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Thermal stress analysis for an aluminum die cast die

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ABSTRACT: In this study, the thermo-elastic behavior of an aluminum die cast die during the casting process is analyzed. The cyclic symmetry nature of the die geometry offers a simplified reduced model for the finite element simulation. It is assumed that the temperature distribution on the molten metal affected boundaries follows a smooth function variation while the free surfaces of the die experience a convection heat transfer type. Considering a particular boundary condition, the results of the current study conform to the available analytical solutions. A detailed sensitivity analysis is conducted to highlight the effects of die preheat, groove corner radius of curvature and the thermal barrier coatings. The results indicate that the die preheating before the casting process can significantly decrease the stress level within the system. Also, an increase in the radius of curvature for the groove corners may result in a 25% reduction of the von Mises stress around these crack susceptible zones. Application of hard chromium or a silicon nitride thermal barrier coating considerably increases the thermal shock strength of the die such that a 0.1mm thick hard chromium coating can decrease the maximum von Mises stress about 49% with respect to the non-coated specimen. Especially for a functionally graded coating type, the reduction in maximum von Mises stress is around 70% compared to the non-coated specimen.

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1- Introduction

Die casting is a common manufacturing process to produce mechanical parts which meet high surface finish and dimensional consistency. On the other hand, the die may experience significant thermo-elastic distortion due to the cycling thermal loading. The cyclic plastic strain and the thermal shock may result in surface cracking and the failure of the die [1].

Several studies have been conducted to explore the die cast die behavior under various thermo-mechanical loadings. Gorbach et al. [2] experimentally studied the thermal fatigue phenomenon of aluminum die cast die. Their results indicate that the material properties, the heat transfer rate and the temperature variation have a pronounced effect on the thermal stresses. Srivastava et al. [3] employed the finite element analysis to investigate the fatigue crack growth pattern in die cast die and showed that the perpendicular edge cracks are the most frequent scenario.

Fazarinc et al. [4] investigated the thermal fatigue life of the functionally graded coating applied to the die casting dies. Their experimental study indicates that the chemical composition of the surface layer has the most dominant effect on the thermal fatigue life. Cha [5] examined the efficiency of various coating types applied to the die casting die. He concluded that TiAl/Cr/SiC/N coating type has the lowest adhesion to the aluminum and sustainable failure strength at very high temperatures. Peter et al. [6] analyzed the effectiveness of the thermal barrier coating for the aluminum die cast dies. According to their results, the nickel alloy barrier coatings offer the highest wear strength and the lowest friction coefficient as compared to the zirconia ceramic coatings.

The thermo- elastic behavior of an industrial aluminum die casting die will be investigated in this paper. The main objective of current study is to determine the localized stress concentration and the crack susceptible areas. Moreover, the sensitivity of the thermo- elastic field is analyzed due to the preheat temperature, the curvature of the groove edges and the surface coating.

2- Problem Statement

The schematic of the industrial die is given in Fig. 1. The die experiences a cyclic pressurized molten aluminum flow at a temperature of 650°C. The cyclic thermal shock will result in surface cracks. Fig. 1 also presents the cyclic symmetry of the die geometry hence one-seventh of the model is simulated via the finite element method.

The finite element model corresponding to the thermal boundary conditions of Fig. 1 is prepared in Abaqus software. It is assumed that the temperature variation of the molten metal affected boundaries (red dashed lines in Fig. 1) follows a smooth distribution as:

$$T = B_0 + (B_1 - B_0)\left(\frac{t}{t_e}\right)^3\left(10 - 15\frac{t}{t_e} + 6\left(\frac{t}{t_e}\right)^2\right) \tag{1}$$

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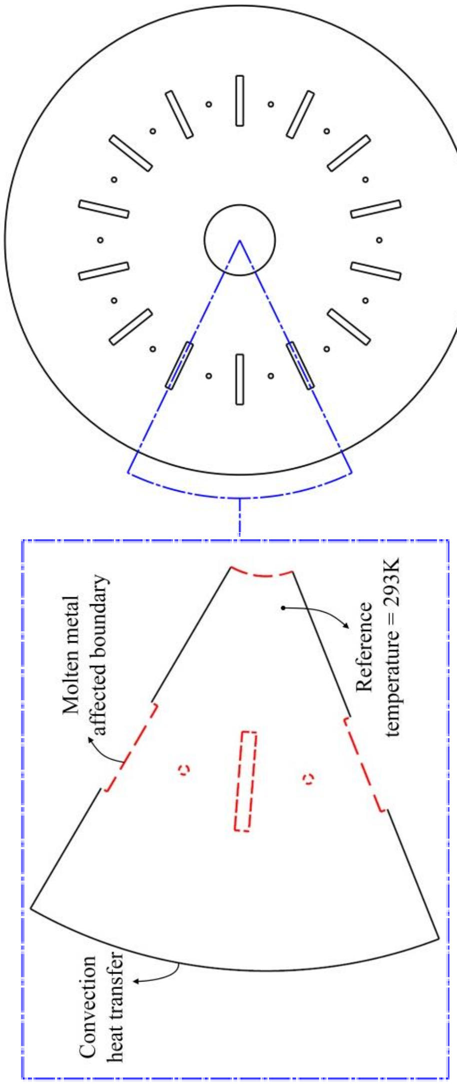

Fig. 1. The schematic, the cyclic symmetry and the thermal boundary conditions of the die

