EFFECT OF LUBRICANT ON STRENGTH OF ALUMINA PARTICULATE REINFORCED ALUMINIUM COMPOSITES PRODUCED BY HOT PRESSING TECHNIQUE

Junaidah Jai

Advanced Materials Centre (AMREC), SIRIM Berhad
Lot 34, Jalan Hi-Tech 2/3, Kulim Hi-Tech Park
09000 Kulim, Kedah, Malaysia.
(junejai@salam.uitm.edu.my)

RINGKASAN: *Komposit berasaskan logam merupakan bahan termaju yang telah dibangunkan untuk digunakan di dalam bidang eroangkasa serta otomotif. Ciri-ciri sifat komposit berasaskan logam ini sangat bergantung kepada taburan saiz butiran, bentuk butiran, pecahan isipadu penguat di dalam logam asas, taburan bahan penguat di dalam logam asas serta kaedah penghasilan yang digunakan. Di dalam kaedah penghasilan secara metallurgi serbuk, pelincir telah digunakan untuk mengurangkan daya geseran yang terhasil di antara serbuk dan dinding acuan. Pada masa yang sama, dengan menggunakan pelincir, taburan serbuk logam yang sekata dapat dihasilkan dan ini menghasilkan produk tersinter yang mempunyai sifat mekanik yang tinggi. Untuk kajian ini, kesan pelincir terhadap kekuatan komposit asas logam telah diselidiki. Zink stearate (ZnS) telah dipilih sebagai pelincir. Aluminium aloi (Al 6061) berpenguat 10 pecahan isipadu (vol.%) Al_2O_3 telah dihasilkan dengan menggunakan beberapa jumlah pecahan berat (wt.%) ZnS seperti 0 wt.%, 0.1 wt.%, 0.5 wt.%, 1.0 wt.% dan 1.5 wt.%. Al_2O_3, Al 6061 serta ZnS pada peratusan yang telah ditetapkan seterusnya digaul menggunakan kaedah 'ball milling'. Untuk penyelidikan ini, komposit asas logam telah dihasilkan dengan menggunakan kaedah penekanan panas. Sampel-sampel yang telah ditekan panas seterusnya dipotong kepada bentuk yang sesuai untuk ujian lenturan tiga-titik. Permukaan sampel yang telah patah seterusnya dianalisa dibawah 'scanning electron microscope' (SEM). Keputusan menunjukkan bahawa penambahan ZnS memperbaiki kekuatan lentur komposit asas logam yang terhasil.*

ABSTRACT: Metal matrix composites (MMCs) are advanced materials that have been developed for aerospace and automotive applications. Properties of MMCs very much depend on the particle size distribution, particle shape, volume fraction of reinforcement in the matrix, distribution of reinforcement in the matrix and the fabrication technique involved. In Powder Metallurgy (PM) technology, a lubricant is used to decrease a friction force, which occur between the powders and the die wall. At the same time, with lubricant, it is possible to achieve a homogeneous distribution of some elements in a metal powder and also to increase the mechanical properties of the sintered product. In this study, effect of lubricant on the strength of the MMCs was investigated. Zinc stearate (ZnS) was chosen as the lubricant. 10 volume fraction (vol.%) of Al_2O_3 particulate reinforced aluminium alloy (Al 6061) MMCs were produced using different weight percent (wt.%) of ZnS, which were 0 wt.%, 0.1 wt.%, 0.5 wt.%, 1.0 wt.% and 1.5 wt.%. Al_2O_3, Al 6061 and ZnS were mixed by ball milling process according to the required formulation. For this investigation, the MMCs were produced by hot pressing technique. The hot pressed samples were sectioned to the required shape for three-point bending test. The fracture surface of the samples was observed under scanning electron microscope (SEM) for surface evaluation. Results show that an addition of ZnS improve the bending strength of the MMCs.

KEYWORDS: Metal matrix composites, aluminium alloy, alumina, hot pressing, bending strength, porosity.

INTRODUCTION

Over the past decade massive US government funding has been directed towards the research and development of MMCs for military and aerospace applications. The benefits of these developments will eventually spin off into every-day life, in electronics and leisure goods, and in machine parts for manufacturing industries. There is now a firm conviction that widespread usage of MMCs will first be adopted by the automotive industry.

The driving force behind the automotive interest is the demand for lighter weight engines capable of delivering higher performance, improved fuel economy, lower emission engine and reduced noise. An important way of reducing engine weight is by substitution of aluminium for cast iron and steel as mentioned by Dinwoodie (1987).

