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THERMO-MECHANICAL CRACKING OF A NEW AND LASER REPAIR WELDED DIE CASTING DIE

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Preliminary Note – Prethodno priopćenje

The paper presents the analysis of thermo-mechanical fatigue cracking of die casting die during industrial use. An innovative, production friendly approach to monitor the surface crack dimensions was introduced, which is based on measuring defect-fin on the casting part. A new four moulds die casting die was monitored 40 000 cycles in order to complete the production series. The production was stopped three times for laser repair welding of cracks since the defect-fins were not acceptable. The defect-fin heights were measured every 1 000 cycles on the castings before and after repair welding of die surface cracks. The in-service die life can be prolonged with laser repair welding for several times, even thought that in-service die life for a particular repair varies.

Key words: high pressure die casting, laser welding, thermo-mechanical fatigue cracking, casting defect-fin

Termo-mehaničke pukotine uslijed toplinskog umora na novom i lasersko zavarenom alatu za tlačno lijevanje. U radu je prikazana analiza termo-mehaničkih pucanja kalupa za tlačno lijevanje tijekom industrijske upotrebe. Inovativni pristup praćenja dimenzija pukotina je uveden, koji temelji na mjerenju defekata na odljevku. Četiri nova kalupa za tlačni lijev su promatrana 40 000 ciklusa tj. jednu proizvodnu seriju. Proizvodnja je zaustavljena tri puta zbog laserskog zavarivanje pukotina na kalupu, jer su defekti na odljevku bili neprihvatljivi. Visina defekta mjerena je svakih 1 000 ciklusa na lijevanim dijelovima prije i nakon popravka pukotina laserskim zavarivanjem. Životna doba kalupa za tlačno lijevanje može se produžiti s laserskim zavarivanjem više puta, iako produženje životne dobe kalupa zavisi od kvalitete laserskog zavarivanja.

Ključne riječi: Tlačno lijevanje, lasersko zavarivanje, termo-mehaničke pukotine uslijed umora, defekti na odljevku

INTRODUCTION

The in-service life of die casting dies and injection moulding tools is correlated with the thermo-mechanical loads during production. The production of 300000 castings is a common series for die-casting industry and 1000000 mouldings for injection moulding industry [1, 2]. The in-service tool life is affected by (a) thermo-mechanical fatigue, which causes heat marks on the surface of the die, (b) corrosion and soldering of aluminium to the die surface, (c) erosion due to melt flow, and (d) catastrophic failures [1-8].

These defects are then reflected on casting parts as defects-fins, marks or burr. If these defects are in acceptable tolerances for the final product the die casting die is good even thought the surface has cracks or is eroded. If these defects are too extensive, each casting must be refurbished, or the die must be replaced by a new one or the die must be repaired by welding. The optimal choice depends on the series of castings to be produced, deadlines, costs of the new die and/or die repair, costs of workers, equipment, production space … The most economical is usually the repair of the die by weld cladding. The main advantages of repair welding are short downtime and cost efficiency compared to production of new tool part. Repair welding in general lowers the tool cost in the final part and enables higher added value to the die casting and injection moulding industry [9-12].

Good prediction of mould failure using numerical simulations is demanding due to many failure mechanisms that should be taken into account. An innovative industrial approach is presented, where monitoring of defect-fins on casting parts is done during production in order to predict the tool failure. A continuous monitoring of mould surface cracks is not possible during the production. But measuring the resulting defect-fin dimensions on castings is possible and already used during quality control to distinguish between good and bad castings. Measuring of these defect-fins growth could be used to estimate the size of mould defects like thermal fatigue cracks and consequently prediction of mould failure [13, 14].

The aim of this study was to monitor the defect-fins height on castings before and after repair welding of die casting die in order to predict the die in-service life time. A defect-fin height was measured and monitored at four locations on castings every 1000 cycles. Laser repair welding of mould surface cracks was done based on quality control personnel. A comparison between defect-fin growth for a new and laser repair welded mould

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Table 1 **Chemical composition of mould material, filler material and aluminium alloy [15-17].**

EN	Chemical composition / mas. %											
	C	Si	Mn	Cr	Mo	V	Fe	Cu	Mg	Zn	Ni	Al
X38CrMoV5-1	0,37	0,20	0,30	5,00	1,3	0,50	rest	-	-	-	-	-
Filler material	0,1	0,4	0,6	6,5	3,3	-	-	-	-	-	-	-
AlSi9Cu3	-	8-11	0,55	-	-	-	1,3	3,0	0,5	1,2	0,5	rest

was done. The results show that the in-service life time varies and depends on many factors.

