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Powder metallurgical processing of a SiC particle reinforced Al-6wt.%Fe alloy

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Abstract: Discontinuously reinforced aluminum alloys for elevated temperatures with a matrix hardened by intermetallic phases generally have to be produced by powder metallurgy because of their high content of alloying elements. The objective of this investigation was the evaluation of powder metallurgical processing for an Al6Fe powder alloy containing various fractions and volume contents of SiC particles. During processing, the effect of powder mixing on SiC particle distribution in the extruded product was emphasized and examined by scanning and transmission electron microscopy. Gas development during mixing and degassing was investigated by mass spectroscopy and related to strength, fracture toughness and ductility. In addition to room temperature mechanical properties, elevated temperature tensile properties were evaluated for the various SiC particle distributions.

Introduction

Powder metallurgical processing has been applied to reinforce aluminum alloys with SiC particles with the intention to increase the elastic modulus, elevated temperature properties and thermal stability of the matrix alloy. Al-6wt.%Fe is a powder metallurgical alloy, that is strengthened by a fine distribution of intermetallic particles generated by rapid solidification (RS) and that is well known for its thermal stability [1]. This alloy is considered a suitable matrix for particle reinforcement that is aimed at elevated temperatures. However, consolidation of a mixture with SiC powder is expected to be more critical than consolidation of age hardenable alloys that are heat treated only after consolidation.

SiC powder was mixed with rapidly solidified (RS) Al6Fe powder by different methods, cold isostatically pressed and extruded. Microstructure, tensile properties, fracture toughness and modulus of elasticity were determined and related to processing conditions. Investigation of processing steps was emphasized that are critical for the powder particle surface such as powder mixing, degassing and extrusion conditions.

Experimental Methods

The aluminum alloy powder was produced by gas atomization in argon by Alpoco/Metalloys, England, with 98% of the powder <45µm. The average particle size was 28 µm. SiC powder was obtained from Elektroschmelzwerk Kempten, Germany. SiC powder fractions were F1200, F1000, F800, F600 and F500, corresponding to mean particle diameters of 4.2, 5.6, 8.6, 11.3 and 15.7 µm, respectively. The volume content of particles added to the alloy powder was either 10 or 15%. Powders were mixed in a glass vessel in a tumble mixer in air or in steel containers with steel balls in a planetary ball mill in

air or in an attritor in air or argon flow. After mixing, mass spectroscopy was performed and the mixed powders were cold isostatically compacted at a pressure of 200 MPa. The cold compacts were machined to cylinders and welded into cans for degassing and extrusion. The cans with the billets were degassed inside the extrusion press and extruded at 400°C. Billets of 55 mm diameter were extruded into round shapes of 12 mm diameter corresponding to a reduction of area of 21:1. After extrusion, the can material at the outside of the rods was removed before mechanical testing. Tensile properties determined at room temperature and elevated temperatures. Fracture toughness was measured on short rod specimens at room temperature [2].

Results and Discussion

Powder surface effects

Mixing of alloy powder with SiC powder is one of the main parameters determining the homogeneity of reinforcement particle distribution in the compacted and extruded material. Powders were examined by scanning electron microscopy before and after mixing (Fig.1).

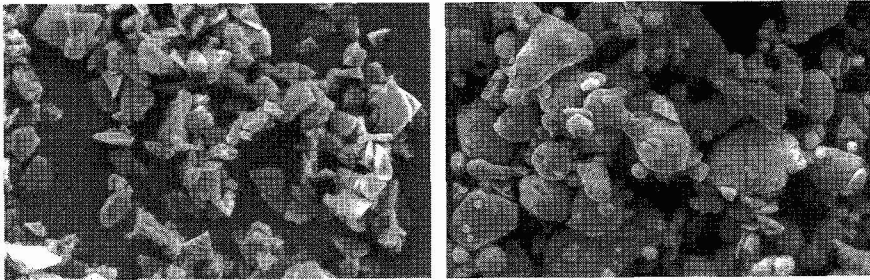


Fig. 1 Scanning electron micrograph of F800 SiC powder (left) and a mixture of Al-6wt.%Fe powder < 45 μm with 10 vol.% of SiC F800 powder after 6 hours of attritor milling (right). □ 10 μm

In the attritor and the ball mill, powders were mixed with the aid of steel balls in order to intensify mixing. It was observed at higher magnifications, that more SiC particles were indented into the alloy powder surfaces than has been the case with tumble mixing. This is considered detrimental, because reaction of fresh alloy surfaces with water vapor generates hydrogen gas according to the equation:



The result of mass spectroscopy on alloy powder and powder mixtures confirms these observations [3]. The first step in aluminum powder degassing is the removal of water from the powder surfaces. Figure 2 shows that all mixing processes lead to a reduction of water compared with the alloy powder before mixing. Mostly the physisorbed water is removed during the mixing process that supports powder drying [4].

