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Through Process Modelling applied to the fatigue resistance of cast Aluminum

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Abstract

The aim of this study is to evaluate a full integrated modelling strategy to evaluate the influence of casting defects on the fatigue life directly from process simulation. We have shown that defects characterized by their size and the microstructure characterized by the SDAS, are the main parameters that control the fatigue limit. A fatigue criterion that already takes into account for the effect of the defect on the fatigue limit was modified to introduce the effect of SDAS. This improved criterion has been employed to predict the Kitagawa diagram for multiaxial loading for different loading cases. The simulation of the modified criterion showed that the reduction of the fatigue limit with the defect size and SDAS is well described. In the last part a numerical model was developed to perform a simulation of the fatigue limit starting from the simulation of the casting process. Using this numerical model, we simulated the defect size and SDAS depending on the solidification time, the fatigue limit is simulated using the improved criterion. We proposed in this part a mold which let to obtain samples with two different microstructures. In this study, a second fatigue tests was carried out on these samples to validate the numerical simulation on the proposed mold. It turns out that the numerical model provides reasonably well the obtained experimental results.

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Keywords: Through Process Modelling; Cast Aluminum Alloy; Fatigue design

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HCF studies on cast aluminum alloys have shown [1, 2] that the effect of defect size is in competition with other microstructural features such as SDAS/DAS to limit fatigue life. It has been clearly observed that casting defects have a detrimental effect on fatigue limit above a critical size [3, 4]. In addition, the influence of microstructure defined by DAS or SDAS on the fatigue behaviour of cast aluminum alloy cannot be neglected [5-7]. It has been demonstrated [6] that the eutectic phase can cause micro-cracking due to strain accumulation in proximity to Si-particles. As reported in [1], for small defect sizes, there is a prominent interaction between defects and microstructure on the fatigue limit of cast A356-T6 aluminum alloy. Therefore, the simulation of defect size and microstructure distributions within a cast aluminum alloy component are critical inputs for fatigue design. In this context, several studies [8-12] have proposed models to simulate the solidification process and the formation of porosity. A number of models combine the shrinkage pressure and hydrogen concentration to describe porosity formation. In these models the defects were explicitly assumed to be spherical [13-15]. Atwood *et al* [11] assumed that during solidification, due to solid-liquid balance, pore shapes become complex as they grow between grains or between dendrite arms. Several studies [8, 13] have suggested that it is more appropriate to consider an equivalent pore size rather than trying to characterize the complex 3D shape. This assumption is useful in simplifying the fatigue design for casting aluminum alloy components. In some studies [8, 10-12], the effects of pressure, cooling rate and the distribution of hydrogen in the casting on the formation of pores has been studied. Yao et al [8] have shown that the distribution of hydrogen in the liquid phase of the melt depends on the cooling rate, which affects pore growth: the volume of pores decreases when the rate of solidification increases. In the same context, Carlson et *al* [12] developed a model to predict the evolution of porosity during solidification phase. This evolution depends on hydrogen diffusion during solidification. It was shown that, at high cooling rates with a low temperature gradient and low pressure, shrinkage and gas pore formation are more pronounced at low hydrogen concentrations. From this literature summary, the important points that should be considered to predict defect size include the temperature gradient, hydrogen diffusion and local pressure in the melt during solidification. When modeling aluminum alloy casting processes, there are several ways to simulate microstructure formation. Experimental observations have shown that the cooling rate is the major factor that affects dendritic structure [17, 18]. The microstructure of a cast aluminum alloy can be quantified as the SDAS calculated as a function depending on the solidification time or the cooling rate [9, 10, 17, 19]. The aim of the current work is to present a Through Process Modelling for the fatigue design of cast A356 components. This model will be applicable to gravity die cast components. The whole process contains 4 steps: (i) simulation of cooling history during solidification (ii) SDAS simulation based on cooling rate (iii) shrinkage and porosity simulation based on hydrogen diffusion and solidification time, and (iv) fatigue life assessment in a multiaxial context. It is worth noting that the numerical framework developed in this study can be easily extended to any Al-Si-Mg cast aluminum alloy.

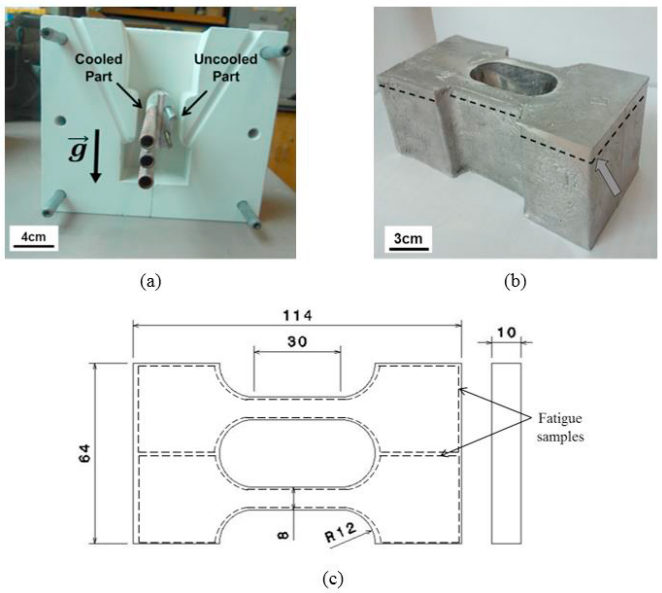

Fig. 1 (a) Mold with cooled/uncooled details (b) resultant casting (c) fatigue specimen geometry