Sintering behaviour of Al-Cu-Mg-Si blends

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Abstract

The increasing demand for automotive industries to reduce the weight of the vehicles has led to a growing usage of Al alloy powder metallurgy (P/M) parts such as camshaft bearing caps, shock absorber pistons and brake calipers [1,2]. In order to control the sintered microstructure and mechanical properties of the aluminium alloy powder metallurgical (P/M) parts, it is essential to establish a fundamental understanding of the microstructural development during the sintering process. Current research at Birmingham University is focussed on the investigation of the sintering behaviour of Al-Cu-Mg-Si powder blends using a combination of Scanning Electron Microscopy, Energy Dispersive Microanaylsis (SEM) and Differential Scanning Calorimetry (DSC). This paper presents a detailed study of the effect of temperature and initial starting materials on the evolution of microstructure during the sintering of Al-Cu-Mg-Si blends for PM.

1. Introduction

The demand for Al powders for P/M products in North America has increased by 15% per year to 1353 tonnes in 1999 [3, 5]. These Al P/M products are primarily based on blended powder mixtures. Several P/M aluminium alloys are available for commercial use. The most commonly used for automotive components is 2xxx series, especially 2014 grade. This alloy is the P/M equivalent to the wrought AA2014 alloy. However, the P/M 2014 alloy contains Si addition for improved wear properties [6] and enhanced liquid phase sintering behaviour [7]. Liquid phase sintering of Al alloy is currently the only accepted technique that is capable of producing P/M components with acceptable mechanical properties[8, 9]. The liquid phase sinteraids usually are made up of either low melting point elemental additions such as Sn, Zn, Pb, etc or a low melting point eutectic phase such as Al-12%Si master alloy. The presence of a liquid phase not only enhances the atomic interdiffusion but also helps to break up the oxide layer on the powder. However, the disadvantage of liquid phase sintering of Al alloy is that distortion within the P/M part and a reduction in mechanical properties due to the formation of a brittle intergranular phase can occur.

Current research is focussed on the optimisation of sintering conditions to improve the mechanical properties of aluminium P/M components[7,10]. Schaffer et al.[11,12,13] demonstrated the benefficial effect of Sn as a sinteraid in the liquid phase sintering of Al alloy powders [14].

They observed that trace addition of elemental Sn to the blended powder can enhance the liquid phase of Al-Cu alloys by diffusing into the Al matrix ahead of Cu and thus decreasing the transient aspect of the cycle. However, there is a limited amount of data available in the literature about microstructural developments undergone by different aluminium blends during sintering.

This paper presents a detailed study of the phase transformation occurring during the sintering of Al-Cu-Mg-Si blended powder mixtures as a function of initial starting particulate constituents and sintering temperature using a combination of differential scanning calorimetry (DSC) and scanning electron microscopy (SEM).

2. Experimental

Two types of aluminium blends namely *EleMix* and *AlloyMix* provided by The Aluminium Powder Company Limited (Alpoco) were studied. *EleMix* is a blend of gas atomised elemental Al powders with elemental Mg and Cu powders and Al-12wt%Si master alloy powder. *AlloyMix* is a blend of gas atomised elemental Al powders with additions of Al-50wt%Mg, Al-54wt%Cu and Al-12wt%Si master alloy powders. The gas atomised elemental Al powders used in EleMix and AlloyMix have the same size distribution (+45-150μm) that was optmised for maximum flow properties [16]. The overall chemical composition of both blends was the same Al-4.4%Cu-0.5%Mg-0.6%Si. Both *EleMix* and *AlloyMix* powder mixtures were blended in a Turbula mixer operating at 50 rpm and 25 mins.
The blended powders were compacted into discs of 5mm in diameter and 10mm thick using a pressure of 20tsi. The die wall was lubricated with Accrawax to ease removal of the compacted samples.Sintering of compacts were carried out in a horizontal tube furnace with a dynamic flow of nitrogen to maintain a dew point of -45 ^{o}C. The compacts were heated at a rate of 10 ^{o}C /min to a range of temperatures of 475 ^{o}C, 510 ^{o}C, 540 ^{o}C and 600 ^{o}C for a fixed time of 10mins, before the microstructures of the sintered components were frozen by quenching them in a pool of liquid nitrogen. The quenched samples were then mounted in cold mount resin and polished for subsequent SEM studies. Microstructure and chemical composition were studied using a Jeol 6060 SEM coupled to an Oxford Instruments Energy Dispersive Analyser.

