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Thermo-mechanical fatigue test of a wrought Co-based alloy as potential tooling material for die casting

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ABSTRACT

Thermo-mechanical fatigue (TMF) test of a wrought Co–Cr–Mo alloy was investigated and Co-based alloy showed superior TMF properties than the control sample of a hot work tool steel. During TMF test, high oxidation resistance and increased hardness were observed in the Co-based alloy in contrast to the low oxidation resistance and decreased hardness in the tool steel. The γ-phase-to-ε-phase transformation of the Co-based alloy was considered as the main hardening factor during the TMF test.

1. Introduction

Die casting is a near net-shaped process that has been widely applied to produce the non-ferrous alloys (such as Al, Mg, Cu, and Zn based alloys) with high strength, close tolerance, complex shape, various surface finishing, and high manufacturing rate [1–3]. However, the high efficiency of this casting technique has to be guaranteed by the high performance of molds (called dies) to withstand the severe conditions in service. The elevated temperature, wear, molten metal corrosion and the thermo-mechanical fatigue (TMF, induced by the cyclic thermo-mechanical loading during die casting cycles) are the major threats to the durability of molds. Surface of molds would be gradually destroyed by these attacks, giving rise to both the decrease in quality of cast parts and the early failure of molds. Currently, hot work tool steels are mainly adopted as tooling materials for die casting due to their superior mechanical properties; however, their low resistance to molten metal corrosion and TMF cracking are the urgent problems having to be resolved in the die casting industry [4–7]. Various techniques such as surface treatments and coatings have been applied to tool steels with the purpose of enhancing the resistance to wear and molten metal corrosion [8–10]; however the TMF properties were significantly deteriorated by the surface treatments [11,12]. Since tooling accounts for a great part of the total cost of the final die casting products, the tooling materials with longer service life are extremely effective in reducing the manufacturing cost in die casting industry.

On the other hand, Co-based alloys have been widely applied to withstand severe conditions for more than a century, because of their excellent wear resistance, heat resistance and corrosion resistance [13–15]. Recently, by virtue of some unique properties as compared with tool steels, Co-based alloys have been considered to be the promising tooling materials for die casting. Mihelich et al. [16] reported that Co–Cr alloys showed much higher corrosion/erosion resistance to molten Al alloy than both tool steels and Ni-based alloys. Quite recently, aiming at developing novel high temperature tooling materials for the thixoforming (a forming technology similar to die casting) of Al alloys, Mg alloys and steels, a series of works were carried out by Birol [17–19] on the thermal fatigue tests of Co–Cr alloys, Ni-based alloys and tool steels. The results indicated that Co–Cr alloys showed the highest resistance to the thermal fatigue cracking among the tested alloys and this high performance was ascribed to their high resistance to both oxidation and temper softening [17,18]. Especially, the compact oxide film, which formed on the surface of Co–Cr alloys, not only the enhanced resistance to oxidation and thermal fatigue cracking as mentioned above [17,18], but also significantly improved the resistance to molten Al corrosion according to our previous researches [20,21]. Therefore, by virtue of their superior resistance to thermal fatigue cracking and molten metal corrosion

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as compared with the currently used tool steels, Co-based alloys are considered as the prospective tooling materials in die casting and the other industry with similar service environments.

Nevertheless, very few researches were reported on the TMF tests of Co-based alloys. Birol [17–19] well revealed the superior thermal fatigue properties of Co-based alloys; however, the test system was inadequate to simulate the service environments of the die casting tools due to that the cyclic mechanical loading was not taken into account. In addition, Birol mainly investigated the thermal fatigue behavior of Co-based alloy with typical cast structure, and so far, there is no report on the TMF tests of the wrought Co-based alloys, even though their properties were expected to be higher than the corresponding cast alloys owing to the modified microstructure. In this study, for the development of a novel Co-based tooling material for die casting, the TMF test of a wrought Co–Cr–Mo alloy was carried out under programmed cycles of both temperature and mechanical strain, and the superior TMF life of this Co-based alloy was presented with the comparison of the tool steel for the first time.

2. Materials and experiments

A wrought Co–28Cr–6Mo alloy (⌀22 mm, supplied by Eiwa Co., Ltd., Japan) was adopted for TMF test with the comparison of the SKD61 tool steel (⌀19 mm, supplied by Daido Steel Co., Ltd., Japan). Their chemical compositions were tabulated in Table 1.

Table 1
Chemical compositions of tested materials (wt%).

Alloy	Co	Fe	Cr	Mo	Si	Mn	V	N	C
Co–Cr–Mo	Balance	0.02	28	6	0.5	0.6	–	0.12	0.04
SKD61	–	Balance	5	1.25	1	≤ 0.5	1	–	0.36

SKD61 is a tool steel grade in Japanese Industrial Standards (JIS), and its equivalent grade in American Society for Testing and Materials (ASTM) is H13.

