factors:

- piston velocity in the filling chamber,
- specific pressure on melt,
- period of mould cavity filling, temperature of casting alloy,
- temperature of die casting, mould pressure as well as filling chamber temperature.

These factors mutually affect one another. It is a complex of interrelationships among alloy character, filling period, mould design and die casting machine effectiveness as well as knowledge of the whole die casting process beginning with cavity filling and ending with casting solidification [1, 2].

Quality of pressure die castings is influenced by technological parameters of a casting process as well as adequate purity of melting stock. To achieve good properties of aluminium alloys, the appropriate technological parameters in the process of melting and rafination should be selected. Due to chemical affinity of aluminium to oxygen, oxide inclusions occur. Together with hydrogen solubility, they result in spoiled castings and production loss [4].

Aluminium alloys react easily with the elements, especially gases. Aluminium melt often contains small amount of hydrogen, oxygen and other gases. They could be present either in elementary form or form alloys. Hydrogen mainly dissolves in aluminium alloy melt. Its amount is more than 97 percent, consequently this fact encouraged some scientists to simply state that hydrogen is the only gas to be dissolved in the melt. Hydrogen does not form a compound with aluminium and is actually being engulfed in atomic state. This phenomenon could be simply considered as absorption subjected to the normal physical laws.

Hydrogen is an impurity occurring in real operation and substantially affects the alloy quality. Porosity as a specific foundry error of the pressure die casting made from aluminium alloy is caused by gas bubbles that occur in the process of hydrogen cooling affected by its decreasing dissolution dependent on temperature. Hydrogen solubility in aluminium below the melting point is very low, though it slightly increases with increasing temperature. The substantial change occurs during the melting process because during transition from solid to melt state, gas solubility highly increases. Scientists present almost the same solubility values, but they agree that the melt increases solubility approximately by one order of the magnitude.

In the melt, hydrogen solubility increases with the increasing temperature. The increase is very significant. For example, if the temperature is increased by approximately 100°C, maximum amount of dissolved hydrogen in the melt is doubled up. During the solidification process, dissolved hydrogen must be released because being in solid state it is not able to take so much gas. Only 10 percent of hydrogen dissolves, the remaining 90 percent must be released from the solidified metal. If solidified casting crust enables hydrogen to be released from metal, hydrogen bubbles or solid solution of aluminium saturated with hydrogen can occur. On the contrary, with high cooling velocity, diffusion is not possible and hydrogen remains trapped in metal grid. Consequently, saturated solid solution is being formed [4, 5, 7].

Oxygen enters the melt from different humidity sources. It is released according to the following equation:

$$2Al + 3H_2O = Al_2O_3 + 3H_2$$

From the equation it follows that the melt is being polluted both by oxygen and oxide inclusions, though in favourable conditions oxides can remain in oxide membrane on the melt surface. It is known that alumina occurs in several modifications, mainly in the form of γ - Al_2O_3 that highly absorbs water even at higher temperatures above the melting point of aluminium.
Thus, oxides are considered to be one of the way how to gasify alloys. According to some scientists, hydrogen occurs in ionized state in the melt, it is attracted by the Al_2O_3 particles and create the complex Al_2O_3 - H_2. This approach could be connected with the fact that degasification conducted by any method leads to inclusions at the same time, and on the contrary, when the oxide inclusions are removed, the gasification degree of the melt greatly reduces. The process of hydrogen dissolution in the melt is affected by its composition. From the practice it follows that well degasified alloys of the AlSi type, the surface of which remains quiet and is covered with the compact layer of oxides, does not show much inclination to gasification with the increased atmospheric humidity.

