Tehran International Congress on Manufacturing Engineering (TICME2005)
December 12-15, 2005, Tehran, Iran

Effect of repair-welding parameters on life time of die casting moulds

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Abstract

In die casting, H13 hot working tool steels are exposed to heat shocking and cracking due to the thermal fatigue which is exerted by die casting process. The gradual destruction of mould surfaces during the service, decreases casting piece quality and limits the mould life time. These moulds are expensive and replacing of them is the main problem of the die casting industries therefore repair-welding of die casting moulds can be helpful. H13 steel has low weldability because of the significant hardening resulted from large amounts of alloying elements. Within this study, results were obtained on the performance of repair welded parts that were welded by three types of filler metals on the thermal fatigue test. The filler metals that are used in this study are H13 tool steel, maraging steel and Co-base alloy. Maximum and minimum life time of the repair welded parts of die casting mould in the thermal fatigue test were obtained from Co-base alloy and H13 hot work steel filler metals, respectively. Repair-welding by maraging filler metal shows the intermediate life time. It seems that repair-welding of H13 moulds by maraging filler metals is more economic because of its lower price in comparison with the Co-base filler metal.

Keywords: Die Casting Moulds; Thermal Fatigue; Repair-welding; Filler Metal.

1 Introduction

Today, high-quality die castings are usually produced using permanent metallic moulds in the gravity or pressure die-casting. Compared with sand casting, permanent moulds permit the high-volume production of more uniform castings, with closer dimensional tolerances, superior surface finishing and improved mechanical properties at relatively low cost for parts such as engine blocks, carburetor bodies, transmission cases, and valve bodies. Chromium-alloyed or

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maraging hot-working tool steels are heat-treated to the hardness of typically 29 to 48 HRC and are widely used for die casting dies [1–2].

Mould life is a major consideration in a die casting process because, depending on the complexity of the part being produced, a mould may cost more than US$ 100,000. Mould life may vary from 20,000 to over 250,000 parts depending on the casting procedure, casting alloy and the shape of products. During service life, the mould cavity and cores experience a large number of thermal cycles. Usually, commercial mould lubricants or mould release agents are sprayed each cycle on the mould surface, which reduce wear, act as a coolant, and facilitate the removal of the casting [3].

Wear and failure of moulds involve a complex interaction between various mechanisms. Thermal fatigue is the most important failure mode in die casting [1]. Thermal fatigue cracks may be classified by their appearance in heat media and stress cracks [4] (Fig. 1). The characteristic feature of heat shocking is a net-shaped crack pattern that occurs on the mould surfaces. Stress cracks mainly appear as individual and clearly pronounced cracks as a result of stress concentrations due to the configuration of the mould cavity [5]. Generally, thermal fatigue cracks will already have appeared after a few thousand cycles or even earlier, i.e. in the low cycle fatigue regime. The crack depth and the the openings (which are sometimes filled with molten metal) can be seen from the inset in Fig. 1.

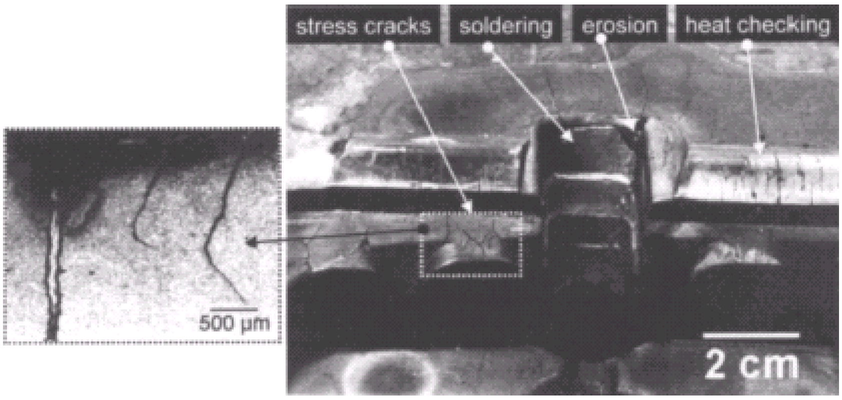

Fig. 1. Damage mechanisms in aluminum die casting (the inset on the left shows a scanning electron microscope cross-section of the mould on the right with thermal fatigue cracks) [5].

