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Impact behaviour of A356 alloy for low-pressure die casting automotive wheels

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ABSTRACT

Instrumented impact strength tests have been carried out on KV sub-size Charpy samples drawn from A356 aluminium alloy 17-in. wheels, produced by a low-pressure die casting. The wheels show different geometry and thermal treatment. In this paper, the effects of microstructure and defects on the impact properties are studied. The results indicate that the impact energy is lower in as-cast wheel than in T6 heat-treated wheels. A finer microstructure always corresponds to higher impact strength, while a direct correlation between the resistance to crack propagation values and secondary dendrite arm spacing (SDAS) exists. Casting defects, revealed by means of X-ray and density measurements techniques, become critical when concentrated around the V-notch, where they reduce the load bearing area of Charpy specimens. The fracture profile and surface of Charpy specimens have been investigated revealing how the crack crosses the interdendritic eutectic region where a significant fraction of cracked eutectic silicon and intermetallic particles is found.

Numerical simulations have been performed to study the filling and solidification behaviour of the alloy of the wheels analysed, in order to predict the final microstructure and shrinkage formation. Solidification times, estimated by means of SDAS measurements and calculated with a numerical simulation approach, show a good correspondence. Critical areas, as concern hot spots and shrinkage porosities, are generally revealed in the zone of the wheels between the spoke and the rim, as well as in the rim area.

1. Introduction

Lowering pollutant emission is a priority objective of international policies together with lowering energy consumption and increasing recycled materials; not only for its effect on the quality and environmental equilibrium, but because it has a strong impact in the competitiveness of companies in several sectors. In this context, only the introduction of technological innovation will be able to reconcile objectives of an environmental and energetic nature with those of a competitive type. Recently, the application of aluminium alloys in automotive sector can be one of these economically sustainable innovations, which enable a wider mix of objectives to be achieved. Both Flinn (1963) and Sicha (1971) affirm in their works that, due to their excellent castability and good compromise between mechanical properties and lightness,

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aluminium–silicon alloys are the most important and widely used casting alloys in order to cast components with complex shapes.

A consolidated example of aluminium alloy employment regards the production of wheels, which, together with an improved aesthetic appearance, guarantees an improvement of driving, like directed consequence of the inertia reduction of the wheels. These components are somewhat unique as they must meet, or exceed, a combination of requirements, from high-quality surface finish, as wheels are one of the prominent cosmetic features of cars, to impact and fatigue performance, because wheels are critical safety components. Generally, the main technology for casting aluminium alloy wheels is the low-pressure die casting (LPDC), which guarantees to obtain a good compromise between high-mechanical properties, high production, cost-effectiveness and design demand. Street (1986) stated that LPDC allows to produce castings similar to those obtained by gravity casting, with good superficial aspect and thin thicknesses, but the advantage to have one central metal inlet and the absence of risers allows to obtain an optimal yield, around 85–95%.

Li et al. (2004) analysed the effect of various alloying elements and different heat treatments in A319-type alloys by means of instrumented impact test; in particular they found that impact tests can give a measure of the capability of the material to resist to crash, providing an useful estimation of the ductility of an alloy under conditions of rapid loading. Analysing the impact properties of Al–Si foundry alloys, Paray et al. (2000) evaluated the total absorbed energy of the samples subjected to impact test like the sum of the energy required for crack nucleation and the energy required for crack propagation, in order to describe the dynamic toughness of the material. Srivastava et al. (2006) demonstrated that in the case of cast aluminium alloys the presence of a notch can decrease the impact values even further, by up 80%, when compared to un-notched specimens; even a shallow scratch of 0.1 mm reduces the energy absorption by 30%. If a notch is present, the absorbed energy can be dependent on the notch geometry than on the microstructure.

Impact test is a useful methodology in evaluating the effects of process parameters and microstructure on dynamic fracture toughness of engineering materials. Murali et al. (1992) evaluated the influence of magnesium content in the AlSi7Mg0.3 alloy with low-iron level: the absorbed energy drops significantly by about 50% with increasing magnesium content from 0.32 to 0.65 wt.%. Similar behaviour is observed increasing the iron content from 0.2 to 0.8 wt.%, at 0.32 wt.% Mg, due to an increased precipitation of β-Al_5FeSi platelets. Shivkumar et al. (1994), analysing Charpy specimens in A356-T6 machined from plate and cylindrical castings, demonstrated that the strontium modification, as well as an increase of solidification rate, improves the impact properties of sand and permanent mould castings, even if the effect is more pronounced at low-magnesium and -iron content.

As specified by Zhang et al. (2002), the T6 heat treatment provides beneficial effects to cast aluminium components: it increases the yield strength, through the precipitation of a large number of fine β'-Mg_2Si particles, and improves the ductility, through spheroidisation of the eutectic silicon particles. Earlier Cáceres et al. (1995) and later Wang and Cáceres (1998) observed that the inter-particle spacing plays a dominant role in determining cracks' nucleation and propagation and that the fracture path considerably depends on the dendrite cell size. The nucleation of the cracks usually starts with cracking of brittle particles. Once a large number of particles are cracked, cracks grow by linking microvoids formed by the cracking of these particles. With a smaller inter-particle spacing, the microvoids link and grow easily. Li et al. (2004) demonstrated that oxides, such as phosphorous oxides, which act as nucleation sites for Al_2Cu precipitates in A319-T6 alloy, can accelerate the cracking process reducing the impact properties.

While the benefit effect of T6 heat treatment is recognized, the additional cost and required time are substantial. Zhang et al. (2002) showed that shortening the total time of the T6 heat treatment cycle there exists a region where the impact energy decreases to a minimum before increasing. The cause of this region seems due to a conflict between the negative effect of solution treatment on ductility and impact strength, associated with a rapid increase in the yield strength and the more slowly developing positive effect associated with the spheroidization and coarsening of silicon particles.

The aim of this study is to investigate the impact properties of KV sub-size Charpy specimens, drawn from A356 17-in. wheels with different geometry and temper, by means of instrumented Charpy impact testing including discussion of individual energy portions during fracture. Microstructural features, such as secondary dendrite arm spacing (SDAS) and eutectic silicon particles, have been correlated to impact properties: absorbed energy, maximum load, crack nucleation and propagation energy. Cáceres and Selling (1996) carried out a series of experiments to quantify the effect of casting defects in AlSi7Mg0.4-T6 casting alloy and they found that porosity is critical on mechanical properties of cast aluminium alloys, since it can overcome the effect of microstructure itself. In order to evaluate the presence of porosity, density measurements and X-ray investigations have been carried out on KV samples. In addition to metallographic inspections, fractography has been presented to underline the effect of microconstituents on crack nucleation and propagation. Concurrent with experimental approach, the filling and solidification behaviour of the wheels analysed have been assessed via numerical simulation codes.

2. Experimental procedure

Instrumented impact tests have been performed on KV sub-size Charpy specimens drawn from different A356 wheels, named wheel-1, wheel-2 and wheel-3, respectively. While wheel-1, a 7-spoke wheel in the as-cast temper, has a weight of 10.6 kg, wheel-2 and wheel-3, which are 5-spoke wheels in the same T6 condition, weigh 12.2 and 11.9 kg, respectively. The wheels' diameter is 43.35 cm, while the rim width is 21.8 cm for wheel-1 and 19.1 cm for wheel-2 and wheel-3. The wheels differ mainly on the geometry and thickness of spokes and rims. All the wheels were cast by LPDC.