Aluminium alloy is capable of offering weight saving in lowering density, improving strength and stiffness. MMCs in general, consist of two or more dissimilar phases, namely the metal matrix combined with a high-strength reinforcement phase. The two constituents must be compatible with each other, both physically and chemically. MMCs can be classified into either continuous-fibre composites and discontinuous reinforced composites. The reinforcement is added to the metal matrix in order to improve strength and stiffness. The potential of MMCs has improved with the advent of new and less expensive reinforcement such as Al_2O_3 and SiC. With the addition of these ceramic reinforcements, the strength, modulus and wear resistance increase with a reduction in ductility and fracture toughness as stated by Tan *et al.* (1993).

Ibrahim *et al.* (1994) reviewed that for application which does not require extreme loading and thermal conditions, such as in automotive application, discountinuous reinforced MMCs offer isotropic properties with improvements in strength and stiffness, relative to those available with unreinforced materials.

A variety of processing techniques have evolved over the last two decades in an effort to optimise the structure and properties of particulate (discontinuous) reinforced MMCs. The processing method can be grouped according to the processing temperature of the metallic matrix. Accordingly, the processes can be classified into three categories; (a) liquid phase processes, (b) solid state processes and (c) two-phase (solid-liquid) processes as reviewed by Ibrahim *et al.* (1994).

In solid state processes, the fabrication of particulate reinforced MMCs involve a number of steps prior to final consolidation either by PM (Powder Metallurgy) or high energy rate processing. PM route includes sieving of powders, mixing of matrix with the reinforcement, pressing to approximately 75% density and final consolidation by extrusion, forging, rolling, vacuum hot pressing or some other hot working method. Properties of MMCs that are produced by PM technique are very much dependent on particle size distribution, particle shape, volume fraction of reinforcement in the matrix, distribution of reinforcement in the matrix and the fabrication technique involved.

In PM technology, a lubricant is used to decrease the friction force that occurs between the powders and also between the die wall and the powder. With lubricant added, it is possible to achieve a homogeneous distribution of some elements in a metal matrix powder and also increases the mechanical properties of a sintered product due to the increase in a compact density as quoted by Yoichi *et al.* (1998). The zinc (Zn) stearate and lithium (Li) stearate are among the familiar lubricants used in PM industries.

This paper investigates the effect of lubricant on the strength of Al_2O_3 particulate reinforced Al 6061 MMCs. 10 vol.% Al_2O_3 particulate reinforced Al 6061 MMCs were produced using different wt.% of ZnS, which were 0, 0.1, 0.5, 1.0 and 1.5 wt.%. The MMCs were produced by the hot pressing technique, whereby the mixed powders were pre-formed and hot pressed at a temperature of 550°C under a pressing load of 280 MPa for 10 minutes in a vacuum environment. The hot pressed samples were sectioned to the required shape for a three-point bending test. The fracture surface of the samples were observed under the scanning electron microscope (SEM) for surface evaluation.

MATERIALS AND METHODS

The matrix is aluminium alloy (Al 6061) powder with a particle size range of 38 to 53 μm. The shape is a combination of spherical and irregular and it was produced by the gas atomisation process. The shape is shown in Figure 1(a). The reinforcement used is Al_2O_3 particulate and it is irregular in shape. Size of the particle is in the range of 59 to 130 μm, as shown in Figure 1(b). The chemical composition of both the matrix and reinforcement are as listed in Table 1. ZnS is used as the lubricant in this experiment.

The matrix and reinforcement are mixed with the lubricant. The mixing process is carried out using a one-litre ceramic container and 12 pieces ceramic balls of 10-mm diameter. Mixing ratio of the matrix and the reinforcement is fixed at 90:10 with different amounts of the lubricant; 0, 0.1, 0.5, 1.0 and 1.5 wt.%. The mixing time and speed are 6 hours and 90 rpm respectively. A mixture of the matrix and the reinforcement is pre-formed at 186 MPa. The pre-formed samples are then delubricated at 450°C for 5 minutes before being hot pressed at 550°C for 10 minutes with 280 MPa pressing load in vacuum atmosphere better than 1×10^{-5} torr. The hot pressed samples were sectioned to the required shape for the three-point bending test. The fracture surface of the samples were observed under scanning electron microscope (SEM) for surface evaluation.