Furthermore, gross cracks may be due to thermal shocks or mechanical overloadings that are often leading to total failure of the mould. Mould maintenance may be done by the grinding or welding when the castings surface quality or dimensions are no longer sufficient [5]. However, the tool and service costs constitute a remarkable part of the production costs in die casting and there are numerous approaches to repair welding of these moulds. In general, mould life time may be enhanced by geometric factors in the mould design (governing stresses and thermal gradients), the mould material considerations (e.g. machinability, heat treatment, toughness, wear resistance and heat checking), processing conditions (e.g. preheating, heating and cooling cycles, machine closing force, lubricants, service intervals), and mould surface considerations [1-6].

Repair welding of a damaged mould is the best approach to have an extra life time of die casting moulds. However, welding of this type of steel is difficult because of the significant hardening resulted from large amounts of alloying elements. In recent years, the application of Co-base alloy filler metals has been reported in the literature. [3,7-17]. The aim of this paper is to present and to discuss the results that are obtained on repair-welded parts of moulds in the thermal fatigue test.

2 Experimental details

H13 hot work steel plates was uses to repair-welding. Elemental analysis of this steel is seen in table 1.

Table 1: Elemental analysis of H13 steel in weight percent.

C		Mn		P	S	Si		Cr		V		Mo	
Min	max	min	max	max	max	min	max	min	max	min	max	min	max
0.32	0.45	0.2	0.6	0.03	0.03	0.8	1.26	4.75	5.5	0.8	1.2	1.10	1.75

It can be seen in table 1 that the Cr, Mo and V are the major alloying elements of H13 steel. Because of these elements, H13 steel has a great high temperature resistance and is the first choice for die casting moulds [17].
Repair-welding was done by using Gas Tungsten Arc Welding (GTAW) method. Repair-welding parameters are represented in table 2.

Table 2: Repair welding description of H13 hot work steel

Welding Current (A)	120
Voltage (V)	36
Welding Speed (mm/sec)	2.5
Preheat Temperature (°C)	150
Argon Flow Rate (Lit/min)	10

Because of alloying elements of this type of steel and its high hardenability, heating and cooling rate of welding is very important. For repair-welding of H13 steel, it was prefered to decrease the rate of cooling and heating. Three parameters affect the welding cooling and heating rate [19]:

(1) Welding current; is the most important parameter that controls the heating and cooling rate of welding cycle. For this reason we must use the least possible welding current. This can be obtained by choosing 120 (A).
(2) Preheating that decreases the cooling rate of welding cycle.
(3) Welding speed.

In this study we work on effect of filler metals on the life time of die casting moulds. H13 and maraging rods are used for repair-welding of H13 die casting mould steel. Three types of filler metals were studied in this paper; (1) H13 hot work steel filler metal that has the same analysis with the base metal; (2) Maraging steel filler metal; (3) Co-base alloy filler metal because of its high heat resistance. The analysis of maraging steel and Co base alloy filler metals are presented in table 3.

Table 3: Elemental analysis of maraging steel (a) and Co-base alloy filler metals (b) in weight percent.