Phase transformations during the heating of blended powders of blended *EleMix* and *AlloyMix* were studied using a Netzch Jupiter DSC operating with a dynamic flow of nitrogen, a heating rate of 10 ^{o}C /min over a temperature range between 200°C and 700°C. In addition the reactions between binary mixtures of Al-4.4%Cu, Al-0.6%Si and Al-0.5%Mg prepared by either mixing Al powder with elemental Cu and Mg powders or master alloys powder (eg. Al-50%Mg, Al-50%Cu and Al-12%Si) were also studied in the DSC using a similar procedure.

3. Results

3.1 Differential Scanning Calorimetry Study

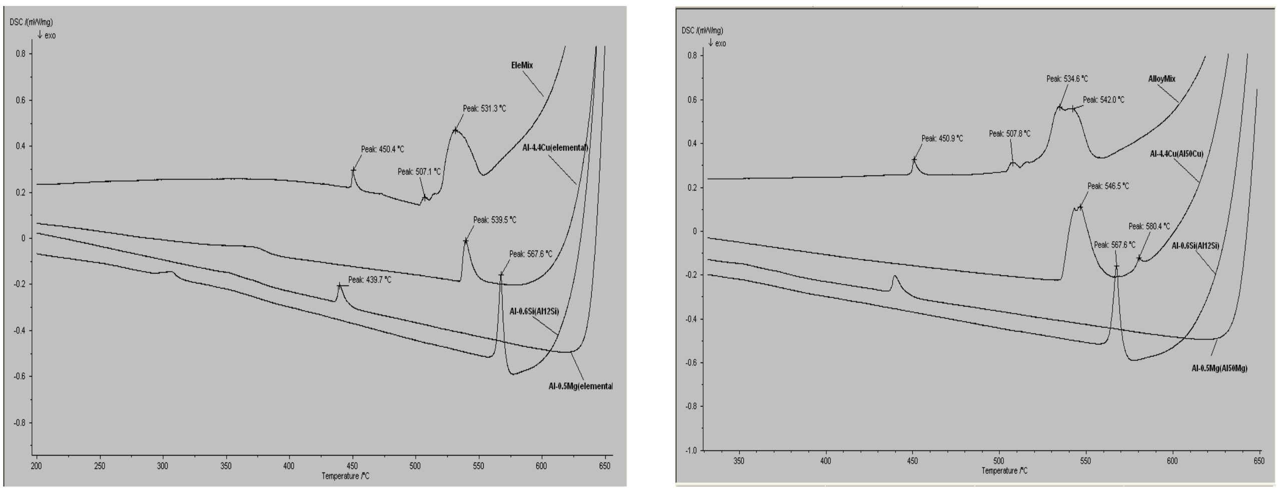

Figure 1. DSC traces of (a) EleMix and (b) AlloyMix Al-Cu-Si-Mg powder blends and Cu, Mg andSi binary combination with Al using elemental (a) and master alloy (b) alloying additions.

Figures 1(a-b) show typical DSC traces of *EleMix* and *AlloyMix* AlCuSiMg powders, respectively together with binary elemental mixture of Al-4.4wt%Cu, Al-0.6wt%Si and Al-0.5wt%Mg for comparison. For binary Al-4.4%Cu, Al-0.6%Si and Al-0.5%Mg systems prepared using Al and elemental alloying additions, DSC shows endothermic peaks at about 440ºC, 540ºC and 567ºC which correspond to the eutectic melting temperature[15] as shown in Fig.1(a). Similar DSC peaks were observed for binary compositions prepared using Al and master alloy alloying additions. In addition another endothermic peak with an onset temperature around 590 ^{o}C, corresponding to the melting of Al-Mg, Al-Cu and Al-Si solid solutions, is observed.
It is believed that interdiffusion between the starting particulate constituents causes the intial formation of eutectic liquid. However, further heating causes more interdiffusion and changes the composition and amounts of the liquid-solid phases (eg. transient aspect). Eventually, all the liquid dissapears and the solid solution remains which melts at a higher temperature. However, this mechanism of phase transformation in binary systems appears to be independent of the type of starting alloying addition (eg. elemental or master alloy).
For the *EleMix* samples, the DSC trace in figure 1(a) consists of three endothermic peaks at 450 ^{o}C, 507 ^{o}C and 530 ^{o}C. *AlloyMix* samples show a very similar DSC trace in Fig 1(b). The 450 ^{o}C peak is believed to correspond to the formation of Al-Mg eutectic liquid. However, the subsequent peaks at higher temperature are believed to be caused by formation of a ternary liquid phase.