Alloying elements, especially magnesium, increase hydrogen solubility in aluminium. Being in solid state, magnesium can dissolve hydrogen much more better than aluminium (more than three orders of magnitude), thus hydrogen concentration in the melt depends on the type of the alloy. Casting alloys usually contain more hydrogen than alloys for machining purposes.
When the level of spillover is very high and the oxide layer tears very often, the melt greatly gasifies and oxidizes when being transported and poured. Alumina has got extremely high melting point – about 2000° C. In the melt, alumina always occurs in solid phase. Alloying elements and impurities highly affect melt oxidation. It is theoretically proven that some elements will oxidize preferably before aluminium, the other will oxidize very little. It is caused by different value of free energy of oxidation.

Oxides which have greater specific volume than the elements from which they have originated do not worsen but improve the quality of the surface membrane of the melt. On the contrary, the elements the oxides of which have low specific volume, degrade the oxide membrane on the melt surface, for example Pb, Mg, Ca or Na. These elements create the fluffy oxide membrane which vapour or oxygen can easily pass through [4, 9].
Alumina density almost does not differ from oxygen, thus the oxide particles including scattered pieces of oxide membrane, freely floating in aluminium melt, can hardly float to the surface. The authors are sceptical about eliminating the oxides by dead melting.

From the above it follows that the oxide layer on the melt surface of AlSi alloys is constant if it is not mechanically damaged. If it damages, the new layer of the same thickness will be formed. Consistent oxide layer can protect the AlSi alloys against excessive oxygenation. However, it is not always possible in practice as the oxide level is always being damaged at each melt dose. Increased attention is being paid to the internal quality of pressure die castings because of different types and ranges of foundry errors. On the one hand, the structure of casting alloys is a determinant factor of castings properties, on the other hand, it is a limiting factor of foundry errors inside the castings from the point of view of operational reliability. From the point of view of the casting resulting quality, the

cavity filling velocity that determines the filling regime as well as casting temperature is considered to be the most important parameter of the pressure die casting. The cavity filling velocity is dependent on the piston velocity inside the filling chamber, hydrodynamic loses, ratio of surface notch and die parts into which the notch is led into, die vent channels, etc. [3, 8].
The other important casting parameter is alloy quality after rafination which also affects the resulting quality of the casting.
Influence of piston velocity in the filling chamber and alloy quality after rafination towards the character of damage and foundry errors has been experimentally observed using pressure die castings made from STN 42 4331 alloy which corresponds to EN 43 100 alloy.

2. Evaluation of damage character and foundry errors

Macroscopic analysis of longitudinal and cross sections of the casting wall enabled to obtain information on the size of cavities and their distribution using a light microscope with 10-fold magnification.
Based on cavities distribution along the section, it is possible to consider the filling regime of the certain casting part, as shown in Fig. 1 and Fig. 3. The cavities shown in Fig. 2 are of smaller dimensions and their localization in the middle part of the casting is more definite. The cavities shown in Fig. 1 are also located in the middle part of the casting but they are interrupted by relatively large bands of healthy material.
Fig. 3 shows different situation and at first sight it appears chaotic. Detailed study shows circles, eventually spirals (Fig. 3a) of cavities distribution. This sample also contains the larger cavities and it is possible to prove that they have originated from the fusion of several cavities located at different circles.

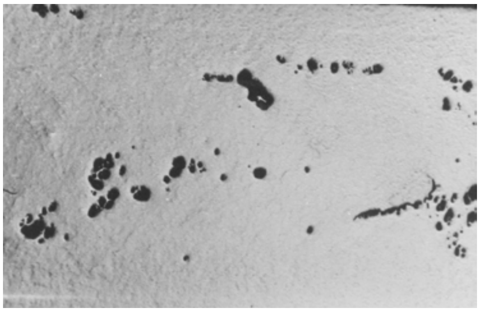

Figure 1 Casting with cavities – sample 1
Slika 1 Odljevak sa šupljinama - uzorak 1

