Influence of Main Alloying Elements on Key Physical Properties of Heat-Resistant Al-Si Cast Alloys

The January 2012 issue of AluReport contained a detailed account of the influence of Ni on the thermal conductivity of heat-resistant Al cast alloys. This article is intended to clarify the importance of the alloying elements Si and Cu.

In addition to thermal conductivity, λ, the coefficient of thermal expansion, α, plays a vital role in the selection of alloys for motor components. For example, materials that have minimum thermal expansion are to be used for drives to prevent the piston seizing in the cylinder [1].

Amongst other things, understanding the influence of the above alloying elements on thermal conductivity and the coefficient of thermal expansion is a prerequisite for determining useful concentrations in the relevant alloys and/or estimating physical characteristics in good approximation when the alloy composition is known, thus AMAG is in a position to increase its expertise in giving advice to customers on key physical characteristics.

Thermal Conductivity

Fig. 1a shows the influence of Si on the thermal conductivity of secondary Al alloys and compares the measured data with literature values [2] for pure aluminium.

To simplify matters, Al-Si alloys are considered a sort of „composite material“ consisting of an Al matrix and eutectic silicon. The value of such a material lies between the respective values for the individual components of the composite and can be estimated using models [3, 4]. At a value of 25 W/mK [5, 6] for λ_{Si}, the calculated values correspond well with the measured values [1]. It should be taken into account that AMAG did not use a pure Al99.99 matrix when measuring the influence of the alloying elements but an AlFe0.4Mn0.3Mg0.35 base alloy that more appropriately reflects the real composition of a cast alloy made of recycled material.

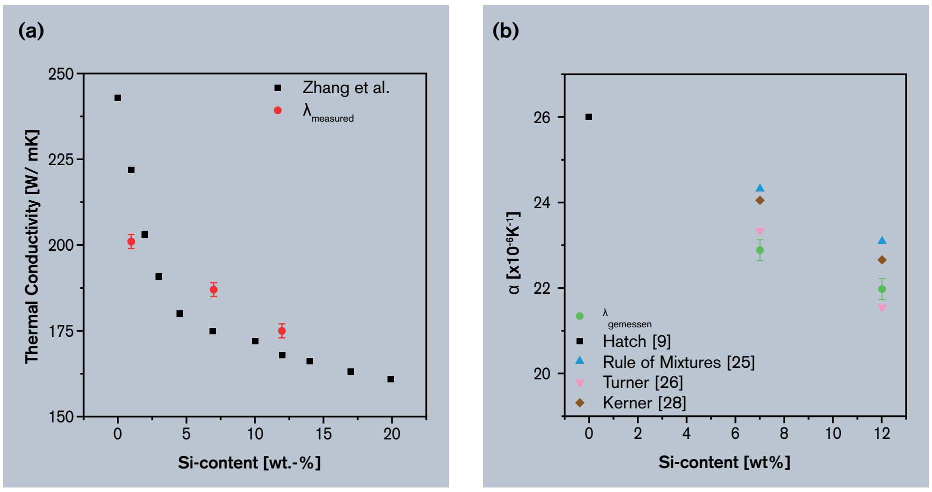

Fig. 1a: Influence of Si on the thermal conductivity λ at 40 °C [1] and comparison with values from literature [2]

Fig. 1b: Influence of Si on the thermal expansion coefficient α and comparison with values from literature [7-9, 14]

Fig. 2a shows the influence of Cu on the thermal conductivity of hypoeutectic and near-eutectic recycled Al alloys, where in both cases λ decreases almost linearly as the Cu concentration increases [1].
The investigated alloys contain 0.35% Mg each, which results in type θ-Al2Cu and Q-Al5Cu2Mg8Si7 secondary precipitates formed during artificial aging, which reduce thermal conductivity. In the hypoeutectic alloys, all Mg and Cu is brought into solution by a preceding annealing process at 495 °C. In AlSi12Cu4(Mg), some of the Cu remains undissolved during that solution treatment and occurs in the form of primary Al2Cu phases that have a more adverse impact on λ than dispersed secondary phases, which explains the relatively sharper decrease in thermal conductivity between 3 and 4 % Cu for the eutectic variations [1].

Fig. 2b shows the influence of Ni on the thermal conductivity of the alloys AlSi7(Mg) and AlSi12(Mg). This coefficient decreases much more sharply than for Cu as the Ni concentration increases. The solubility of both Fe and Ni in the α solid solution is negligible, so primary phases (Al9FeNi and/or Al3Ni) containing Fe and Ni will form even if the concentrations of these elements are low, and the material character will change from a „homogenous material“ to a more complex „composite material“ [10-13].
In that case, λ can also be estimated by approximation using the above models. A detailed description of the procedure for modeling thermal conductivity as a function of the Ni content and/or the volume fraction of intermetallic phases containing Ni has already been published [11].

Coefficient of Thermal Expansion

Fig. 1b shows the effect of Si on the coefficient of thermal expansion, α. Models to estimate the α value of two-phase materials provide an option to assess the influence of silicon [7-9, 14].