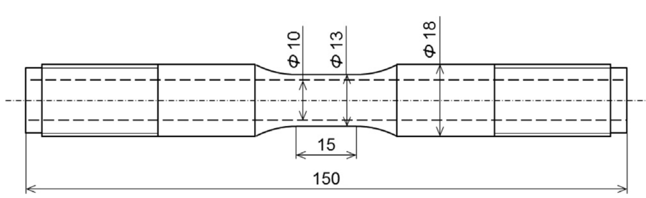

Fig. 1. The geometry of the tubular specimen.

For TMF tests, the bars of the test materials were machined into the tubular specimen with the geometry as shown in Fig. 1. The TMF tests were carried out with Instron 8862 tester (Fig. 2). During TMF tests, the specimen was heated with an external induction coil and internal cooled with compressed air. An R-type thermocouple and a strain gauge were applied to monitor the temperature and strain, respectively. The conditions of TMF test were set as an out-of-phase program according to die casting cycle in industry (Fig. 3). The temperature (400–700 °C) and the mechanical strain (−0.1% to 0.1%) changed linearly in the program (32 s/cycle), and

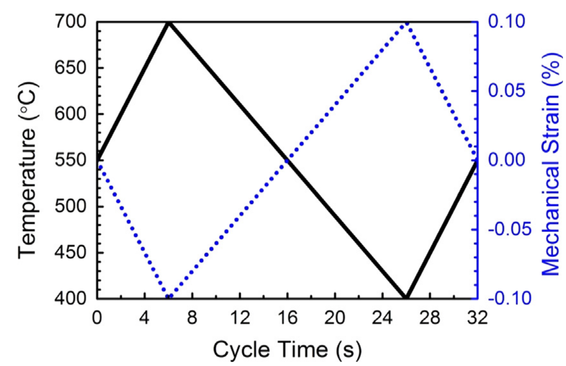

Fig. 3. The out-of-phase program with triangle waves of temperature and mechanical strain.

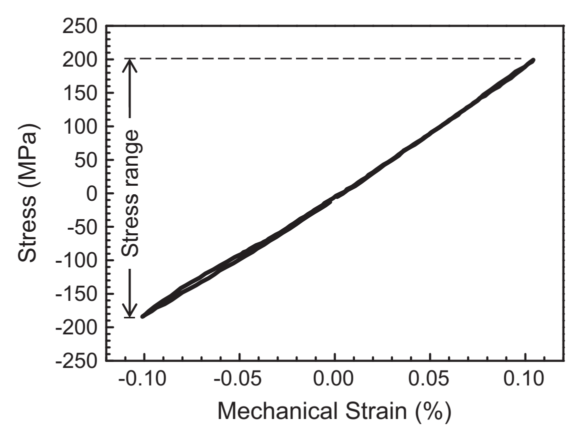

Fig. 4. Typical stress–strain loop of the Co–Cr–Mo alloy during TMF test. The stress range (as indicated) of each TMF cycle was recorded by the tester automatically.

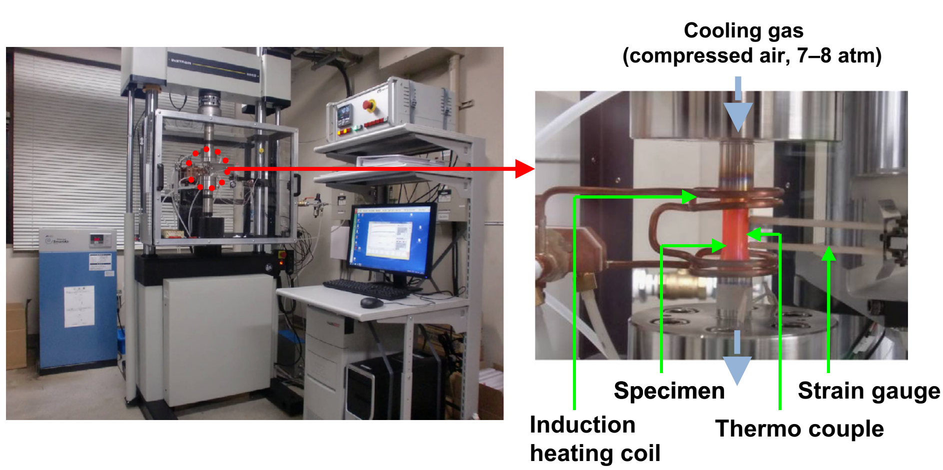

Fig. 2. The Instron 8862 TMF tester. The specimen was heated with the induction heating coil and cooled with the compressed air. The temperature was monitored with a thermocouple and the strain was measured with a strain gauge.