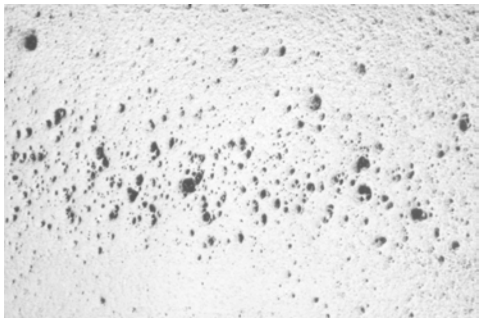

Figure 2 Casting with cavities – sample 2
Slika 2 Odljevak sa šupljinama - uzorak 2

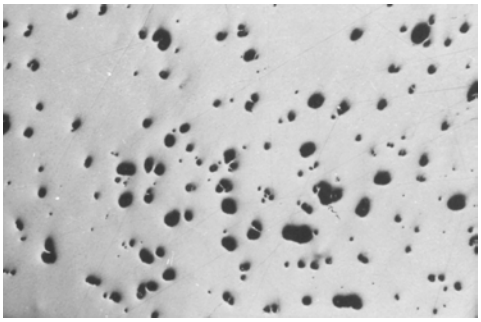

Figure 3 Casting with cavities – sample 3
Slika 3 Odljevak sa šupljinama - uzorak 3

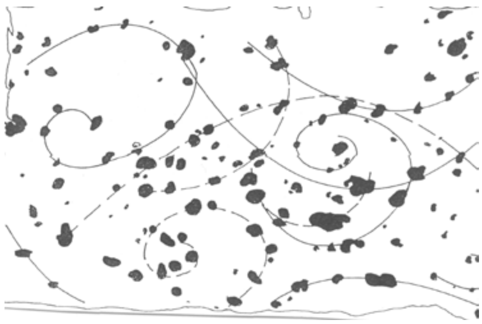

Figure 3a Detail of the the figure 3
Slika 3a Detalj slike 3.

From the above it follows that based on microscopic analysis of the sections of the selected castings it is possible to obtain information about influence of filling regime (or to be more precise: influence of different filling regime in compared sections in the casting) on cavities occurrence in the casting as well as partial information about their origin. Fig. 1 shows that this part of the casting was filled up by return turbulent asymmetric jet with the small number of larger vortices. Part of the casting documented by fig. 2 was filled up with higher velocity, probably by turbulent-dispersive jet of melt. Situation presented in Fig. 3 can result from higher melt velocity than it was in the first case, but lower than in the second case.
Based on cavities morphology and their distribution, it can be concluded that we deal with bubbles (in no case with porosity) and the primary origin of their occurrence is the filling regime of the die.
From a macro point of view, fracture of hypoeutectic silumins is brittle, plane, arranged perpendicular to

the tensile force. Such a fracture occurs when the alloy contains a lot of tiny particles that do not allow stronger internal plastic deformation of small volumes of metal among the particles with the small ratio of macroscopic deformation.

The micro mechanism of deformation of hypoeutectic silumins depends on eutectic silicon morphology.

It is known that eutectic silicon is a very brittle phase. If the samples made form this alloy are loaded, a brittle deformation occurs. Cleavage of unmodified silica is the leading micro mechanism of the process.

With the brittle deformation, the ratio of ductile elements in the fracture is minimal.

Macroscopic analysis of the fracture planes showed that the fracture was caused by low energy ductile fracture and has brittle appearance (see Fig. 4). Fracture initiation was observed mainly in casting errors.

In order to study samples deformations and identify internal casting errors, the micrographic analysis has been realised. The character of deformation of all the analysed samples is identical. Fig. 5 shows typical deformations of the dendrites of the α -phase and eutectics. The dendrites of the α -phase are the structural component with high plasticity. Before the deformation, they are plastically deformed and consequently result in bright peaks which define individual craters on the fracture plane, fig. 6.