EXPERIMENTAL WORK

Die casting die and processing

A four nest die casting die was made of Cr-Mo-V hot work tool steel X38CrMoV5.1 (Table 1). Moulds were hardened at 990 °C and tempered three times at 620 °C, 590 °C and 570 °C to achieve the hardness of 46 HRc (Figure 1).

The dies have run on a 8 MN cold chamber machine in industrial environment. The aluminium alloy AlSi9Cu3 with the chemical composition shown in table 1 was used for casting. The aluminium alloy AlSi9Cu3 was injected at temperature 680 °C into the mould. The die was closed for 25 s and opened for 35 s and the total cycle time was 60 s. The die was tempered to 200 °C. The die surfaces were lubricated before starting a new cycle. The weight of each casting was 332 g, the casting pressure was 50 MPa, filling time 23 ms and the entrance melt speed was around 52 m/s.

Laser repair welding

When the quality control manager find defect-fins around 0,35 mm in height, the die casting stopped and dies were sent to repair shop. After cleaning the die, the cracks were either mechanically and laser grooved or only laser grooved in the case of repairing small cracks. During grooving, a special attention was taken in order to fully remove the crack.

Laser beam cladding was done using pulsed 200 W laser equipment (Lasag Easy welder SLS CL 60) and a 0,5 mm diameter filler wire with the chemical composition shown in Table 1.

A ramped down pulse with pulse peak power of 2 kW, repetition rate of 15 Hz, pulse duration of 10 ms and pulse energy of 12,5 J was used for cladding. The welding speed was 16 cm/min, the focal length 160 mm and the focus of laser beam was on the mould surface. The argon gas at 8 l/min was used for shielding. The filler wire was fed manually. After the welding the welds on refurbished mould were manually grinded and polished. The mould was than mounted on a machine where it produced castings to complete the desired series.

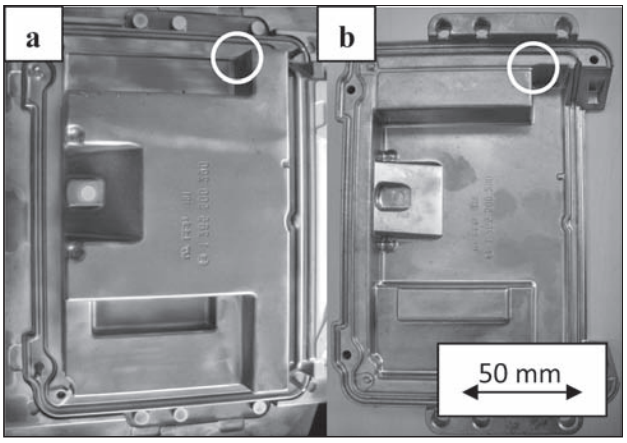

Figure 1 a) Mould and b) casted part with indicated observed location.

Defect-fin measurement

Casting defects-fins were measured using the profilometer Mitutoyo Contracer CV - 2000. The measurement stylus was dragged across the castings surfaces and the size and the shape of defect-fin cross-section was recorded (Figure 2). Maximum defect-fin heights (depths) were determined (Figure 2c).

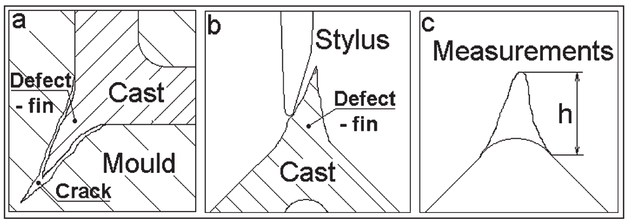

Figure 2 Schematic presentation of (a) die casting mould and casting, (b) measurement stylus drag across the castings surfaces, and (c) defect's-fin's height.

The measurements were done every 1 000 cycles up to 40 000 cycles at four equal dies on the most critical location in order to get the relationship between crack height and the number of die casting cycles.

RESULTS AND DISSCUSION

Measurement of the length of thermo-mechanical fatigue cracks on mould surfaces during the actual production run is practically impossible. Approx. measurement of crack length would be possible by sticking thin wires into the crack and measuring the penetration depth [8]. This could not be done without stopping the production. Another more precise way would be by cutting the tool and measuring the crack length on the prepared micro-sections (Figure 3). This is hardly affordable, since the die casting dies are very expensive [9]. Therefore, idea was to measure the defects-fins on the castings [7]. These defects-fins are basically the negatives of the cracks and other surface irregularities on the mould (Figure 1 – 5). The basis for this idea is that in industrial practice the tool fails when the mould starts to produce castings with defects-fins, which are no longer acceptable for the final product. In fact, the size of the casting defect-fin is a bit different from the corresponding mould defect-crack (Figure 3). The cause for this deviance could be in detection possibility of relatively wide cracks that are filled with melt during die casting. The thinner parts of cracks that can not be filled up are undetectable by this method of monitoring (Figure 3). Nevertheless, our innovative monitoring method can be used to continuously monitor the condition of die casting die in order to estimate and predict the time for changing or repairing the mould.