However, hydrogen is more critical in processing. After powder mixing, the hydrogen peak of the alloy powder at approximately 430°C is still present (Fig. 3). The amount of hydrogen that develops during degassing and processing is increased slightly by ball milling and drastically by attritor milling. This effect is attributed to the fresh aluminum surfaces that are generated by the sharp edges of SiC particles during milling. Tumble mixing does not lead to an increase in hydrogen development.

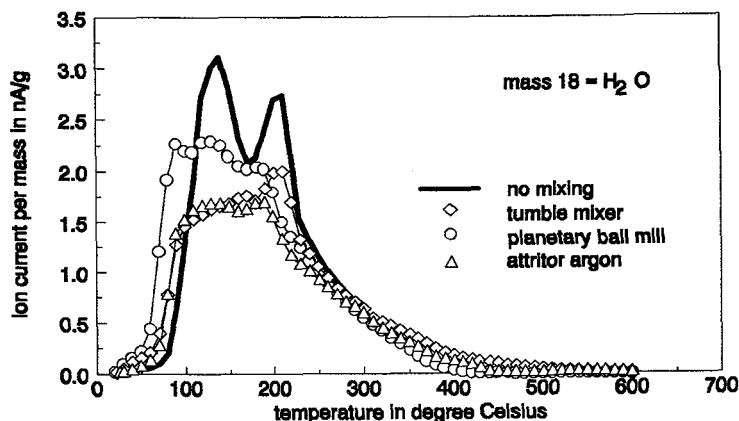


Fig. 2 Mass spectrum of water in gas from Al-6wt.%Fe powder and mixtures with SiC powder.

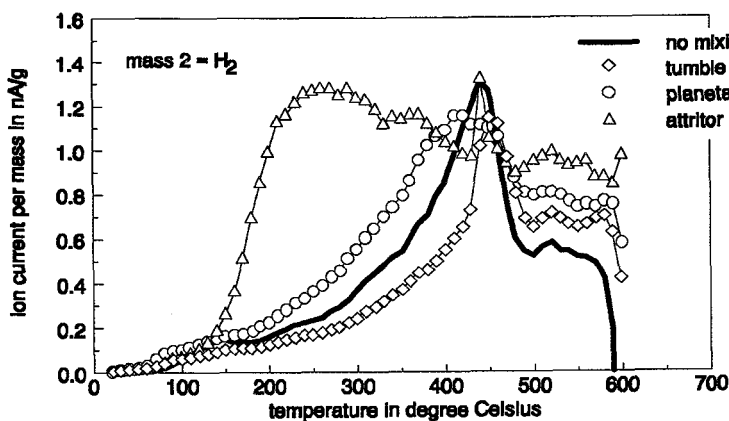


Fig. 3 Mass spectrum of hydrogen in gas from Al-6wt.%Fe powder and mixtures with SiC powder.

Microstructure

The microstructure of extruded powder mixtures as observed in the scanning electron microscope is shown in Figure 4. This is a typical distribution of 10 vol% SiC particles inside the extruded powder as obtained with most of the experiments. The distribution is quite homogeneous and the difference in particle distributions in longitudinal and transverse specimen orientation is only minor, which is an indication for a good mixture of SiC and AlFe powders. Homogeneity of particle distribution decreases with particle size, because at a given volume fraction the number of particles increases with decreasing particle size. The microstructures are sufficiently homogeneous at the smallest particle sizes and at the highest volume fractions.

The uniform flow of the hard matrix with intermetallic phases around the SiC particles is clearly visible. Because of the hard matrix, cracking of SiC particles is often observed that happenend during extrusion. Since these cracks are not filled by matrix material, the density of the composite is lower than expected from the volume content of particles. Mechanical properties that depend on this parameter such as the elastic modulus are also affected.