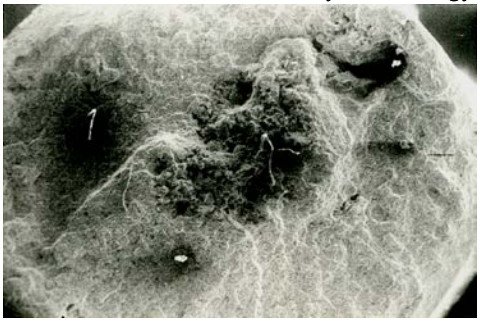

Figure 4 Macroscopic view of the fracture

Slika 4 Makroskopski pogled loma

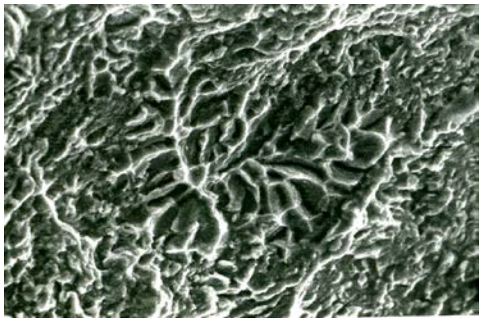

Figure 5 Character of the dendrites deformation α of the solid solution and eutectics.

Slika 5 Priroda deformacije dendrita α čvrstih otopina i eutektika

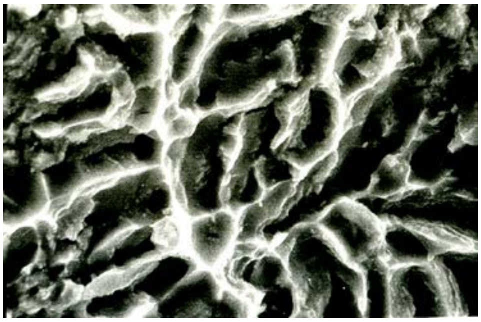

Figure 6 Detail of the Figure 5

Slika 6 Detalj slike 5.

Irregular shape of the craters with ductile fracture of the α -dendrites is connected with the fact that their occurrence is initiated by the eutectics located between the secondary axes of the dendrite. Except big, deep non-equiaxed craters of the primarily excreted α - solid solution on the fracture planes, flat or developed eutectic craters related to the less relief surface with the fracture transition through eutectics are being observed. Tiny particles of eutectic silicon and local tiny peaks of ductile deformation of the eutectic α - phase can be observed on the surface of this part of the fracture. The following casting errors have been observed on the fracture planes:

- the cavities with surfaces produced by the dendrites, between the axes of which the oxide layer of Al_2O_3 is located,
- the cavities, the surface of which is produced by continuous oxide layer of Al_2O_3,
- Al_2O_3 particles.

The cavities of the first type were the most common with all the analyzed samples. The cavities of the second type occurred sporadically. Based on the cavities morphology, their position in the casting and the presence of Al_2O_3 layer (continuous or between the dendrites), we can determine these cavities as exogenous bubbles occurring as a result of trapping the gases and air contained in the form of turbulent melt flow. Oxygen dissolved in the melt could diffuse into these bubbles. The process of hydrogen elimination (if realized) is considered to be the secondary process. Based on the wall thickness of the analyzed castings, fine – grained structure of the casting moulds, operating pressure, etc., hydrogen elimination is highly unlikely to occur. The next fact to be taken into consideration is the ability of hydrogen to diffuse from the solid solution to empty spaces in the casting. The empty spaces are the exogenous bubbles and inter-dendritic porosity occurring with the pressure die casting as a result of late frontal crystallization relative to the bulk crystallization. If hydrogen is excreted in the exogenous bubbles, it can react with the gasses inside the bubble. If hydrogen is excreted to the inter-dendritic spaces, the dendrites surface can stay clean. Pure dendrites were not observed.

Part of the fracture plane with the mentioned bubbles is shown in Fig. 7. Fig. 8 shows the bottom of the bubble.

Fig. 9 shows the exogenous bubble, the whole surface of which is produced by Al_2O_3.

