THE RESEARCH OF THE FRACTURE PROCESS AND ANALYSIS OF THE FOUNDRY ERRORS OF DIE CASTINGS FROM HYPOEUTECTIC SILUMIN

STEFAN GASPAR, JAN PASKO

Technical Universtity of Kosice
Faculty of Manufacturing Technologies with a seat in Presov
Department of Design Technical Systems
Presov, Slovak Republic

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e-mail: stefan.gaspar@tuke.sk

The research in the technology of production of die castings from hypoeutectic silumin which are nowadays deeply implemented in the rapidly developing automobile, shipping and airline industry aims to increase the manufacture and quality properties of the castings. A higher attention is paid to die castings inner quality which is characterized by a type and range of casting-related defects. In accordance with a specific character of this production technology, the major casting defects are cavities, Al_2O_3 particles and internal cold laps. The presenting contribution deals with the research of the fracture process and analysis of the foundry errors of die castings from hypoeutectic silumin.

KEYWORDS

die castings, fracture process, foundry errors, quality of cast

1 INTRODUCTION

The nature of die casting consists in mechanical metal casting method whereby the movement of the plunger and the pressing force applied to the plunger induced by hydraulic system will act on the molten metal contained in the filling (pressing) chamber of die casting machine. Thus, under high pressure (up to 250 MPa), molten metal from the filling chamber is pressed-in through the sprue in the cavity of the parting die casting mould. During pressing-in the cross-section, so called ingate, is suddenly narrowed in the sprue before the mould cavity entrance, which causes achieving high filling speed of the mould cavity (up to 100 $m.s^{-1}$) [Ruzbarsky 2014]. Owing to the action of high pressure and high speed in the ingate the mould cavity is filled within the time of a few milliseconds. Presented technology thus enables the production of complex shaped thin-walled castings at high dimensional accuracy and with perfect copying of inner surface layers relief of the mould cavity. To cast aluminium alloys a die casting machine with the cold horizontally arranged filling chamber is used in most cases [Pasko 2014].

The final quality of the casting is conditioned by technological parameters of casting, such as: the plunger speed in the filling chamber of die casting machine of which depends the mould cavity filling time, specific pressure on the melt and the resistance pressure, the melt temperature, the filling chamber temperature and the mould temperature, a structural concept of the mould with the gating, cooling and venting system and ultimately metallurgical preparation of the melt, its purity and temperature [Krsak 2014, Orlowicz 2015].

The most important parameter of die casting in terms of the final quality of the casting is speed of the mould cavity filling with liquid metal determining the filling mode and the casting temperature. This is dependent on the plunger speed in the filling chamber, hydrodynamic losses, mutual proportion of the ingate area and the mould part into which the ingate is mouthed, the venting channels of the mould etc. [Malik 2012].

Another important parameter of casting is the quality of the casting alloy after refining which also affects the final quality of the casting. Oxidized raw material surface of a charge has a substantial negative impact on the value of the melt contamination by hydrogen and oxides. Such oxidized surface membrane may contain from 30 to 60% of aluminium hydroxide Al(OH)3, whereby such chemically bound moisture is quite difficult to remove even at 900°C. Alumina particles thus significantly contribute to increase the amount of contamination of the molten metal. Aluminium is characterized by a high chemical affinity to oxygen. This feature results in the formation of oxide inclusions in the melt which together with the solubility of hydrogen represent a significant cause of rejects in the production process. By selection of appropriate technological processes of melting and the melt preparation we can fundamentally reduce the emergence of defects in castings. Most harmful gases for aluminium alloys are: hydrogen, oxygen, water vapour. Aluminium melt always contains a certain volume proportion of hydrogen, oxygen and other gases. These will reach the melt through the atmosphere, casement wall, handling melting-pots, tools, etc. These elements are found in elementary form or in the form of compounds. Hydrogen is dissolved in the melt in either the atomic form or it creates bubbles in the molecular form. In liquid aluminium the hydrogen solubility is very high and with increasing temperature it increases significantly. Such dissolved hydrogen in the subsequent crystallization process of the alloy is excreted in form of bubbles or pores according to the equation [2]: [Malik 2012]

