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Preparation of aluminium–fly ash particulate composite by powder metallurgy technique

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Aluminium–fly ash mixtures containing different weight percentages of fly ash were prepared and compacted at pressures from 138–414 MPa. The compacts prepared at 414 MPa were sintered in nitrogen atmosphere at 600, 625 and 645 °C, respectively. The time of sintering ranged from 0.5–6 h. The densification parameter and the green densities of the compacts were determined as a function of compacting pressure and fly ash weight per cent. Density, hardness and strength of the sintered compacts were determined as a function of weight per cent of fly ash particles. Volume changes during sintering of green compacts were also evaluated as a function of increasing fly ash weight per cent. Microscopic studies of green and sintered compacts were done to study the effectiveness of sintering. Green and sintered density of the compacts were found to decrease with increasing weight per cents of fly ash. Sintering results in slight decrease in density and increase in volume of green compacts within the range investigated. Strength of the sintered compacts decreased with increasing weight per cent of fly ash under the present experimental conditions; however, the hardness was found to increase slightly up to 10 wt% fly ash, beyond which it decreased.

1. Introduction

Particulate composites have been developed now to a level of commercial production. Ingots of cast aluminium matrix composites are being produced by Duralcan [1]. Aluminium matrix powder metallurgy (P/M) composites are produced in amounts up to 22 700 kg y^{-1} by DWA composites [2]. Potential users of aluminium–silicon carbide composites are expected to be the automotive industries. However, the cost of silicon carbide is a barrier in the widespread use of composites in automotive applications. Therefore, we studied the powder metallurgy synthesis of aluminium–fly ash composites which have the potential of becoming a low-cost composite.

Millions of tons of fly ash powder is generated in coal-based power plants and only a small portion of it is being utilized. This is a waste by-product and is being used as a filler in aluminium matrices [3, 4]. Where fly ash particles are used as filler in aluminium alloy casting, it reduces cost and density and increases wear, seizure and abrasion resistance and stiffness [5]. Dispersion of particulate material in metal matrices results in composites with improved damping capacity, machinability, wear and seizure resistance, and low coefficient of friction and thermal expansion [6, 7]. The above properties are desirable in materials for automotive applications. Various components such as pistons, engine cover, connecting rod castings have been made out of cast aluminium alloy–fly ash composites [5]. The powder metallurgy technique is capable of producing composites with a uniform distribution and range of concentration of particles. This paper describes the preparation of aluminium–fly ash particulate composites by conventional powder metallurgy (compaction and sintering) route.

2. Experimental procedure

Commercially pure (99.9%) aluminium powder of less than 106 μm size supplied by Aldrich Chemical was used in this investigation. Fly ash powders were received from Wisconsin Electric Power Company, USA (precipitator fly ash), and PSI Energy, USA (cenosphere fly ash). The size of precipitator fly ash was less than 75 μm and that of cenospheres ranged from 50–150 μm. The size, distribution and shape of the powder particles were evaluated using scanning electron microscopy. Cenosphere particles were hollow spheres with an apparent density ranging from 0.4–0.6 g cm^{-3} whereas precipitator fly ash consisted of solid particles with apparent density ranging from 2.1–2.3 g cm^{-3}.

Aluminium and fly ash powders were dried in an oven at 110 °C for 1 h. These were mechanically mixed

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using a rotating drum blender. Mixtures of aluminium–fly ash powders containing 5–20 wt % fly ash, were prepared. The powder mixtures were compacted at pressures ranging from 138–414 MPa using a uniaxial hydraulic press. Graphite powder mixed with silicone fluid was used as die-wall lubricant. Compacts of 25.4 mm diameter and 6.4 mm thickness were made using a hardened steel die. The densification parameter and green density of the compacts were evaluated as a function of compacting pressure and fly ash weight per cent. The effects of sintering were studied on compacts made at 414 MPa. The compacts were sealed in transparent silica tubes under pure nitrogen and sintered at temperatures above 600 °C for 0.5–6 h. The change in volume during sintering and density, hardness, compression strength and microstructure of sintered compacts were evaluated.

3. Results and discussion

The effect of compaction pressure on densification parameter is shown in Fig. 1. This figure indicates that the densification parameter increases with increasing value of the compacting pressure and approaches 0.85 and 0.95 at 414 MPa for 20 and 5 wt % fly ash, respectively. The above values of densification parameter are close to 1, hence all the compacts subjected to sintering were made at 414 MPa. Scanning electron micrographs of green compacts of aluminium–precipitator fly ash and aluminium–cenosphere fly ash are shown in Figs 2 and 3, respectively. These figures show uniform distribution of fly ash particles in the aluminium matrix. Fig. 3 shows that some cenosphere particles are broken into pieces during the compaction conditions of present study. This adversely affects their capability of reducing the density of the composite by virtue of their hollow shape and low density. Because the cenosphere particles break during compaction and are not able to maintain their hollow shape, a detailed sintering study was carried out only on aluminium–precipitator fly ash compacts, because precipitator particles are mostly solid and do not break during compaction as shown in Fig. 2.

