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Predicting Thermal Fatigue Life of Aluminum Die Casting Molds - An Experimental and Computational Approach

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The cost effectiveness of the die casting process correlates to a large extent with the lifetime of die casting molds. Hence, ensuring a predictable and adequate lifetime of aluminum die casting molds is of high importance for foundries worldwide. Within the scope of this work, methods to quantify the thermal fatigue life in critical areas of an aluminum die casting mold were developed. The results can serve to support engineers in designing optimized die casting molds.

Keywords: *lifetime, thermal fatigue, die casting mold, hot work tool steel, simulation*

1. Approach of the developed lifetime assessment

The work is based on strain-life fatigue analysis. As depicted in Fig. 1, an extensive number of further aspects were taken into account in order to ensure the relevance of the approach for the die casting process. The identified correlations were considered by correction factors.

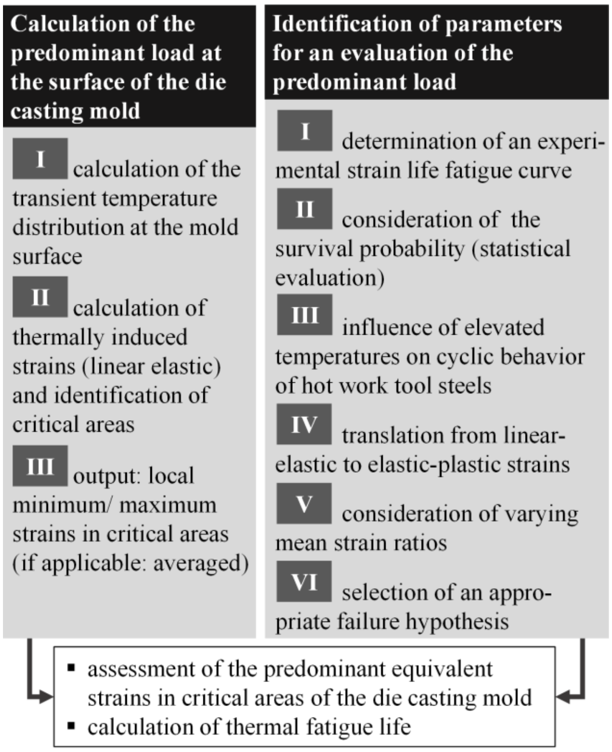

Fig. 1 Approach of the developed lifetime assessment

2. Experimental methods: cyclic material properties

In order to obtain strain-life curves for the hot work tool steel AISI H11, cyclic strain-controlled tests were conducted. Within the scope of this work, well established aviation-specific standards respectively code-of-practices for thermomechanical fatigue (TMF) testing were considered [1]. The experiments were carried out with a servo-hydraulic fatigue testing machine (maximum load: 50 kN). For the measurement of the specimen mechanical strain, a laser extensometer P50 (Fiedler Optoelektronik GmbH) was used. The assessment of the recorded hysteresises were performed by automated evaluation routines. In this context, Fig. 2 shows the strain-life curve and the corresponding parameters for the strain life equation according to Coffin, Manson and Morrow. This data constitutes the basis for an evaluation of the predominant load. Moreover, it should be taken into account that the aspects II to VI (cf. Fig. 1) have a significant influence on the calculation of the thermal fatigue life.