Fracture of SiC particles is also demonstrated in the transmission electron micrograph in Fig. 5. This effect is likely to reduce a number of mechanical properties that depend on particle distribution or are affected by void formation and internal defects. Processing conditions have to be optimized in order to reduce cracking during extrusion. One of the possibilities is the use of smaller SiC particles that do not as easily fracture during extrusion.

For all particle sizes and both volume fractions, distribution of SiC in the extruded material was sufficiently homogeneous. SiC particle sizes were all smaller than the alloy powder particle size. However, there was no optimum size regarding the distribution of SiC in the extruded material. Since larger SiC particles fracture more frequently during extrusion than smaller particles, there was an indirect effect on particle distribution with particle size.

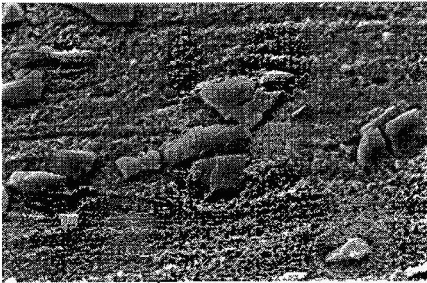


Fig. 4 Scanning electron micrograph of an Al-6wt.%Fe + 10 vol.% SiC particle powder extrusion. \square 10 μ m



Fig. 5 Transmission electron micrograph of an Al-6wt.%Fe + 10 vol.% SiC particle powder extrusion. \square 1 μ m

Effects of particle volume fraction, particle size and powder mixing on mechanical properties

The average increase in yield strength and elastic modulus by the addition of 10 and 15 vol% F800 SiC particles is shown in Fig. 6. Yield strength increase is pronounced at higher particle volumes, the elastic modulus increases nearly linearly. Strength increase is attributed to changes in the matrix microstructure due to material flow and possibly work hardening during extrusion. The gain in elastic properties is slightly smaller than expected from the rule of mixture [5] which is explained by the reduced density of the composite due to void formation in the vicinity of fractured SiC particles.

Particle reinforcement is maintained at elevated temperatures (Fig. 7), but the amount of strength increase is reduced at higher temperatures. The loss in ductility over the matrix alloy caused by the SiC particle dispersion increases with temperature. A minimum at intermediate temperatures in this alloy is due to surface effects of alloy powder and to the precipitation of an AlFe phase at approximately 150°C [6].

There were no or very small effects observed that could have been attributed to differences in particle sizes. In accordance with the composite microstructure, mechanical properties, too, did not show significant variations with particle size at a given particle volume fraction. It appears that the particle size range in this investigation was not sufficient to produce any appreciable effect on mechanical properties.

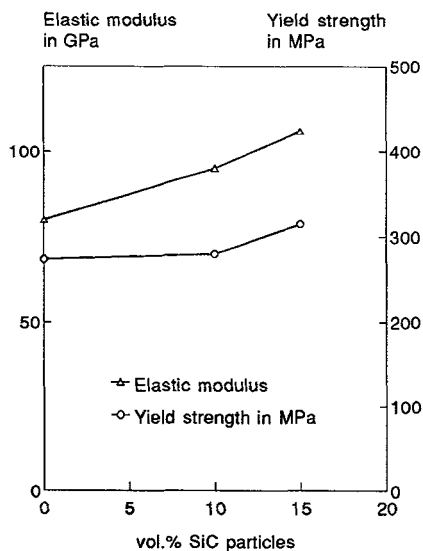


Fig. 6 Effect of particle content on strength and elastic modulus of F800 SiC particle reinforced Al-6wt.%Fe powder extrusions.

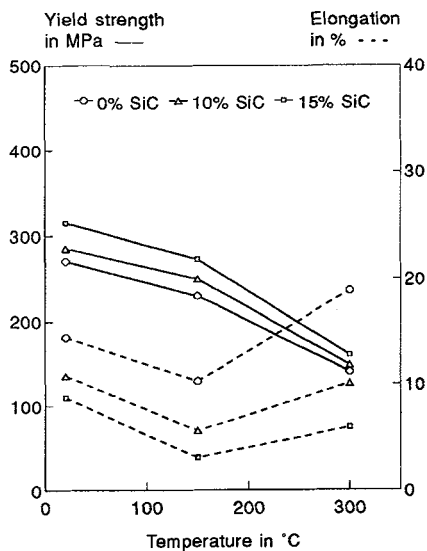


Fig. 7 Temperature effects on tensile properties of F800 SiC particle reinforced Al-6wt.%Fe powder extrusions.