Being below the resolution limit of the measuring method employed in that work (see Fig. 3), the separate influence of Cu and Ni on α is relatively small, which is attributable to the relatively small volume fractions of secondary and/or primary phases formed by separate addition of Cu or Ni. The coefficient of thermal expansion does not significantly change until the Cu and Ni contents become extremely high [1].

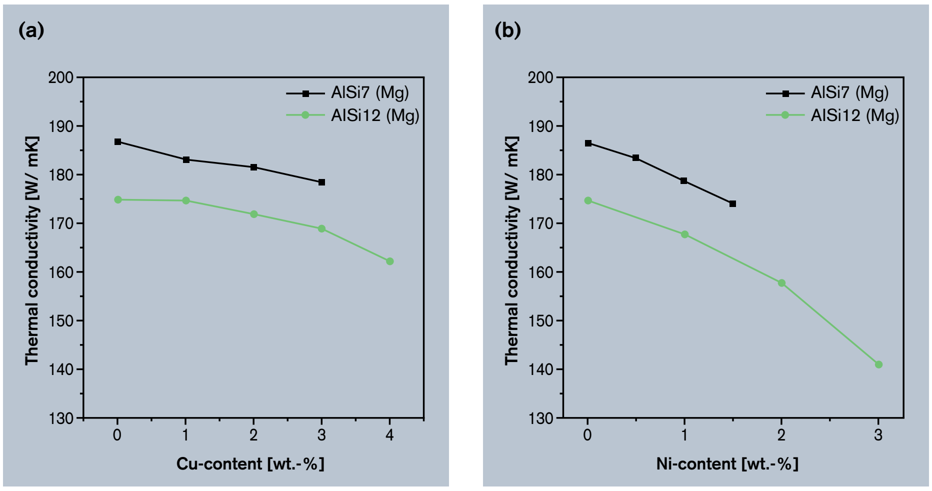

Fig. 2: Influence of (a) Cu and (b) Ni on the thermal conductivity λ of AlSi7(Mg) and AlSi12(Mg) [1]

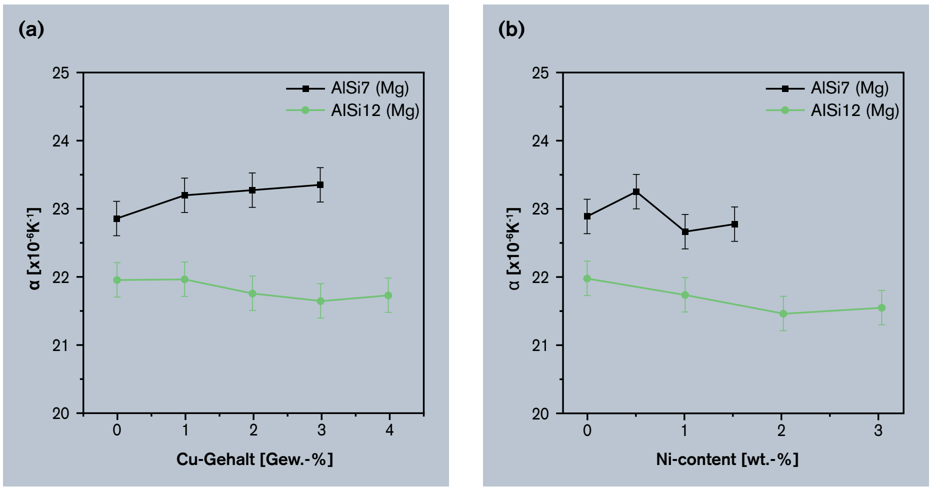

Fig. 3: Influence of (a) Cu and (b) Ni on the thermal expansion coefficient of AlSi7(Mg) and AlSi12(Mg) at 250°C [1]

→ Thermal Shock Resistance:

Despite the fact that no extensive measurements of the thermal shock resistance were performed in the context of that work, it is possible to rank various alloys by their resistance to thermally induced stresses by calculating the second thermal shock parameter, R'_S [1]:

$$R'_s = \lambda \cdot \sigma_{krit} \cdot \frac{1 - \nu}{E \cdot \alpha} \left[\frac{W}{m}\right]$$

Accordingly, the thermal shock parameter describes the resistance of a material to thermally induced cracking. The higher the respective value, the less sensitive the material to thermally induced stresses. It thus becomes clear that under cycle thermal loads, the susceptibility of a material to failure increases as the high-temperature strength and thermal conductivity decrease and the coefficient of linear thermal expansion increases [15].

Customer Benefit

Understanding the competing interactions among the main alloying elements and their influence on the mechanical and physical properties are of fundamental importance to developing and optimizing heat-resistant alloys on the basis of recycling. It turns out that using a large quantity of expensive alloying elements such as copper and nickel does not always yield better results. Additionally, it is essential to focus not only on strength but also on other characteristics specific to alloys, such as thermal conductivity, coefficient of thermal expansion and thermal shock resistance. Depending on the component and application, an improvement of these properties can be more effective and yield better results.

The comprehensive investigation of various alloy variations, combined with a scientific understanding of the mechanisms going on, enables AMAG to tailor an optimum solution according to the customer's needs, while at the same time identifying cost optimization potentials for existing solutions.

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