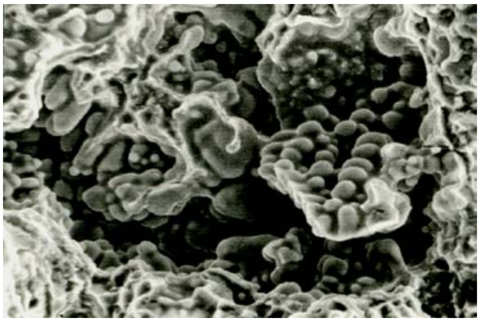

Figure 7 View of area with exogenous bubbles.
Slika 7 Pogled na područje s egzogenim mjehurićima

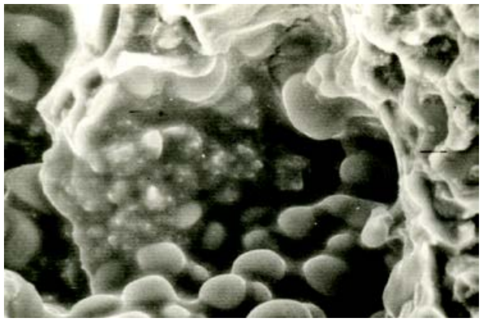

Figure 8 Detail of the Figure 7
Slika 8 Detalj slike 7.

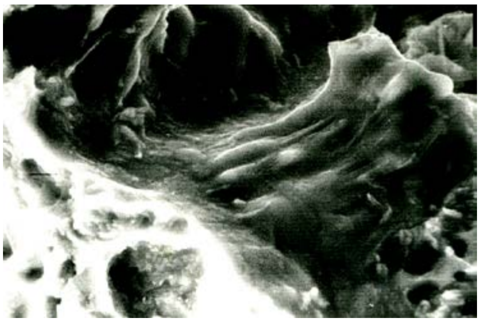

Figure 9 The surface of the exogenous bubble with the continuous layer of Al_2O_3

Slika 9 Površina egzogenih mjehurića obložena slojem Al_2O_3

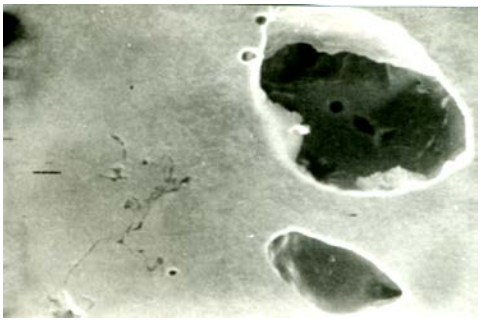

Figure 10 Exogenous bubble in the metallographic section

Slika 10 Egzogeni mjehurić u metalografskoj sekciji

When studying the mentioned bubbles, the metallographic sections observed in REM have been used. From the Fig. 10 it follows that the bubble was trapped by the turbulent melt flow and hold in the casting by vortex force. Probably because of the local effect of centrifugal force, the part of the melt was pressed inside the bubble (see Fig. 11).

Except the bubbles on the fracture planes of the analysed samples, the particles of Al_2O_3, occurring separately or in the clusters, have been observed (see Fig. 12, 13, 14). The Al_2O_3 particles affect the mechanical properties greater than the bubbles because material loses its cohesion.

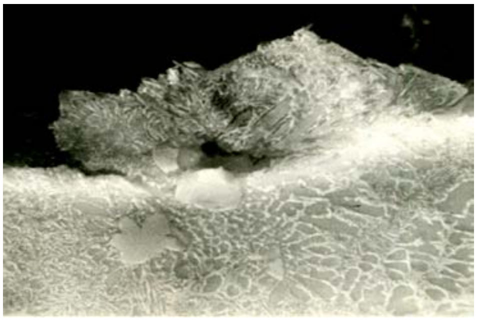

Figure 11 Detail of the Figure 10
Slika 11 Detalj slike 10.