No powder mixing effects were visible in microstructures of the powder composites that would give any indication for possible effects on mechanical properties. Figures 8 and 9 show yield strength, elongation, fracture toughness and elastic modulus of Al-6wt.%Fe powder extrusions reinforced with 10 vol.%SiC particles (Fig. 8). Differences in strength and elastic modulus are most likely caused by scatter that is due to the different locations in the extrusions where the specimens were taken from and were not related to powder mixing techniques.

An effect of hydrogen would be expected in ductility or fracture toughness of the composites. With all material, elongation is reduced by about 30 % by the presence of SiC particles. Fracture toughness is even more reduced, but still acceptable for a number of applications. The increased hydrogen content in the powders milled in the planetary ball mill and the attritor, as detected by mass spectroscopy, does not additionally affect these properties. In comparable alloys it has been observed that the effect of hydrogen or additional internal defects on fracture toughness and ductility is not visible below certain limits of properties. The loss of ductility caused by the addition of SiC particles to Al-6wt.%Fe alloy powder most likely is already too high that the contribution of hydrogen content would lead to a lower ductility.

In the Al-6wt.%Al matrix, alloy powder particle surface oxides and hydroxides affect ductility and fracture toughness of the consolidated material. Degassing of powders generally improves these properties and an increase in hydrogen content leads to deterioration. With the addition of SiC particles, SiC surfaces and interfaces of these particles with the matrix determine the mechanical properties at a higher degree as the alloy powder surfaces.

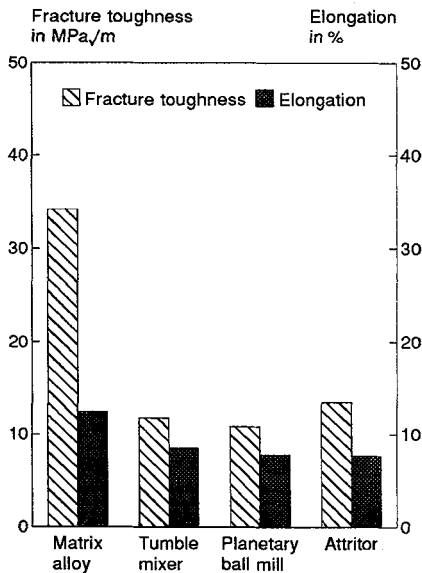


Fig. 8 Effect of mixing techniques on fracture toughness and elongation of Al-6wt.%Fe powder extrusions reinforced with 10 vol.%SiC particles

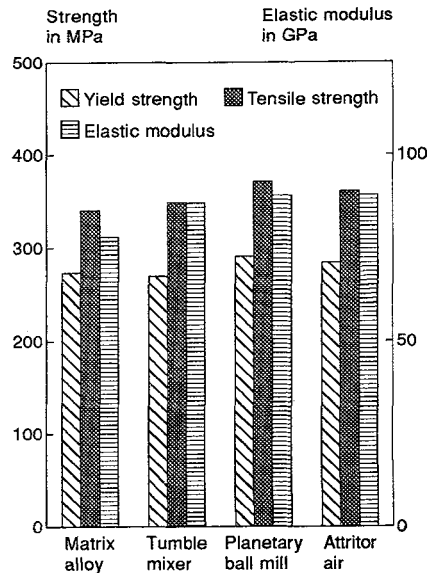


Fig. 9 Effect of mixing techniques on strength and elastic modulus of Al-6wt.%Fe powder extrusions reinforced with 10 vol.%SiC particles

Summary

Mixing techniques for Al-6wt.%Fe and SiC powders have an effect on the hydrogen that evolves from the powder mixtures during processing. Mixing processes such as planetary ball milling and attritor milling can lead to the creation of fresh aluminum surfaces by hard and sharp SiC particles. This process leads to oxidation of aluminum and generation of hydrogen.

In the consolidated and extruded products, no effects of mixing on the microstructure was observed. There were also no effects of particle size on the particle distribution in the extruded material other than effects caused by the particle density at a given volume fraction. Large particles were cracked more frequently during extrusion than small ones.

The gain in strength and elastic properties of the composites was qualitatively maintained in the full temperature range of the Al-6wt.%Fe alloy up to 300°C. In the particle size range investigated (4 to 16 μm), the size of the particles and the mixing technique almost did not affect mechanical properties.

Acknowledgement

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