$$2Al + 3H_2O = Al_2O_3 + 3H_2 \quad (1)$$

From the above equation it is clear that the aluminium melt contamination can occur either by oxide inclusions of Al_2O_3, although oxides under favourable conditions may remain in oxide membrane on the surface of the melt, or by hydrogen which causes the formation of bubbles in the walls of the casting [Ruzbarsky 2014]. The pollution of aluminium alloys occurs by the formation of oxide inclusions and also through a variety of non-metallic particles. Of the oxides, it particularly concerns aluminium oxide Al_2O_3 with melting temperature of approx. 2000°C. Therefore, it will always occur in the solid state in aluminium alloys. The alumina is characterized by high hardness and fragility. Oxide membranes Al_2O_3 can due to their low specific weight float in the melt, and they reach the surface of the melt only with difficulty. There are two forms of oxides in the melt [Malik 2012]:

- form of large inclusions Al_2O_3,
- form of fine dispersed particles Al_2O_3,

The presence of oxides mainly in the form of large inclusions significantly reduces the values of strength, ductility, acts as a notch in the wall of the casting with consequent formation of cracks and subsequently a component fracture [10]. The melt, in addition to the above mentioned oxide impurities, can be degraded by foreign particles such as pieces of casement wall, various salts, debris, etc. [Malik 2012, Gaspar 2014].

2 EXPERIMENTAL METHDOLOGIES AND EQUIPMENT

The rods (Fig. 1) cast into a double foundry mould obtained after static tensile test intended for the evaluation of mechanical properties presented by an ultimate tensile strength and ductility were subjected to the experimental analysis concerning the nature of the fracture process and the evaluation of casting defects.

Figure 1. Test rod with the fracture area

These experimental samples were cast at different plunger speeds in the filling chamber of die casting machine with a horizontally arranged filling chamber. It concerns a die casting machine of Bühler Classic B66D type. Melt dosage was carried out of the pneumatic maintenance and dosing furnace Stotek - Dosotherm 800. Mould treatment was performed by treat equipment Wollin with an agent Dascocast in proportion 1:100 and lubrication of the pressing plunger in the pressing chamber with an agent Metalstar FE82.

In the implementation of the experiment the following constant and variable technological factors were determined:

Constant technological factors:

- melt temperature: 720 °C
- mould temperature: 220 °C
- resistance pressure 16 MPa
- chamber diameter: 70 mm
- chamber length: 560 mm
- casting solidification time: 5.3 s
- height of the metal residue: 25 mm

Variable technological factor:

- pressing speed of a plunger: 1.6; 1.8; 2.0; 2.2 m.s^{-1}

At speeds less than 1.6 m.s^{-1} there was a lack of the mould run-in and at speed higher than 2.2 m.s^{-1} there occurred flashes in a parting mould of the pressure foundry mould under the influence of high kinetic energy of the melt flow.

Static tension test was conducted under the standard STN 42000-1 at ambient temperature during test implementation of 23 ± 0.5 ºC on the equipment ZDM 30/10, at the speed of the jaws shift at 10 mm. min.$^{-1}$. Subsequently, ductility test was evaluated on these rods.

Macroscopic analysis for the evaluation of the fracture process analysis and the effect of the cavity filling mode was conducted on microscope NEOPHOT 21. Micrographic analysis of determining the type and extent of internal casting defects was performed on scanning electron microscope JEOL JSM 35CS.

3 CHEMICAL COMPOSITION ANALYSIS

Chemical composition of experimental melting was determined on spectrometer SPECTROCAST and evaluated out of the average of five sparkings and complies with EN 1706, Tab. 1.

