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Effect of elevated temperature on the fatigue strength of casted AlSi8Cu3 aluminium alloys

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Abstract

In this paper, the fatigue strength of casted aluminium alloy AlSi8Cu3 T5 and T6 is investigated at room and an elevated temperature of 150 °C. The specimens are extracted from cylinder heads (AlSi8Cu3 T5) at one and from crankcases (AlSi8Cu3 T6) at two defined specimen locations. In addition, quasi-static tensile tests are executed for both temperature conditions. Extensive fractographic analyses of tested specimens are performed to characterise the failure mechanisms and measure the crack initiating defect size. This work is supported by computed tomography analysis to achieve an enhanced knowledge of the micropore morphology. The experiments demonstrate that the fatigue strength of the AlSi8Cu3 T5 (cylinder head) and the position 1 of the AlSi8Cu3 T6 (crankcase) significantly decreases at 150 °C by 25 % and 7 % respectively. These two specimen positions exhibit smaller micropore sizes (120 µm and 85 µm at room temperature) compared to position 2 of AlSi8Cu3 T6 (crankcase) and show a partially change in the failure mechanism from defect at room temperature to slip band induced crack initiation at 150 °C. Position 2 of AlSi8Cu3 T6 (crankcase) indicates a partial change of the fatigue strength level at 150 °C compared to room temperature. Additionally it illustrates no change in failure mechanism, whereby all specimens reveal a defect induced failure, which can be explained by significant higher micropore sizes (537 µm at room temperature) compared to the other extraction positions.

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Keywords: micropores; elevated temperature; slip bands; failure mechanism

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1. Introduction

In principle, the micro porosity majorly affects the fatigue strength of casted aluminium as shown by Buffière et al. (2001); Gao et al. (2004); González et al. (2011); Linder et al. (2006); Zhang and Sonsino (2004). Among the numerous cast aluminium material types, Al-Si alloys are commonly utilized in automotive components due to their sound castability (Di Sabatino and Arnberg (2009)) and favorable mechanical properties (Canales et al. (2012)). However, it has to be considered that manufacturing process dependent characteristics, like demonstrated in Tabibian et al. (2015), eutectic modifier, such as Sr or Na, stated in Lu et al. (2005), as well as the final heat treatment, described by Yang et al. (2015), may have a distinctive influence on the microstructure and hence, a potential impact on the fatigue performance of the component in service. Aluminium castings are typically utilized for lightweight engine parts (Javidani and Larouche (2014)), like crank cases (González et al. (2013)), cylinder heads (Mattos et al. (2010)), and pistons (Mbuya et al. (2012)). As elevated temperatures commonly occur during operation, it is of utmost importance to characterize the material properties under such increased temperature conditions, as demonstrated in Chang-Yeol Jeong for a casted Al-Si-Mg cylinder head. A study in Özdeş and Tiryakioğlu (2017) indicates that the high-cycle fatigue life of cast aluminium alloys can be estimated from tensile test results. However, as elevated temperatures significantly influence the microstructure and the fatigue performance (Ceschini et al. (2016) and Konečná et al. (2016)), a detailed investigation of both quasi-static mechanical and fatigue properties of the cast material is needed.

Therefore, this paper focuses on the effect of elevated temperature on the material behavior of casted AlSi8Cu3 aluminium alloys. The experimental investigations cover microstructural analyses, an evaluation of quasi-static mechanical properties as well as fatigue tests. The experiments are performed at room temperature and 150 °C for the purpose of comparison. Based on experimental fatigue test results at room temperature, 150 °C, and 250 °C, of an Al-Si-Cu cast alloy in Zhu et al. (2006), it is concluded that an increasing test temperature results in a decrease of the fatigue resistance. Furthermore, it is stated that the dependency of the high-cycle fatigue strength can be linearly related to the quasi-static mechanical properties, more precisely yield or ultimate tensile strength, at the corresponding temperatures. A detailed fracture surface analysis of fatigue tested Al-Si-Mg-Cu cast alloy specimens in Mohamed et al. (2013) for room and several elevated temperatures ranging up to 300 °C shows that a certain change of the fracture mechanism, depending on the test temperature, can be observed. In case of room temperature, the failure origin preferably arises at micropores. On the contrary, cracks occur at the coarse constituent particles and other second-phases within the microstructure at elevated temperatures. Fatigue tests at room temperature in Ammar et al. (2008) incorporating A356-T6 cast samples reveal that in general the micro porosity acts as most likely site for crack initiation, but in case of the absence of such casting defects, other microstructural features like slip bands may act as failure origin. In addition, the thermo-mechanical fatigue test results in Beck et al. (2007) highlight the presence of slip band induced fatigue failure at elevated temperature conditions. Hence, special focus is also laid on the fracture mechanisms of the tested samples within this work in order to observe the fatigue crack initiating characteristics in the microstructure under both room and elevated temperature.

2. Material and methods

The investigated round specimens are extracted from cylinder heads and crankcases of an Al-Si-Cu casted aluminium alloy. For the cylinder head of AlSi8Cu3 aluminium alloy with a T5 heat treatment one specimen position is examined. Specimens are manufactured from two positions of the AlSi8Cu3 crankcases with a T6 heat treatment. All tested alloys are modified with the eutectic modifier Strontium (Sr). In Table 1 an overview for the investigated specifications is shown.