3.2 Microstructural study

Microstructure of specimens heated up to the critical transformation temperatures indicated by the DSC peaks was evaluated.

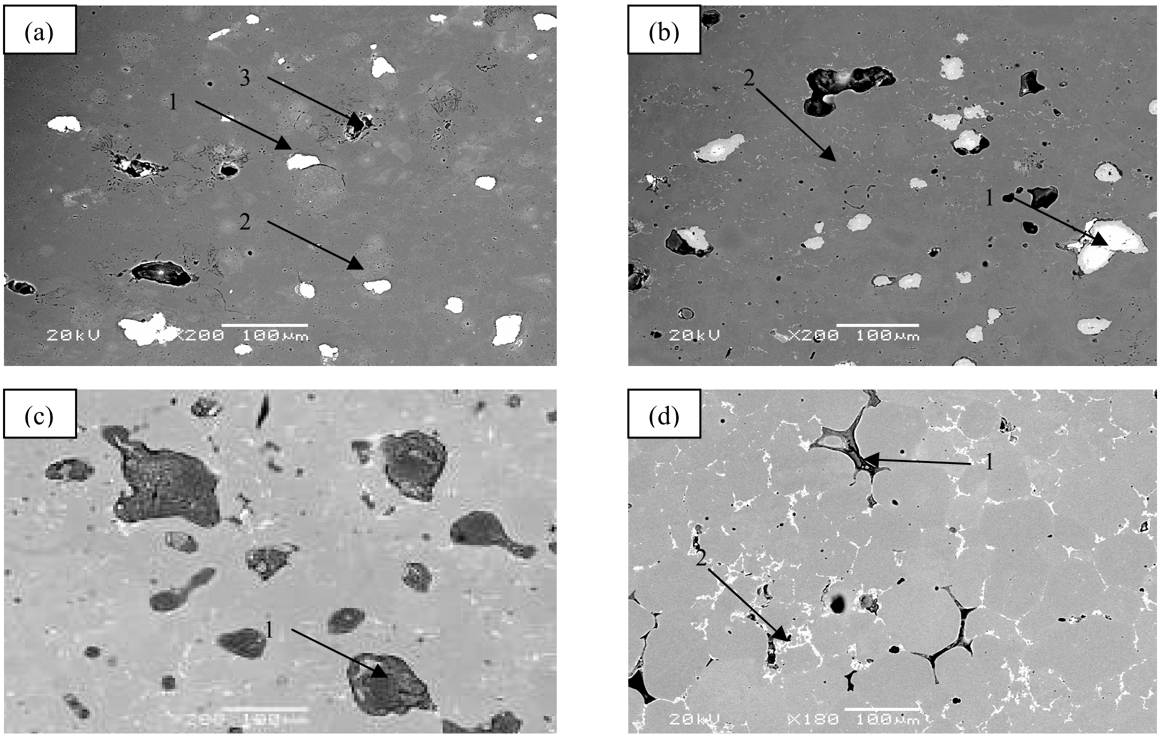

Figure 2 SEM micrographs of AlloyMix Al-Cu-Si-Mg powder blend heated upto (a) 475 ^{o}C, (b) 510 ^{o}C, (c) 540 ^{o}C and (d) 600 ^{o}C for 10mins and quenched in liquid nitrogen.

At 475 ^{o}C the microstructure consisted of Al matrix with undissolved Cu particles (1), Si rich eutectic regions (2) and pores (3). At 510 ^{o}C the microstructure consisted of Al matrix with large Cu particles (1) and very fine Cu precipitates (2) and pores. The region in the vicinity of pores in the above cases appeared to be rich in Mg. At 540 °C the microstructure consisted of large melt pools (1) which have a composition of mainly Al-Si but traces of Cu and Mg were found.

At 600 °C the microstructure consisted of a fully developed Al grains with a grain boundary phase rich in Cu and Si (2). However, remnants of the Al-12%Si eutectic liquid can still be observed (1). At temperatures below 540 °C sintering involves diffusion of Mg into Al and formation of Al-Mg eutectic liquid. At 540 °C Cu formed Al-Al2Cu structures and Al-12%Si master alloy eutectic powder turned into liquid. Higher temperature brings the formation of a ternary eutectic liquid located at the Al grain boundaries.

4. Conclusion

- DSC studies suggest the formation of a series of liquid phases (eg. Al-Mg, Al-Cu and Al-Si)
- Low sintering temperature involves the diffusion of Mg and Cu into the Al matrix.
- High sintering temperature involves formation of eutectic liquids leading to liquid phase sintering.

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