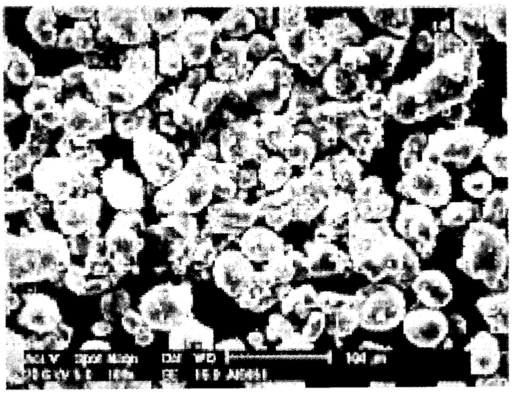

Figure 1 (a). *Particle shape of Al 6061 powder*

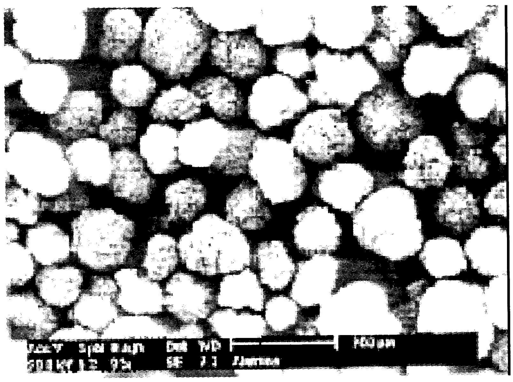

Figure 1 (b). *Particle shape of alumina powder*

Table 1. Chemical composition of both the Al 6061 matrix and Al_2O_3 reinforcement

Al 6061		**Al_2O_3**	
Element	**wt/wt %**	**Element**	**wt/wt %**
Aluminium	83.1	Alumina	99.85
Magnesium	0.64	Na_2O	0.02
Silicon	0.66	SiO	0.05
Iron	0.38	Fe_2O_3	0.02
Copper	0.19	TiO_2	0.01
Chromium	0.20	MgO	0.01
Zinc	0.13	CaO	0.03
Titanium	0.04	K_2O	0.01

RESULTS AND DISCUSSION

The bending strength is as shown in Table 2 while Figure 2 shows the microfracture surface of Al 6061 matrix with different wt.% ZnS. With 0.0 and 0.1 wt.% ZnS the bending strength of the MMCs is 344.30 MPa and 305.11 MPa respectively while fracture surface of both MMCs show agglomeration of Al_2O_3. The cavities observed are not regular in shape and size. Small pores at the grain boundaries can be observed within the fracture surface.

Table 2. Mechanical strength of 10 vol.% Al_2O_3/AL 6061 MMCs with different wt.% ZnS

MMCs	Bending Strength (MPa)
0.0 wt.% ZnS	344.30
0.1 wt.% ZnS	305.11
0.5 wt.% ZnS	398.41
1.0 wt.% ZnS	404.93
1.5 wt.% ZnS	370.63

An increase of wt.% ZnS to 0.5 and 1.0 wt.%, increases the bending strength of the MMCs to 398.41 MPa and 404.93 MPa respectively. There was a drastic change in the fracture surface of 0.5 and 1.0 wt.% ZnS as compared to 0.0 and 0.1 wt.% ZnS. Fracture surfaces show that the cavities are regular in shape and size. There are some Al_2O_3 agglomeration on the fracture surface of 1.0 wt.% ZnS and pores are observed along the grain boundaries for both of the MMCs. At this stage the pores do not affect the strength of the MMCs.

With 1.5 wt. % Al_2O_3, cavities are still regular in size and shape, there are no Al_2O_3 particles clusters but big pores can be observed in the fracture surface. The bending strength of the MMCs decline to 370.63 MPa. The reduction in bending strength is due to the effect of pores in the MMCs. Table 3 shows the effect of wt.% ZnS on the porosity of Al 6061 metal matrix.

Table 3. Porosity of 10 vol.% Al_2O_3/Al 6061 MMCs with different wt.% ZnS

MMCs	Porosity (%)
0 wt.% ZnS	2.8
0.1 wt.% ZnS	7.08
0.5 wt.% ZnS	8.60
1.0 wt.% ZnS	10.55
1.5 wt.% ZnS	14.78

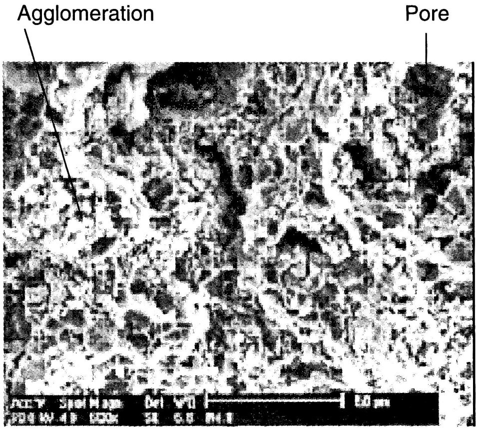

Figure 2 (a). *Microfracture surface of 10 vol.% Al_2O_3/Al 6061 MMC with 0.0 wt.% ZnS*