Table 1. Chemical composition of experimental melting of the alloy used % of elements content

Al	*Si*	*Fe*	*Cu*	*Mn*	*Mg*
85.27	12.02	0.71	1.19	0.21	0.13
according to EN 1706 (STN 424310)					
the rest	10.5 - 13.5	max. 1.5	0.7 - 1.2	max. 0.55	max. 0.35
Cr	*Ni*	*Zn*	*Pb*	*Sn*	*Ti*
0.02	0.02	0.35	0.02	0.03	0.03
according to EN 1706 (STN 424310)					
max. 0.1	max. 0.3	max. 0.55	max. 0.2	max. 0.1	max. 0.2

4 MECHANICAL COMPOSITION ANALYSIS

Tab. 2 shows the values of the arithmetic average out of ten test samples in regard to the observed mechanical properties presented by an ultimate tensile strength and ductility.

Table 2. Arithmetic average values of the obtained mechanical properties

Plunger pressing speed [m.s^{-1}]	Mechanical properties values	
	Ultimate tensile strength R_m [MPa]	Ductility A_5 [%]
1.6	178	1.8
1.8	191	2.0
2.0	214	2.2
2.2	203	2.0

5 FRACTURE PROCESS ANALYSIS

Fig. 2 documents macroscopic view of the fracture area. A fraction of the analysed samples is of fragile nature and performs in a plane perpendicular to the axis of the test rod in which the tensile strength operates.

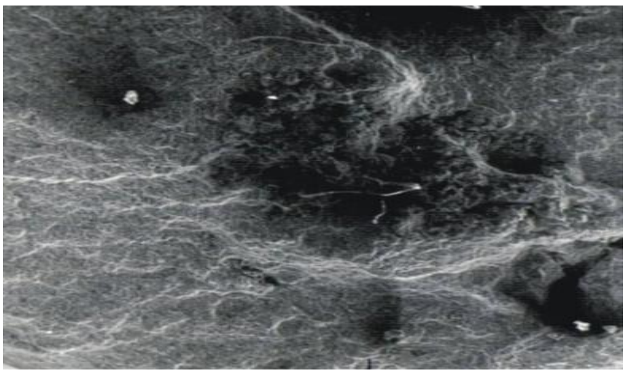

Figure 2. View of the fracture area /10x/

Initiation of a fracture emergence of such nature is a large amount of low plastic elements in the alloy. In Al - Si alloys such a group of low plastic elements include eutectic silicon which will not support a substantial plastic deformation of α - phase dendrites. Under load of test rods with tensile strength there occurs a fragile fracture. Control mechanism of such low energy ductile tearing is fission of eutectic silicon. Mechanism of α - phase dendrites and eutectic disturbance is documented in Fig. 3.

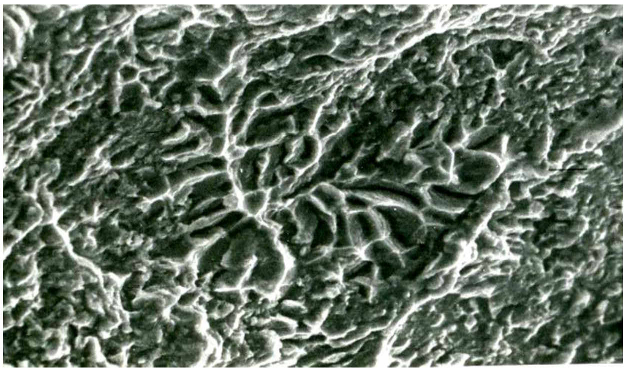

Figure 3. Mechanism of α - phase dendrites and eutectic disturbance/250x/

Mechanism of α - phase dendrites and eutectic disturbance occurs at high plastic deformation of α - phase and it is reflected by the emergence of the fracture area of a ridgy appearance. Bright crooked ridges represent α - phase dendrites that surround individual uneven and deep basins. Formation of uneven and deep basins is initiated by eutectic contained in the volume between the secondary axes of α - phase dendrite. The initiation of disturbance in silumin matrix occurs in eutectic by separating α - Si interface or Si particles cracking. [Gaspar 2011]:

6 FOUNDRY DEFECTS ANALYSIS

In experimental analysis of internal foundry defects the following defects have been observed on the fracture areas of test rods:

- cavities with oxidized surface by oxide membrane Al_2O_3 situated in the interdendritic area,
- Al_2O_3 particles,
- internal cold laps.