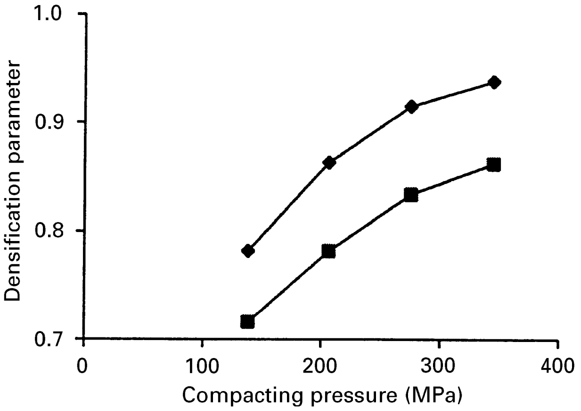

Figure 1 Effect of compacting pressure on the densification parameter. (◆) Al–5 wt % fly ash, (■) Al–20 wt % fly ash.

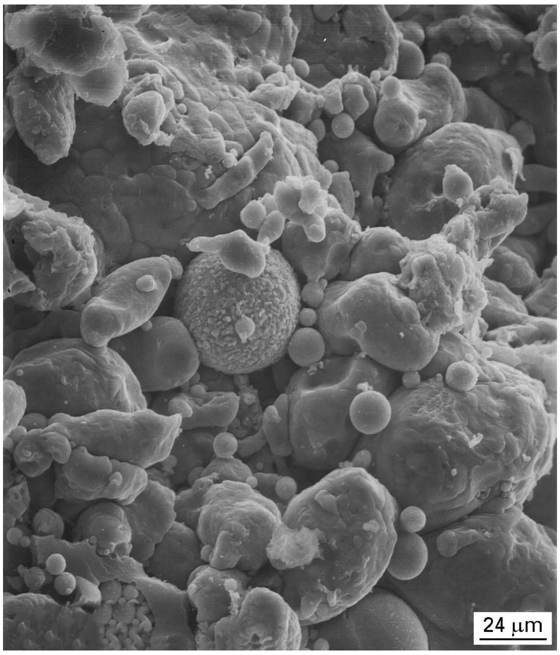

Figure 2 Scanning electron micrograph of Al–10 wt % precipitator fly ash green compact.

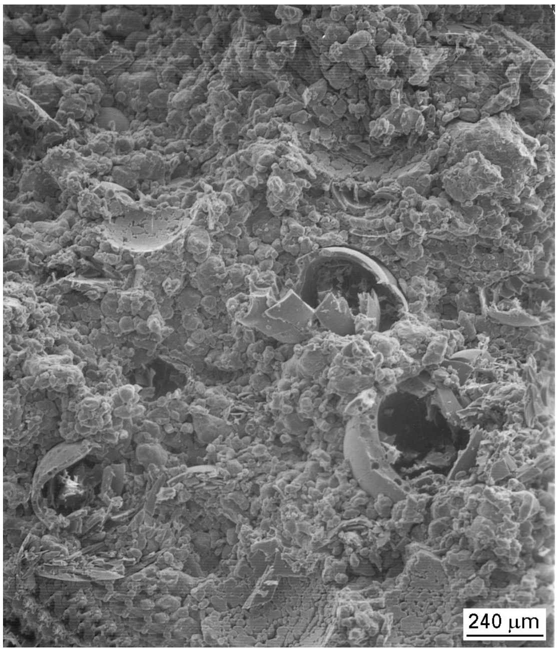

Figure 3 Scanning electron micrograph of Al–5 wt % cenosphere fly ash green compact.

The density of the green and sintered aluminium–fly ash compacts as a function of fly ash weight per cent is shown in Fig. 4. This figure indicates that the sintered density decreases with an increase in the fly ash content. It also shows the calculated density of aluminium–fly ash composite based on the rule of mixtures.