Figure 4 shows a complete history of defect-fin depth over the in-service lifetime of monitored die casting die. The die casting process was stopped there times for laser repair welding during the production of 40 000 cycles. First repair welding was done after completion of 14 000 cycles on moulds two and three. The reason for stopping and repairing the die was because the defect-fin depth (height) exceeded the unacceptable limit by a factor of two. At this time the crack was also repaired on the mould 3, which experienced a fast crack growth i.e. defect-fin growth at the beginning of die casting (Figure 4). A second stop of production was done after completing 28 000 cycles (Figure 4). At this time the moulds one, two and four were subjected to a laser repair. Shortly after that at 34 000 cycles the production stopped and the mould four was refurbished for the second time, after only 5 000 cycles (Figure 4). The reason for that could be in joining of two adjacent cracks, which joined together and produced a surface material in-between to be removed (Figure 3b). This mechanism of tearing of material between the cracks due to closeness is schematically presented on the figure 3b and 3c. Figure 3b shows two adjacent cracks which are growing together. If such surface cracks are subjected to additional thermo-mechanical cycling, the two cracks meet and the material in-between is removed from the surface. This causes tearing of material between the cracks due to closeness, which is causing widening of surface crack (Figure 3c).

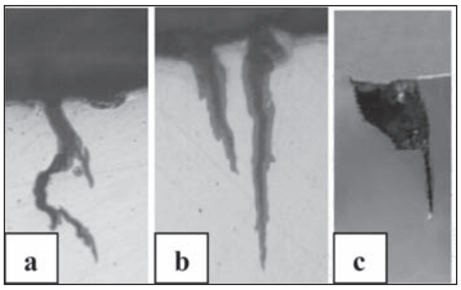

Figure 3 Typical thermal fatigue cracks.

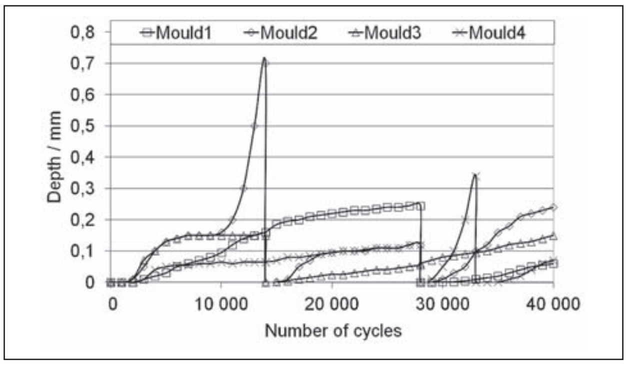

Figure 4 The depth of defect-fins throughout the die lifetime.

Figure 5 shows defect-fins on castings after a) 9 800 cycles and b) after 22 500 cycles. The observed location on mould 2 experienced fast crack growth shortly after 10 000 cycles (Figure 4 and 5a). The reason for that is in widening of surface crack due to joining of two adjacent cracks seen on Figure 5a. At casting from mould 4 only one small defect-fin is observed (Figure 4 and 5a), whereas at castings from mould 2 two bigger defect-fins are observed at 9 800 cycles (Figure 5a and 4). The moulds 2 and 3 were laser repaired after 14 000 cycles. After 22 500 cycles the cracks on the mould 2 have grown fast at the beginning and than steadily proceeded with growth. On castings form mould 2 two defect fins can be observed (Figure 5b). The laser repair done at mould 3 was very good, since a slow and steady crack growth is observed (Figure 4). Even at casting (Figure 5b, mould 3) a defect-fin is hardly observed.

As we mentioned, there are many factors influencing the crack i.e. defect-fin growth and even a few more if we are considering laser repair welding of tools. Usually a fast crack growth is observed when crack widening appears, i.e. when two adjacent cracks joins or meet. On repair welded moulds a faster crack growth could appear due to a) fatigue material or b) faulty repair (Figure 6a). In both cases removing of more material would be beneficial. Faulty repairs could happen if the surface cracks are going zigzag (Figure 3a and 6a) or are long

