

Abstract

Al-Si alloys constitute a widely used group of light metals and alloys. In spite of it traditionally being a well-studied system, no systematic attempts have been made to overcome the strength-ductility limitations existing in these alloys. It becomes even more important to investigate when numerous developments have been witnessed in playing with microstructure control by newer processing methods to enrich our capability of broadening the process-structure-property optimization regimes.

This research investigates the relationship between composition, processing, structure, and properties of binary Al-2Si to Al-30Si alloys at room and high temperatures. The Al-Si alloys were produced by melting and casting in the induction furnace. Microstructure and mechanical property studies were conducted on as-cast, hot extrusion, friction stir processing (FSP), and high-pressure torsion (HPT) processed Al-Si alloys. The minimum grain sizes obtained are 1-2 μm on HPT, 2-3 μm upon FSP, and 5-8 μm on extrusion, which are much smaller than the as-cast grain sizes of 15-115 μm .

Irrespective of processing methods, strength was found to increase with decreasing grain size according to the Hall-Petch type relationship, but the strengthening caused by the grain interior and the grain boundary zone was found to be sensitive to the processing method. In contrast to this, at elevated temperatures (450-840K), the strength decreased, whereas elongation increased with decreasing grain size. Superplastic behaviour investigated in FSP material showed elongations of 191-341%, depending on Al-Si composition, with the maximum elongation of 341% corresponding to the Al-12Si eutectic alloy.

The values of parameters of the constitutive relationship for high-temperature deformation were obtained to be as follows. (i) Strain rate sensitivity index (m) was found to be a maximum of ~ 0.4 for FSPed Al-12Si alloy, whereas it was a minimum of 0.04 for the hypereutectic Al-30Si alloy. The magnitude of m increased with test temperature and generally decreased with increasing Si content for all the processes involved. (ii) The apparent activation energy for deformation (Q_a) was obtained to range from 79.4 \pm 11.8kJ/mol to 572 \pm 148kJ/mol. The FSP material shows $m \geq 0.4$ and true activation energy $Q_t \sim 59.4$ kJ/mol over the temperature range of 530-650K and 221.5kJ/mol over 650-780K. The mechanism for superplastic deformation is accordingly suggested to be grain boundary sliding and its accommodation by grain boundary diffusion at the lower end of the temperature range, and the same by lattice diffusion at the upper end of the temperature range. Q_t generally increased whereas m decreased with increasing Si content, for which the deformation mechanisms were identified to be dislocation climb creep for low Si-containing Al-Si alloys, but power law breakdown appeared for hypereutectic Al-Si alloys in as-cast and extruded Al-Si alloys. According to the present results on FSPed Al-8Si to Al-30Si, both dislocation-based creep mechanisms ($m \leq 0.3$) and superplasticity-type ($m \geq 0.3$) mechanisms occur over different ranges of temperatures, strain rates, and compositions.

In conclusion, it is possible to make Al-Si alloy stronger by selecting higher Si content, but irrespective of composition, the same can be made to exhibit superplasticity, thus providing an opportunity to extend the applications of Al-Si alloys by proper processing and meeting the service conditions.

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