The difference between the calculated and observed density indicates the presence of porosity in the sintered compact. The presence of porosity is a characteristic of P/M products. Fig. 4 shows that the difference between the calculated and observed density increases with increasing weight per cent of fly ash. This indicates that the porosity in the sintered aluminium fly ash compacts increases with increasing weight per cent of fly ash particles. The green density values

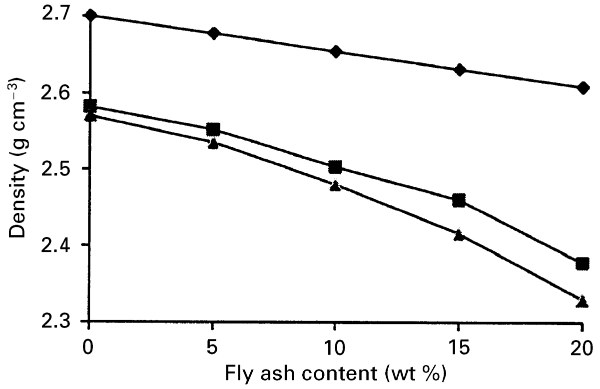

Figure 4 Effect of precipitator fly ash content on the sintered density of aluminium–fly ash composite; sintering temperature 625 °C, sintering time 2.5 h, compacting pressure 414 MPa. (◆) Calculated density, (■) green density, (▲) sintered density.

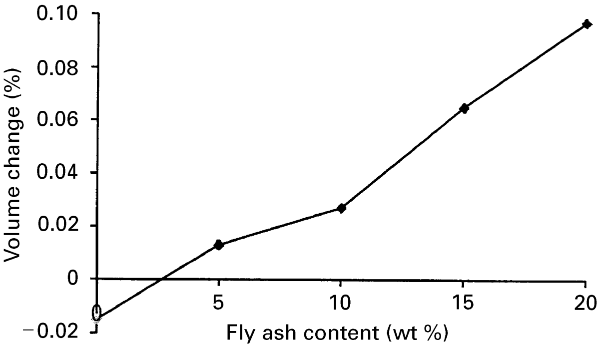

Figure 5 Effect of precipitator fly ash content on the change in volume during sintering of aluminium–fly ash compacts; sintering temperature 625 °C, sintering time 0.5 h, compacting pressure 414 MPa.

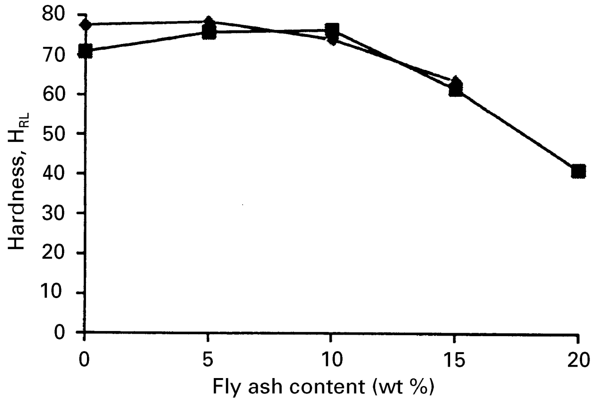

Figure 6 Effect of precipitator fly ash percentage on the sintered hardness; sintering time 0.5 h. Sintering temperature: (◆) 625 °C, (■) 645 °C.

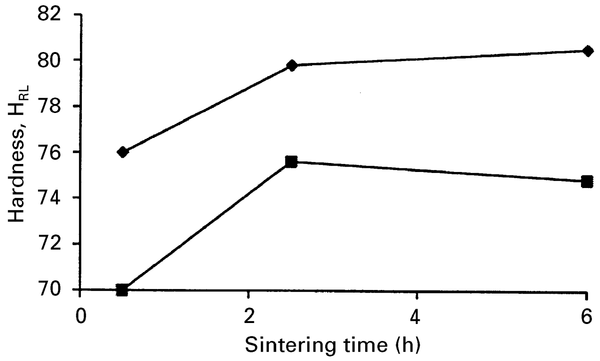

Figure 7 Effect of sintering time on the sintered hardness; sintering temperature 645 °C, compacting pressure 414 MPa. (◆) Al–10 wt % fly ash, (■) aluminium.

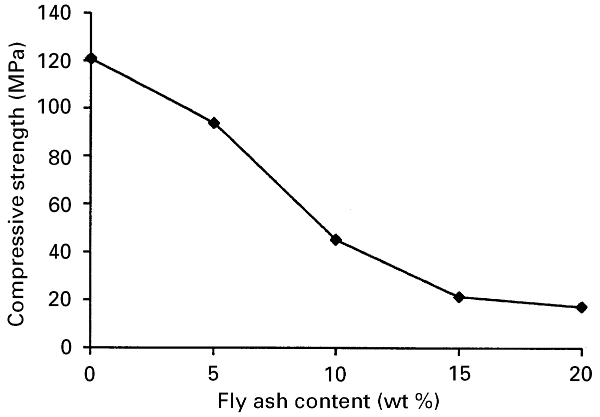

Figure 8 Effect of precipitator fly ash content on the compressive strength of sintered aluminium–fly ash composite; sintering temperature 625 °C, sintering time 0.5 h, compacting pressure 414 MPa.

