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Failure analysis of dies for aluminium alloys die-casting

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Abstract: Dies for aluminium alloys die-casting fail because of a great number of a different and simultaneously operating factors. Die design, material selection, and thermal stress fatigue due to the cyclic working process, as well as to low and inhomogeneous initial die temperature contribute to the failures and cracks formation on/in dies.
In the frame of the presented work the intensity and homogeneity of the temperature fields on the working surface of the testing die were checked through thermographic measurements, and failures and cracks on the working surface of the die were analysed by the non-destructive metallographic examination methods.

Keywords: Technologica sciences, Materials technology, Casting

1. INTRODUCTION

Die-casting is the most economical and technical easy process of casting very sophisticated and precise aluminium products of big-scale series [1]. Comparison of nine parameters of the die-casting versus stamping, forging, sand casting, permanent mold casting and plastic molding is presented in Tab. 1.

Aluminium die-castings are made for final installation, and need very little machining. They are used in automotive industry, household appliences, electrical industry and instalations, fittings, etc. [3].

2. THEORETICAL

Aluminium die-casting dies fail because of a number of different and simultaneously operating stresses. The stresses are of two basic kinds [4]: the first which are created during the manufacturing of the die, and the second which are produced during exploatation process.
For economical production of aluminium and its alloys die-castings it is important that the dies have a long working life. The replacement of a die is expensive in both: money and production time. The most frequent failures of aluminium die-casting dies are [1,2]: heat checking, gross cracking or cleavage cracking, cracking in corners, sharp radii, or sharp edges, and wear or erosion.

Table 1.
Comparison of nine parameters of the die-casting vs other processes [2]

	Compared with				
Nine points of comparison	Stampings	Forgings	Sand castings	Permanent mold castings	Plastic molding
1 Cost	Lower machining	Lower final	Lower production and machining	Lower labor, production and machining	Generally higher
2 Design flexibility	More complex shapes	More complex shapes	Thinner wall sections possible	Thinner wall sections possible, less draft required	Much greater
3 Functional versatility	Better designs possible	More versatile with less machining	More versatile with less machining	More versatile with less machining	Many more uses
4 Tolerances	Closer	Closer	Closer	Closer	Closer
5 Wall thickness	Greater variations	Thinner sections	Thinner sections	Thinner sections	Thinner sections for the same strength
6 Surface finish	Wider variety	Smoother	Smoother	Smoother	Wider variety
7 Material waste	Less	Less	Less	Less	Less
8 Strength	Depends on design	Lower tensile	Greater with same alloy	Greater with same alloy	Much greater
9 Weight	Depends on design	Lighter	Lighter	Less	Less

It is generally agreed that one of the principal causes of termination of die life is heat checking, which occurs through a process of crack initiation and propagation from the thermal stress fatigue induced on a die surface. Some of the factors that affect die failures may be controlled to some extent by the die-casting experts (designers, manufacturers and operators). These factors include [5]: design, materials selection, heat treatment, finishing operations, and handling and use.

When hot aluminium or its alloy strikes the active working surface of the die, the die expands and then contracts during cooling, as the heat in the casting is conduced into the steel bellow the surface of the die. The greater difference between the temperature of the die and that of the hot aluminium shot into the die, the greater will be the expansion and contraction of the die surface, and sooner the die surface will be heat check.

Since the stresses produced on the die surface are inversely proportional to the die temperature, it is good practice to run the dies as hot as is practical and/or economical. Aluminium die-casting dies should be preheated to approximately 240 to 300 ^{o}C. Experiences have shown that by increasing the die operating temperature from 205 to 315 ^{o}C, die production may be doubled [6].

3. EXPERIMENTAL WORK

In the frame of our investigation work a complex analysis of a typical dies for die-casting of aluminium alloys has been carried out. The fixed half of the testing die-casting die are shown in Fig. 1.

The die was made from the well known BOEHLER W300 ISODISC [7] hot work tool steel. This steel is mostly applied and considered material for all kinds of hot working dies.

Thermal and mechanical properties of BOEHLER W300 ISODISC steel are well known. Liquidus temperature of aluminium alloy AlSi9Cu3 is approximately 593°C, therefore the properties in the temperature interval from 20 up to the 700°C are important for the analysis of the discussed case. The density of BOEHLER W300 ISODISC steel at 20°C is approximately equal of 7800 kg/m^3, and it decreases with higher temperature. Up to the temperature of 700°C it drops for about 200 kg/m^3. It is very interesting that this steel has relatively low and nearly linear increasing heat conductivity (19.2 to 26.3 W/m·K), and proportionally constant thermal diffusivity (the whole time aproximately 5·10^{-6} m^2/s). Specific heat is increased with higher temperature to its values of 456 or 587 J/kg·K, respectively for the boundary values of the chosen temperature range. Linear coefficient of elongation slowly increases from 10.7·10^{-6} /K (at 20°C) to 13.2·10^{-6} /K (at 700°C), while modulus of elasticity, with boundary values of 211 and 168 GPa, decreases with the higher temperature.