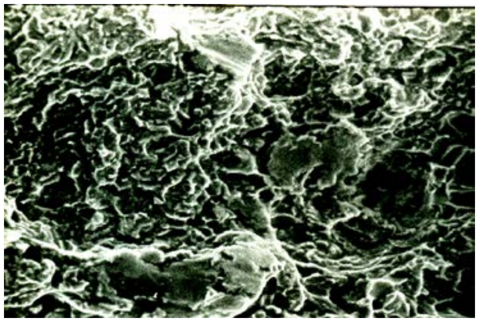

Figure 12 The Al_2O_3 particles on the fracture plane
Slika 12 Al_2O_3 čestica na površini loma

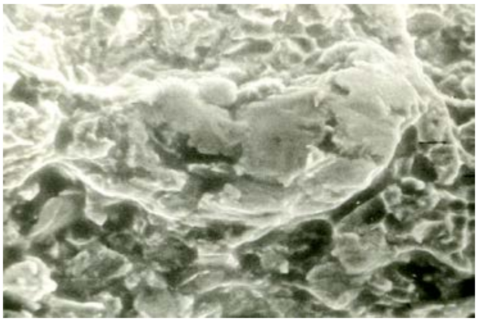

Figure 13 Detail of the Figure 12
Slika 13 Detalj slike 12.

Figure 14 The cluster of the Al_2O_3 particles
Slika 14 Grupiranje Al_2O_3 čestica.

The Al_2O_3 particle, which is imposed perpendicular to the force exerted on the sample load, is considered to be a concentrator of tension in the body of the casting. Based on the morphology of the observed Al_2O_3 particles, it can be assumed that they are the result of the melt turbulence.

The Al_2O_3 particles observed on the fracture planes do not provide a coherent picture of cold joints origin – cold laps visible on metallographic sections in the form of crooked lines.

Fig. 15 shows the view of the cold lap. The oxide layer on the surface of the melt flow indicates its turbulence. The vast length of the crooked line runs along the edge of the dendrites of the α - solid solution.

Fig. 16 shows a special formation in the form of adjacent rounded body with impaired integrity of the middle part. The body form corresponds to the body shown in Fig. 17. The body surface is produced by Al_2O_3 layer. The substance of these formations has not been identified.

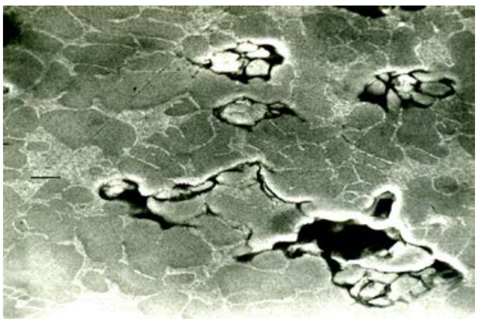

Figure 15 Cold lap
Slika 15 Unutarnje udubljenje

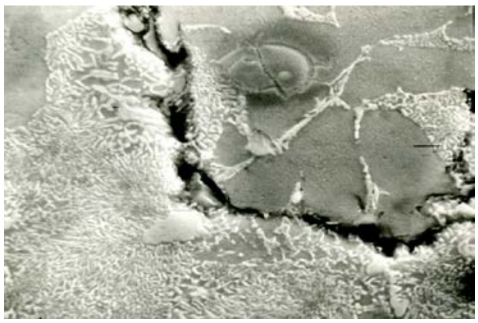

Figure 16 A Detail of Cold lap
Slika 16 Detalj unutarnjeg udubljenja

Figure 17 Part of the surface plane with the body of the circular shape
Slika 17 Dio površine loma sa tijelom kružnog oblika

4 . Conclusion

Based on the samples analysis, it can be stated that the most frequently occurring cavities in the pressure die castings are as follows:

a) the cavities with the surface produced by the dendrites, between the axes of which there occurred the layer of Al_2O_3 oxide,
b) the cavities, the surface of which was produced by the continuous layer of Al_2O_3 in combination with the cold laps.

In fracture planes there occurred Al_2O_3 separated particles or their clusters that affected mechanical properties of the pressure die castings greater than the bubbles.

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