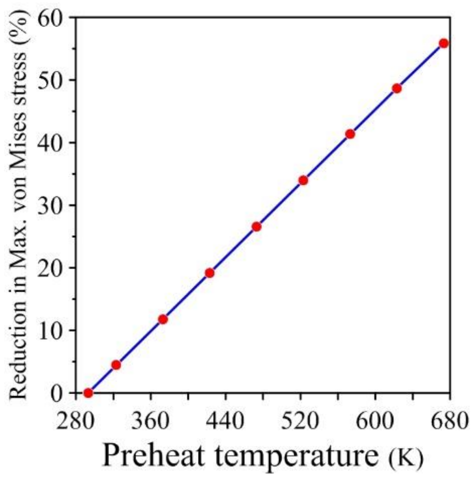

Fig. 2. The impact of die preheat temperature on the maximum von Mises stress reduction

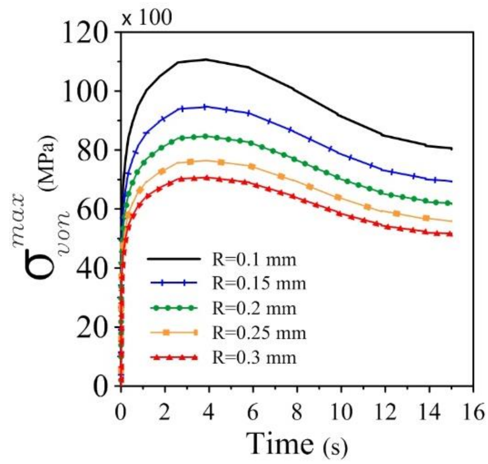

Fig. 3. The effect of groove corner radius of curvature on the maximum von Mises stress

where $A = 993\text{K}$, $B_0 = 993\text{K}$, $B_1 = 723\text{K}$ and $t_e = 15\text{s}$.

The thermo-mechanical properties of H11 hot work tool steel [7] are considered for the die material. Also, DC2D4 and CPE4R element types are employed for the thermal and structural analyses, respectively.

3- Results and Discussion

According to the finite element analysis, the severe stress gradient occurs around the injection groove corners thus the stress sensitivity analysis is mainly given for the groove corners.

Fig. 2 shows the effect of preheating temperature on the maximum von Mises stress reduction compared to the room temperature model. It can be observed that the von Mises stress meets a linear reduction as the preheat temperature increases. However, it must be noted that the preheat temperature is limited since the material strength may decrease at very high temperatures.

The impact of groove corner curvature on the maximum von Mises stress is given in Fig. 3. The von Mises stress builds up at the early stage of the casting process and behaves asymptotically in the final stage. If the radius of curvature at the groove corner increases around 50% then the peak of von Mises stress decreases up to 15%. Simply, this can be obtained by an increase in the strand size of the wire cut machine.

The application of thermal protective coatings can be another effective method to tolerate severe stress localization. Employing a 0.1mm thick protective coating on the injection groove, the efficiency of hard chrome, TiAlN, Si_3N_4 and the Functionally Graded Materials (FGMs) are examined here [8-10]. Variation of the von Mises stress along the groove surface is given in Fig. 4. One may observe that the hard chrome coating can decrease the maximum von Mises stress by a factor of 50% compared to the uncoated model. Similarly, Fig. 5 illustrates the impact of graded coating on the von Mises stress distribution. The FGM coating enables further reduction of the von Mises stress up to 70% with respect to the uncoated model.

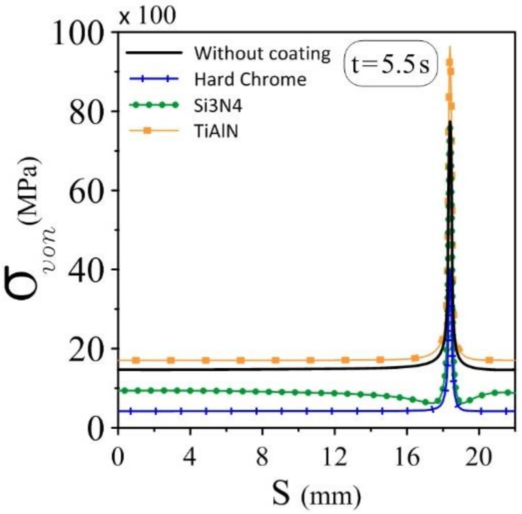

Fig. 4. Distribution of the von Mises stress along the groove edge for the different coating types

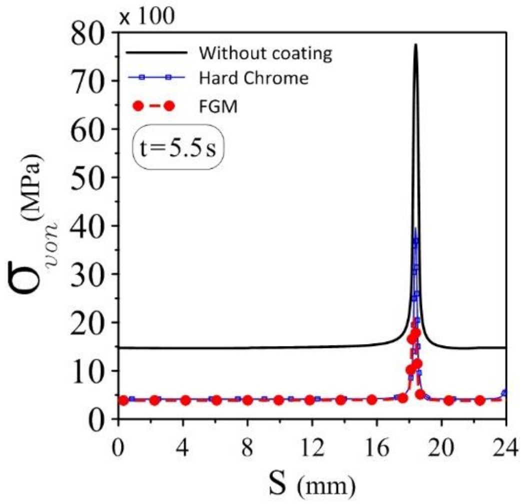

Fig. 5. Distribution of the von Mises stress along the groove edge for the FGM coating type

4- Conclusions

The thermo- elastic analysis of a die casting die was addressed in the current study. The finite element method was employed to simulate the boundary value problem considering a smooth temperature distribution on the molten metal affected boundaries.

The parametric study was conducted to investigate the impact of preheat temperature, groove corner curvature and protective coatings. According to the results, it can be concluded that:

· the die preheating up to one-third of the molten metal temperature can reduce the stress localization around 30% compared to the room temperature model,

· a small increment of the groove corner curvature can considerably alleviate the severe stress distribution around the groove corner,

· the FGM coating is the most efficient method to control the stress build-up around the injection groove during the casting process.

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