High modulus aluminium-based materials for automotive applications

S. Amirkhanlou, S. Ji and Z. Fan

The design of automotive structural components made from lightweight aluminium shape castings are usually based on either yield strength or stiffness (Young's modulus) requirements. Although aluminium alloys have reasonably acceptable yield strength, their Young's modulus is undesirably low. Therefore, the development of aluminium-based materials with improved Young's modulus becomes essential for lightweighting structures.

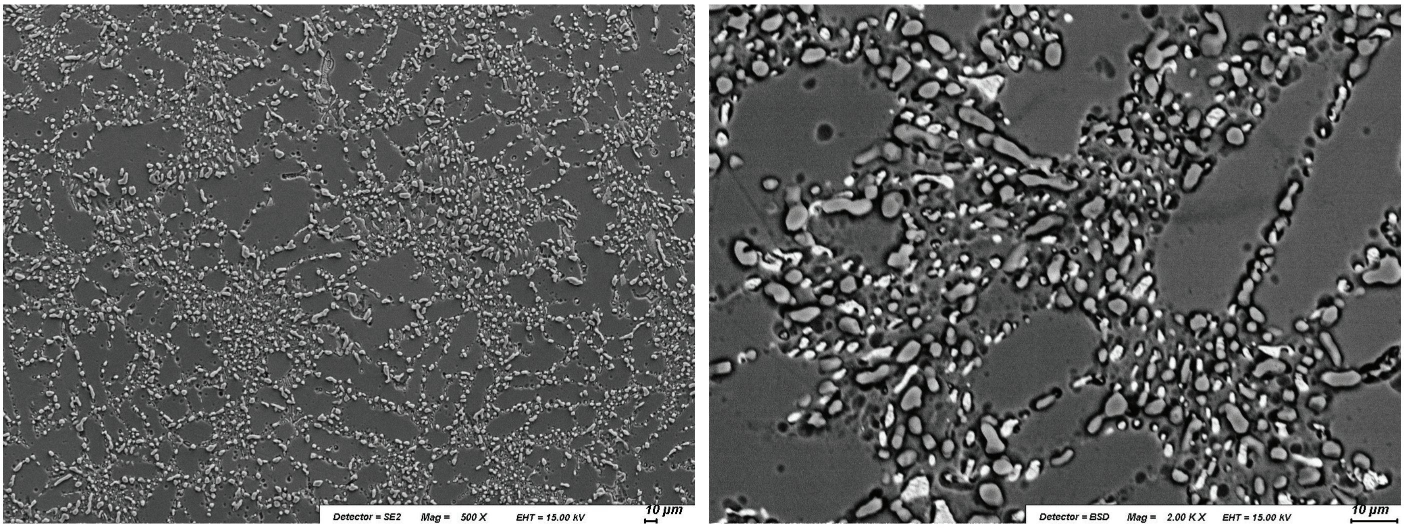

FIGURE 1. Typical microstructures of gravity cast Al-Si-Ni-Mg alloys developed for a high Young's modulus property, taken at low (left) and high (right) magnifications.

The target of this project is to improve the Young's modulus of cast aluminium-based materials from 70 GPa to greater than 85 GPa. The only possible option is to introduce high modulus phases in the microstructure of aluminium alloys, which can be achieved through alloying elements, insoluble metallic or non-metallic components. Therefore, three approaches were considered to improve the stiffness of aluminium alloys. The first approach was to achieve high modulus materials through in-situ formation of TiB_2 phases within aluminium matrix, which can improve the Young's modulus up to 95 GPa within an acceptable level of making sound castings through conventional sand casting or gravity casting routes. The second approach was the fabrication of steel wire reinforced aluminium matrix to form Al/Fe composites, using a combination of sand casting, gravity casting and squeeze casting routes. The third approach was to study the effect of alloy chemistry on the Young's modulus of cast aluminium alloys. It was found that the influence of alloying elements on the Young's modulus depends on the microstructure. If the alloying elements form a solid solution phase, the magnitude of the Young's modulus increment is determined by the nature of the atomic interactions. If the alloying elements form second phases, the magnitude of the Young's modulus increment is determined by the volume fraction and the intrinsic modulus of the second phase. Among the alloying elements (e.g. Si, Cu, Mn and Ni) studied, Si and Ni are favourite candidates to enhance the Young's modulus of cast aluminium alloys. After optimising the heat treatment process, the studies showed that the Al-Si-Ni-Mg alloy could provide a Young's modulus of ~84 GPa, with a yield strength in excess of 200 MPa and a total elongation of 4.6 %, which has fully satisfied the requirement of the project. In addition, the composition of Al-Si-Ni-Mg alloy could be modified to give even higher Young's modulus, reaching ~94 GPa with the yield strength over 200 MPa and 1.2 % total elongation. The ultra-high Young's modulus property in Al-Si-Ni-Mg alloy is mainly attributed to the presence of α-Al, Si, Al_3Ni and $AlNi_3$ phases in the resultant microstructure.

The key concerns for the Al-Si-Ni-Mg alloy with increased stiffness are the relatively low elongation. However, they have been overcome by optimising the alloy chemistry and heat treatment conditions. Figure 1 shows typical microstructures of gravity cast Al-Si-Ni-Mg alloys with exceptionally high modulus.