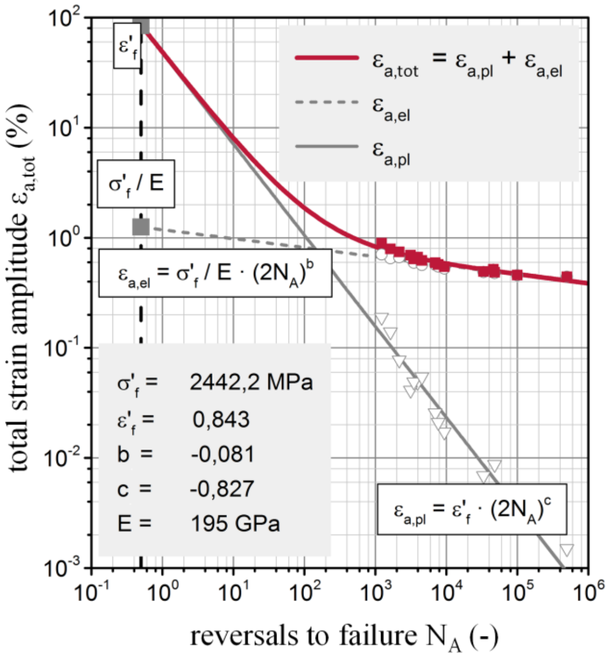

Fig. 2 Strain life fatigue curve of AISI H11

This shall apply in particular to the application of a statistical evaluation of the experimental results. For example, by adopting a survival probability of 90 %, the calculated lifetime for the strain amplitude $\varepsilon_{a,tot}$ = 0,5 % is reduced from approx. 45.000 cycles to approx. 20.000 cycles.

Numerous series of experiments were performed for the purpose of comparing the fatigue behavior of the conventional hot work tool steel AISI H11 with the fatigue behavior of a specially developed steel grade (DIEVAR). A statistical evaluation revealed that there is no significant difference between both hot work tool steels. This statement refers to the examined strain amplitudes and to the specific boundary conditions of the strain-controlled fatigue test series.

An essential part of this work also investigated the influence of the mean strain on the strain-life fatigue of the hot work tool steel. Based on the experimental results, it was suggested to establish a correlation between the relative strain-life and the dimensionless mean stress relation σ*. However, it must be stated that the influence of this parameter is relatively low when compared to the other aspects, mentioned in Fig. 1.

3. Computational methods: lifetime assessment of a die casting mold

The plausibility of the gained experimental results and correlations were validated by the use of an existing die casting mold. For the calculation of the predominant load, the finite element software ANSYS was applied. Sound assumptions must be made on the boundary conditions since they are essential for a meaningful calculation of thermal fatigue life. Within the scope of this work, data from [2,3] was taken into consideration. Fig. 3 shows a detailed view of the predominant von Mises equivalent strains at the cavity surface of the ejector die.

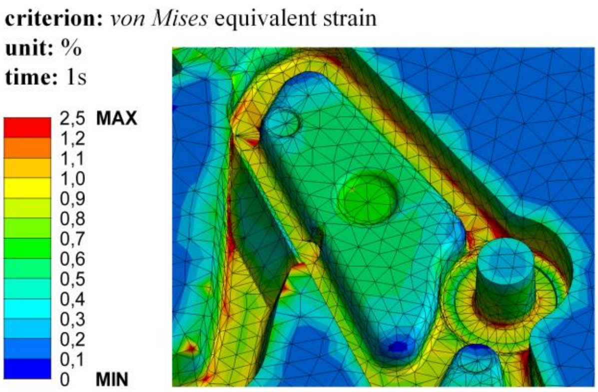

Fig. 3 Load at the cavity surface (ejector die)

Fig. 3 clearly illustrates that the critical areas correspond to the notched areas at the cavity surface. Calculated equivalent strains mostly exceed the linear-elastic range of the hot work tool steel (in critical local areas greater than 1,2 %). Hence, the depicted results emphasize the importance of a translation from linear-elastic to elastic-plastic strains, if the finite element analysis was based on a linear-elastic material model.

By comparing experimental and computational results, a good accordance between the predicted and the actual lifetimes was found.

4. Summary and outlook

Within the framework of this work, thermal fatigue life in critical areas of an aluminum die casting mold has been quantified. A large number of aspects were considered in order to ensure the relevance of the approach for the die casting process.

It has to be taken into account that static/cyclic strengths of hot work tool steels are inhomogeneous due to limitations in the production and heat treatment processes. The predominant load at the cavity surface varies. Hence, load assumptions are still fraught with considerable uncertainties. Consequently, no universal approach can easily predict accurate thermal fatigue life. However, in any case, the depicted method allows a good risk assessment. Furthermore, the presented approach can also contribute to the optimization of the production process since it helps to identify parameters that are sensible with regard to a long lifetime. The modular approach of the work allows future enhancements by correction, refinement or even by the consideration of further correlations that are of relevance for thermal fatigue life.

References

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