(a)

C	Si	Mn	P & S	Ni	Co	Mo	Ti	Al	Fe
0.03≤	0.1≤	0.1≤	0.01≤	18	11.8	4.6	1.35	0.1	Balance

(b)

C	Si	Mn	Fe	Ni	Cr	W	Co
0.1	0. 3	1.5	2	10	20	15	51.1

After the repair-welding of H13 plates by these three filler metals, thermal fatigue test was applied on the specimens. In the thermal fatigue test the specimen was heated by oxyacetylene flame and cooled in water bath immediately. Maximum and minimum temperatures were 700 and 25 ^{O}C, respectively. The maximum temperature was chose according to thermal fatigue property of H13 steel. Under this temperature thermal fatigue cycles for H13 steel are so long [17] and enter some errors in the thermal fatigue tests. The thermal fatigue test device is illustrated in fig. 2. In this device, there are four specimen holders. By rotating this system, the specimen that was exposed by flame, is steeping into the water bath and the other one is exposing by the flame. Thermal cycle of this device was counted by a counter that can be seen in figure 2.

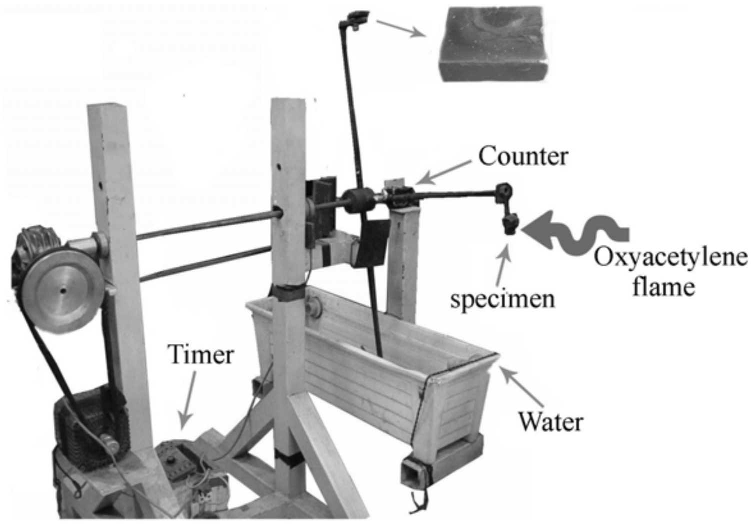

Fig. 2. Thermal fatigue test setup.

After cracking, the specimen was removed from the device. The surface of the specimens were prepared by polishing and etching for studying the thermal fatigue cracks by scanning electron microscopy (SEM).

3 Results and Discussion

The number of thermal cycles that resulted to the crack initiation in the welded specimens by three types of filler metals are illustrated in fig. 3. In this figure, it can be seen that Co-base and H13 steel filler metal have the maximum and minimum thermal fatige life time, respectively.

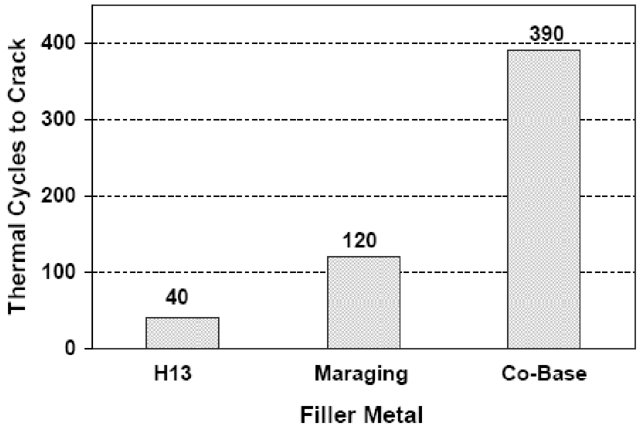

Fig. 3. Thermal cycles to Crack due to the thermal fatigue.

It seems that the high creep strength of Co-base filler metals at elevated temperatures is resulted in the higher thermal fatigue resistance of the repair-welded specimens. There are some hard and dispersed carbide particles in the microstructure of the weld metal of the specimen that is welded by Co-base filler metal. Therefore, this microstrucrure may cause the higher life time of these specimens. Also it can be seen that the entire thermal fatigue crack was started and propagated in grain boundaries (figure 4).

