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Predictive equations of the tensile properties based on alloy hardness and microstructure for an A356 gravity die cast cylinder head

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ABSTRACT

One of the main problems in the design of complex Al–Si cast components is the wide variety of mechanical properties in different regions of the castings which is due to the wide range of solidification microstructures, related to the local solidification conditions. There are many papers available on the widely used A356/A357 Al–Si–Mg alloys, however, most experimental data on their tensile or fatigue properties are generally obtained from specimens cast separately or produced under controlled laboratory conditions, that are extremely different from those of industrially cast components. Moreover, most of these data often relate the mechanical properties to only one microstructural parameter, such as solidification defects or secondary dendrite arm spacing, and do not take their simultaneous effect into consideration. For all these reasons, the main problem, in the design phase, is the lack of knowledge of the true local mechanical properties in complex-shaped castings, which often means a conservative approach is necessary, with a consequent increase in thickness and therefore in weight. The aim of this research was to study a complex A356 gravity die cast cylinder head, in order to verify the range of variability of the main microstructural parameters and tensile properties, using specimens directly machined from the casting. The component was heat treated at the T6 condition, and the effect of the delay between quenching and aging on the alloy hardness was also evaluated. Simple experimental equations have been proposed, able to successfully predict the local tensile properties in the casting, when only the most important microstructural parameters and alloy hardness are known. These equations allow the designer to predict the local tensile behaviour without any tensile tests; moreover they can also link the post-processing results of the casting simulation software to the pre-processing phase of the structural ones, with an approach of co-engineered design.

1. Introduction

Excellent castability, corrosion resistance and high strength-to-weight ratio, which increase performance and fuel economy, make Al–Si–Mg casting alloys suitable materials for various applications in the automotive industry, such as engine blocks, pistons, cylinder heads, and crankcases. These alloys (typically A356 and A357) offer the ability to cast complex, thin-walled components, by sand and permanent mould casting, with tensile strengths up to 350 MPa. This high strength level is achieved by the T6 heat treatment, where Mg–Si precipitates provide strengthening through age hardening.

The mechanical properties of a casting are greatly influenced by the size, volume, and morphology of microstructural constituents, which depend on composition, solidification conditions and heat treatment [1–11].

The microstructure of A356 and A357 casting alloys consists of primary aluminium dendrites, eutectic Si, intermetallic compounds and solidifications defects, such as gas and shrinkage porosity and oxides. The volume fraction of dendrites and eutectic particles is determined by chemistry, whereas the size, morphology and distribution of the dendrites, eutectic particles and intermetallics also depend on the local solidification conditions.

Several works [4–11] report that the ultimate tensile strength (UTS) and the elongation to failure (E%) are strongly affected by the primary and secondary dendrite arm spacing (DAS and SDAS). Moreover, they are also affected by the size and morphology of the eutectic Si, and by the presence of casting defects, while the yield strength (YS) is mainly controlled by age hardening induced by heat treatment. The general results show that UTS and E% increase when SDAS decreases and that small globular Si structures, induced for example by chemical modification, mainly enhance E%.

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