shown in Fig. 4 indicate that these are higher than that of sintered density, thus green compacts expand and their porosity increases on sintering. Fig. 5 shows the percentage change in volume during sintering of the aluminium–fly ash compacts as a function of fly ash weight per cent. This figure indicates that as a result of sintering there is positive change in volume (expansion) of green compacts which increases with increasing weight per cent of fly ash. However, this increase was nominal and for Al–20 wt % fly ash it was less than 0.1%. Such an increase in volume as a result of sintering was also observed in the case of Al–Pb [8] although the values were higher than that shown in the present investigation.

Fig. 6 shows the Rockwell hardness as a function of fly ash weight per cent for the aluminium–fly ash compacts sintered at 625 and 645 °C, respectively. This figure shows that increasing weight per cent of fly ash results in a decrease in hardness of aluminium fly ash compacts. The effect of time of sintering at 645 °C on the hardness of aluminium and aluminium–10 wt % fly ash composites is shown in Fig. 7. This figure shows that the hardness of aluminium fly ash composites sintered at 645 °C was higher than that of aluminium. The above figure also shows that hardness increases with increasing sintering time from 0.5–2.5 h, beyond which increasing sintering time does not cause appreciable change in hardness.

The effect of fly ash content on the strength of aluminium–fly ash powder compacts sintered at 625 °C for 0.5 h is shown in Fig. 8. This figure indicates that under the conditions of present study, the sintered strength decreases with increasing weight per cent of fly ash particles; sintered strength is particularly low above 10 wt % fly ash. The poor strength

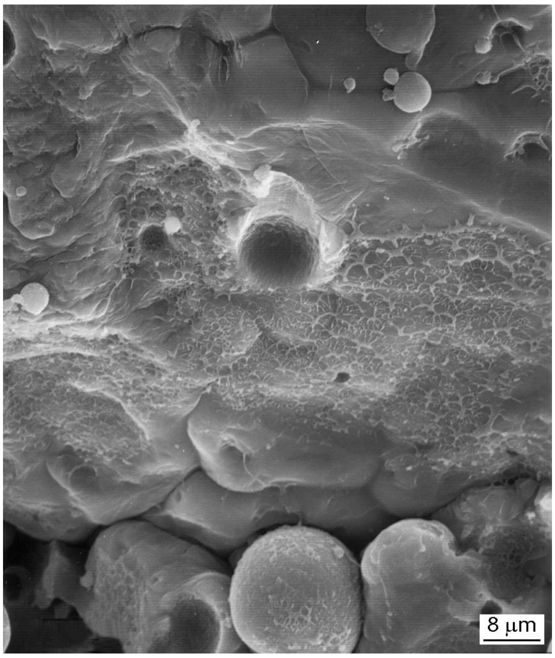

Figure 9 Scanning electron micrograph of sintered aluminium–20 wt % precipitator fly ash compacts; sintering time, 2.5 h, sintering temperature 625 °C.

is also a sign of poor interfacial bonding between the fly ash particles and the aluminium matrix in aluminium–fly ash sintered composite.

A scanning electron micrograph of aluminium–precipitator fly ash compact sintered at 625 °C for 2.5 h is shown in Fig. 9. A comparison of Figs 2 and 9 suggests that recrystallized grains may be developing during sintering at 625 °C for 2.5 h.

4. Conclusions

1. Aluminium–fly ash composites can be prepared by powder metallurgy techniques involving pressing with pure aluminium powder followed by sintering.

2. The densification parameter of aluminium–fly ash compacts increases with increasing compacting pressure and decreases with increasing fly ash weight per cent.

3. Some cenosphere fly ash particles are broken during compaction under the condition used in this study. This suggests that powder metallurgy techniques should be restricted to precipitator fly ash.

4. The green as well as sintered density of aluminium precipitator fly ash composites decreases from 2.58 $\mathrm{g\,cm^{-3}}$ to about 2.3–2.4 $\mathrm{g\,cm^{-3}}$.

5. Sintering of aluminium–fly ash compacts results in a slight increase in volume and decrease in density of the green compacts.

6. The strength of sintered compacts decreases with increasing weight per cent fly ash particles under the conditions of present study. The results suggest that longer sintering times and higher sintering temperature may be necessary to make aluminium–fly ash composite with improved properties.

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