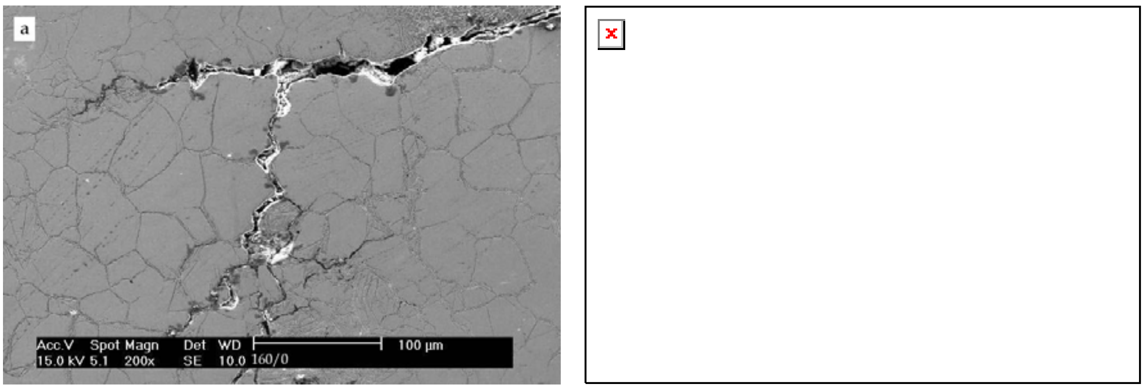

Fig. 4. The SEM images of thermal fatigue cracks of repair-welded specimens that were welded by (a) maraging (b) Co-base filler metals.

This is because of low strength of grain boundaries in addition to grain boundary migration, and the diffusion of molten metal into them in high temperatures. In the specimen that is welded by Co-base alloys, because of hard and dispersed carbide particles, the grain boundaries have a higher strength and also their migration is minimized. Therefore, thermal fatigue mechanism was delayed and life time of die casting moulds will increase.

It can be seen from fig. 3 that the the specimen was welded by maraging filler metal has relatively good thermal fatigue life time. Maraging steels have a martensitic microstructure, and because of this microstructure grain boundary crack that is due to thermal fatigue, can not be propagated easily. Also the martensitic microstructure will temper due to thermal cycles but this tempered martensite has a great strength and ductility to thermal stresses and distortions.
Finally, H13 filler metal have a low tensile and creep strength with respect to the other filler metals and therefore does not have good thermal fatigue properties.
The Coefficient of Thermal Expansion (CTE) of the weld metal in the H13 filler metal specimen is near to CTE of the H13 base metal. Therefore, there will not remain any residual stresses in the fusion line due to thermal cycles. In the specimens that were welded by Co-base and maraging filler metals due to the large difference between the CTE of the weld metal and the base metal, the fusion-line cracking can be seen this (fig. 5).
For avoiding this Phenomenon when dissimilar filler metal is used, we can use repair-welding with low dilution in the primary passes and with the high dilution in the later passes.

Fig. 5. Fusion-line cracks in the specimen that was welded by Co-base filler metal.

4 Conclusions

Repair-welding of the die casting moulds by Co-base alloy and maraging steel filler metals have been proven to increase the lifetime by several hundreds of percent due to an increase of the thermal fatigue limit. The best performance has been obtained for Co-base alloy filler metal showing a maximum resistance to thermal fatigue. It was seen that, there is a tendency to form a fusion-line cracks in the specimens that were welded by Co-base and maraging steel filler metals. This is due to the large difference between CTE of the weld metal with respect to the base metal. Finally, by the results of this research, use of Co-base filler metals proposed for higher thermal fatige life time but in the economic point of view, using maraging filler metals for repair-welding of the H13 die casting moulds is a suitable alternative.

Acknowledgement

The authors would like to thank Mr. A.R Etemadi for scientific and technical assistances and the personnel of the aluminium casting branch in the

IRANKHODRO Co. (IKCO). This work is supported by the casting department of IKCO.

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