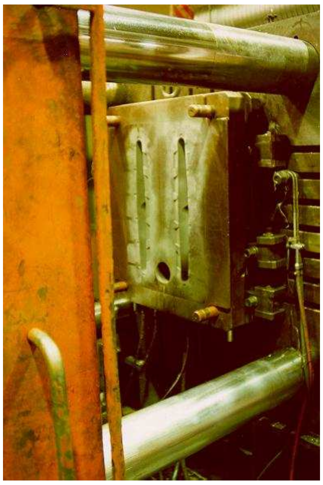

Figure 1. Fixed half of the die-casting die

By thermographic measurements the required intensity and homogeneity of the initial temperature field on the working surface of the fixed die half have been examinated. Testing thermographic measurements on the chosen die have been carried out due to the relatively simple geometry of the discussed die, so the simple heat images (thermographs) analysis have been performed. On the working surface of the fixed die half thermographic measurements have been carried out in the preheating period (Fig. 2) of the die heating to its initial operating temperature (240 ^{o}C and homogeneous through the whole working surface of the die).

The temperature fields between the working process have been measured, too. And two typical sequences of the die-casting process are presented in Fig. 3.

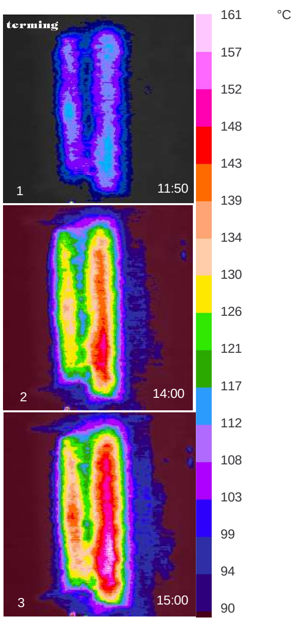

Figure 2. Working surface of the fixed part of die-casting die. Preheating process. Thermographs. At the beginning (1), after approx. 2 hours (2) and at the end (3 – initial temperature field) of the die preheating process

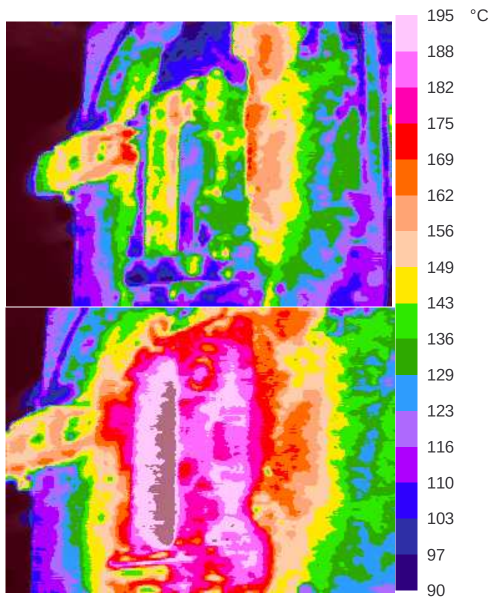

Figure 3. Working process. Thermographs. The fixed part of the die-casting die: working surface and casting (above), working surface without casting (below)

Thermographs (temperature images) in Fig. 2 are represented in the temperature range between 90 and 161°C, and in Fig. 3 in the range between 90 and 195°C, in both cases black (uncoloured) regions are below 90°C.

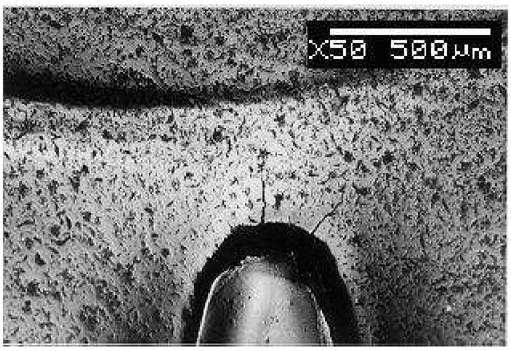

Figure 4. Working surface of the testing die-casting die. Surface crack and pits.

The cracks which appeared on the working surface of the fixed die half after less than thousand shots were revealed and identified by the use of penetrants. Some of them were also clearly seen by the use of magnifying glass or even by naked eye [9]. In the frame of our experimental work also non-destructive metallographic examination by optical microscope (OM) and by scanning electron microscopy (SEM) of polymeric replicas was applied.

The failures observed on the working surface (Fig. 4) belong to heat checking initiated at identification marks, and cracking in corners, sharp edges and transitions.

4. CONCLUSIONS

Cracking on/in die-casting dies for aluminium alloys is caused by a number of different and simultaneously operating factors. Some of them that affect die failures may be controlled to some extent by the die-casting experts.

In the experimental part of our work the failures on the working surface of the fixed half of the testing die for die-casting of aluminium alloys were observed with the use of non-destructive testing (NDT) methods: such as thermographic analysis, penetrants, and metallographic examination of polymeric replicas.

The failures observed on the working surface of the discussed fixed die half for die-casting of aluminium alloys belong to heat checking initiated at identification marks, and cracking in corners, sharp edges and transitions.

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