Based on the conducted analyses of the cavities present in the samples, their morphology and oxidized surface of cavities by oxide membrane Al_2O_3 as a result of contact with the atmosphere in the process of casting the casting, these cavities are included into the category of exogenous bubbles. The initiation mechanism of exogenous bubbles formation and their distribution in the casting body is based on the capture and penetration of air and gases found in the gating system and in the mould cavity by the melt turbulence. View of exogenous bubbles area is documented in Fig. 4.

Another factor to be considered in this analysis is the ability of hydrogen to exclude after its dissolution in aluminium alloys in the molecular state in the form of endogenous bubbles. Subsequently, such excluded hydrogen can diffuse into empty spaces of the casting. The empty spaces in the casting are exogenous bubbles and contractions. With regard to thin-walledness of the castings, rapid procedure of the crystallization front, acting resistance pressure etc., the process of diffusing hydrogen into exogenous bubbles and contraction is unlikely. If hydrogen is excluded into an exogenous bubble it can react with gases contained in this bubble and if it is reflected in endogenous bubbleness of the casting or it diffuses into the interdendritic areas the surface of dendrites should remain clean and free of the reaction products. Clean dendrites in the analysed samples have not been observed.

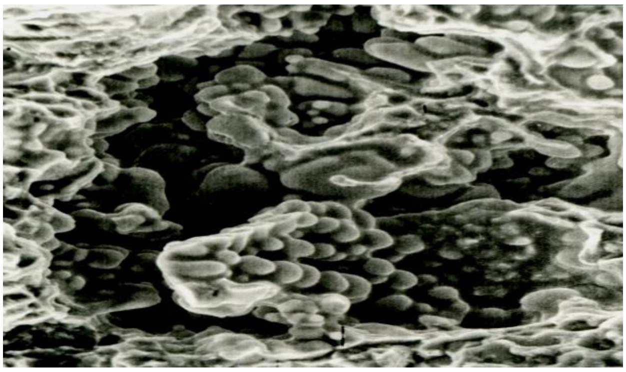

Figure 4. Area with exogenous bubbles

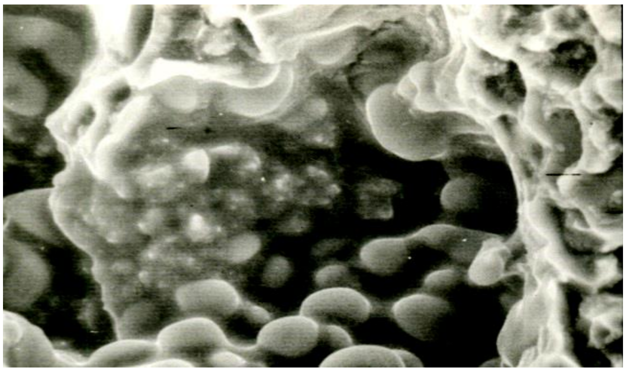

Figure 5. Detail of Figure 4

Other defects observed on the fracture areas of the test rods have been oxide inclusions formed by Al_2O_3 particles. Fig. 6 documents Al_2O_3 particles occurring separately.