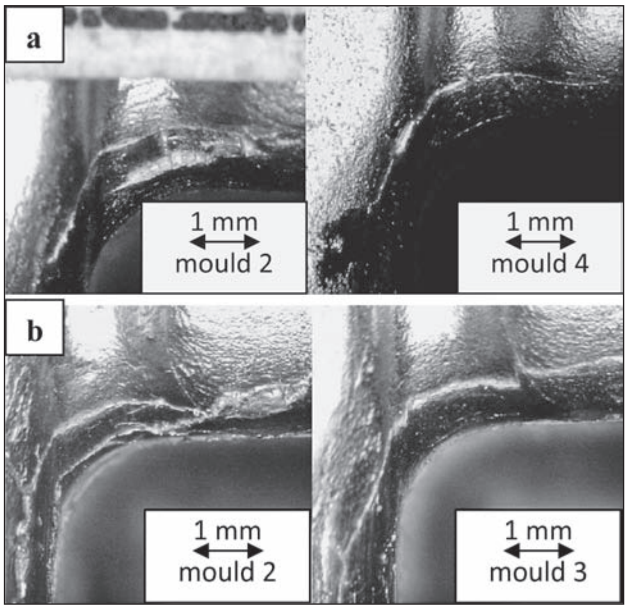

Figure 5 Defect-fins on observed location on castings after a) 9 800 cycles (mould 2 and 4) and b) after 22 500 cycles (mould 2 and 3).

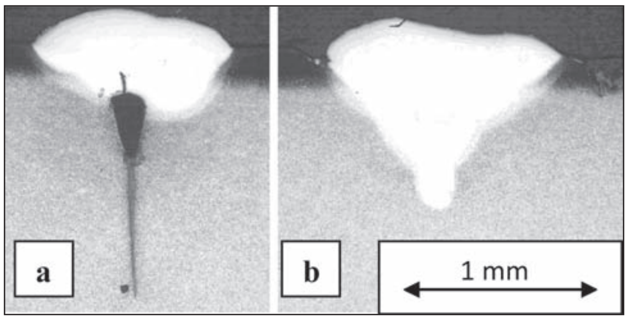

Figure 6 a) Faulty and b) quality repaired surface crack.

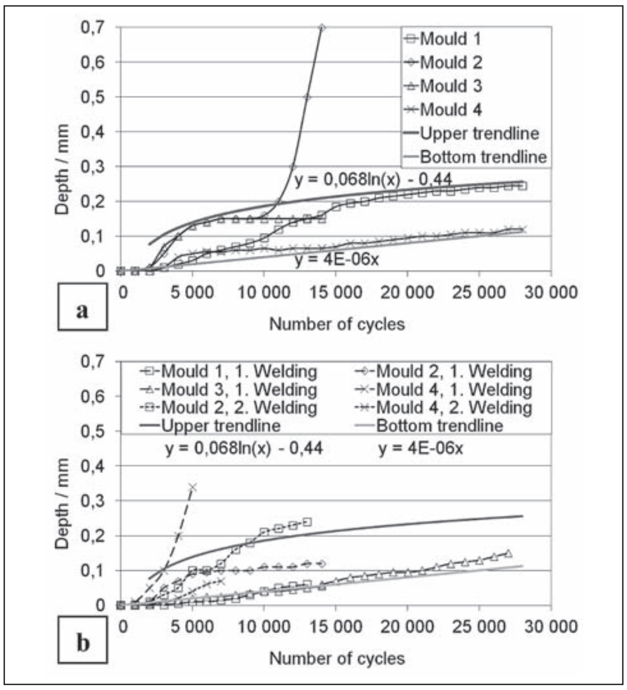

Figure 7 Defect-fin growths vs. number of cycles for a) new and b) repaired die.

(Figure 3b). In both cases after grinding and before laser repair welding the crack is not visible. If laser repair welding is done on the filthy crack, small cracks or porosity could appear in the weld metal. If this is not observed during the repair, a crack could quickly be opened (Figure 7b, mould 4, 2 welding).

Figure 7 shows defect-fin growths vs. number of cycles for a) new and b) repair welded die casting die. In both plots upper and bottom trend line is drawn and their equations are written. The area between this two trend lines indicates the frame of crack growth rate, where the majority of cracks will appear (for this tool material, heat treatment, die casting parameters, mould design and particular location with notch effect). If the crack growth rate is closer to the bottom trend line, the crack grow is slower and the mould lasts longer. If the crack growth rate is faster, it is closer to the upper trend line. If the crack growth rate exceeds the upper trend line (very fast) two adjacent cracks has most probably grew together, which caused crack widening.

CONCLUSIONS

Laser repair welding of damaged die casting die is appropriate technology for elimination of surface irregularities as cracks.

The following conclusions can be summarized:

- The crack growth rate for particular location and mould could be predicted to be between upper and lower trend line (Figure 7).
- If the crack grows at faster rates than indicated with upper trend line, two or more adjacent cracks joined and merged and caused the removal of surface material in-between the cracks.
- With the proper laser repair of damaged mould, the mould life could be extended for the same period or even more, and the repair could be done several times.
- If the repair is not done correctly, the extending of the mould lifetime is very short.

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Note: The responsible translator for English language is Urška Letonja, Moar.Prevajanje, Slovenia.