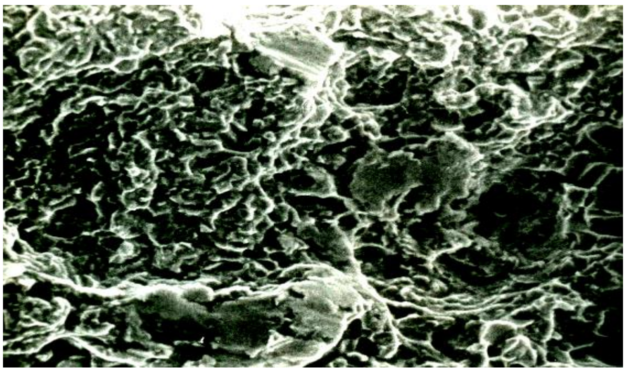

Figure 6. Separated Al_2O_3 particles

Fig. 8 shows a cluster of Al_2O_3 particles. Under the influence of Al_2O_3 particles the material under load is de-cohesively damaged because in the area of the casting where the oxide inclusions are present in the form of documented particles the cohesion of material is vanishing. Al_2O_3 particles are significantly reducing the value of strength and ductility compared with bubbles.

Figure 7. Cluster of Al_2O_3 particles

The origin of Al_2O_3 particles in the melt can be dual. If the metal oxidized during the casting process with high turbulence in the structure the Al_2O_3 particles separated or arranged in clusters of various shapes and sizes can be observed as documented in Fig. 6 and Fig. 7. In case of the melt contamination by surface oxidation on the surface of the molten metal oxide Al_2O_3 inclusions are manifested in the form of thin membranes. Fig. 8 shows an overall view of the area of internal cold laps. The oxide membrane on the surface of the melt flow indicates its turbulence which is clear on details. The prevalent length of a crooked line runs along the edge of dendrites of - solid solution.

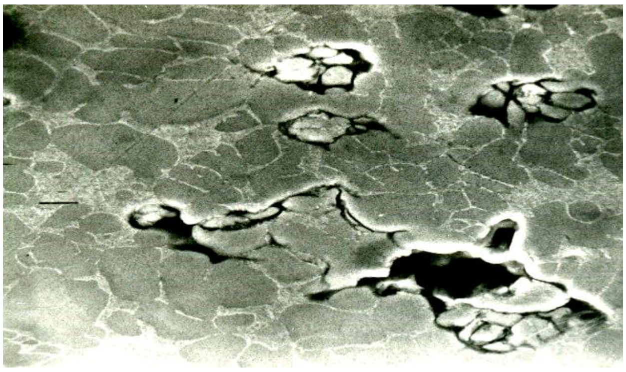

Figure 8. Area of internal cold laps

7 CONCLUSIONS

Increased attention of castings cast under pressure is given to the internal quality of the castings which is characterized by type and extent of foundry defects. The structure of foundry alloys is a determining factor of the casting properties and in terms of operational reliability a factor limiting the distribution of foundry defects in the casting. The most important parameter is the quality of the casting alloy after refining and its temperature which also affects the final quality of the casting. Temperature of the molten alloy during casting of aluminium alloys should only be in tight values above the liquid temperature which provide perfect filling of the mould cavity due to the high affinity of aluminium to oxygen. Affinity of aluminium to oxygen causes the formation of oxide inclusions which, together with the solubility of hydrogen, represent an important cause of rejects and loss in production. Based on the experimental analysis of internal defects of die castings it can be concluded that among the most common internal defects affecting the quality properties of the casting include cavities with oxidized surface membrane of oxide Al_2O_3 situated on the interdendritic space that are classified in the category of exogenous bubbles and Al_2O_3 particles often in combination with internal cold laps. These defects arise from a variety of conditions of melting, casting and solidification of the casting in the mould. For this reason a careful preparation of the melt, its consistent treatment and refining is necessary.

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CONTACTS:

Assoc. Prof. M.Sc. Stefan Gaspar, PhD.
Prof. M.Sc. Jan Pasko, PhD.
Technical University of Kosice
Faculty of Manufacturing Technologies with a seat in Presov
Department of Design Technical Systems
Bayerova 1, 080 01, Presov, Slovak Republic
Tel.: +421 51 772 2604
e-mail: stefan.gaspar@tuke.sk,
e-mail: jan.pasko@tuke.sk
www.tuke.sk