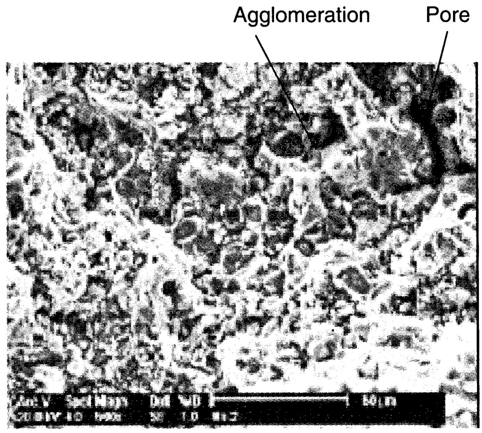

Figure 2 (b). *Microfracture surface of 10 vol.% Al_2O_3/Al 6061 MMC with 0.1 wt.% ZnS*

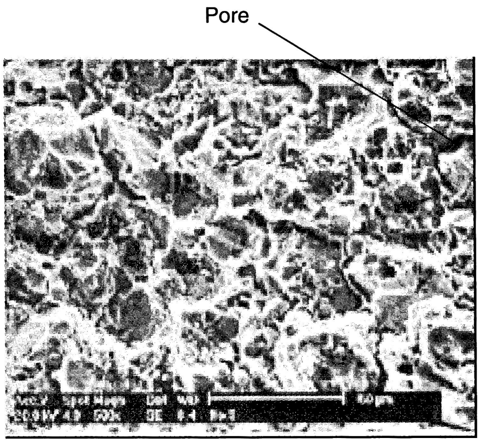

Figure 2 (c). *Microfracture surface of 10 vol.% Al_2O_3/Al 6061 MMC with 0.5wt.% ZnS*

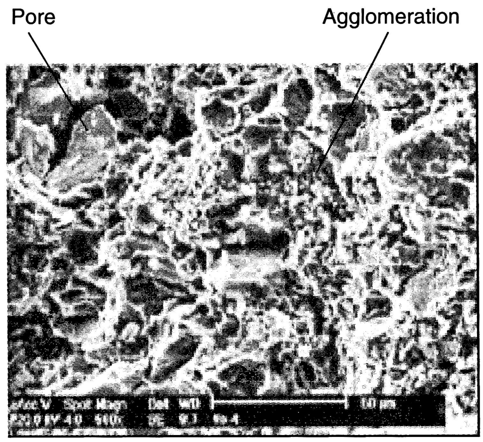

Figure 2 (d). *Microfracture surface of 10 vol.% Al_2O_3/Al 6061 MMC with 1.0 wt.% ZnS*

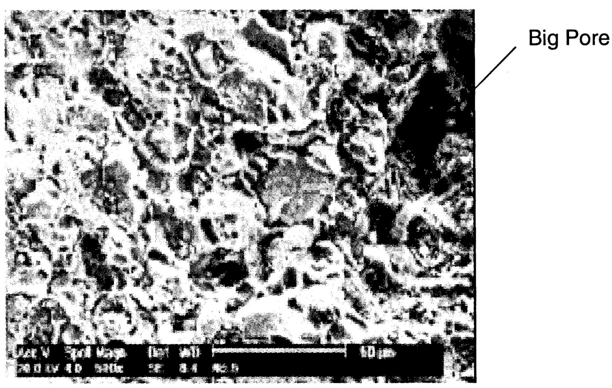

Figure 2 (e). *Microfracture surface of 10 vol.% Al_2O_3/Al 6061 MMC with 1.5 wt.% ZnS*

Strength of MMCs is based on the load transfer from matrix to the reinforcement. The formation of pores due to Al_2O_3 agglomeration disturbed the load transfer from the matrix to the reinforcement in the MMCs. Sweet *et al.* (1991) stated that ZnS helps relative particle movement for better particle distribution. With 0.1 wt.% ZnS, the amount of lubricant is not sufficient in helping the particle movement within the MMCs during the hot pressing process. This leads to the formation of agglomeration and porosity in the MMCs. However with 0.5 wt.% and 1.0 wt.% ZnS, the amount of lubricant is able to help in the particle movement and arrangement to obtain homogeneous particle distribution. Hence, less agglomeration of Al_2O_3 is observed, the cavities of the fracture surface are regular in shape and size, and this improves the bending strength of the MMCs. With 1.5 wt.% ZnS, although the lubricant helps in the distribution of particles and in shaping the fracture surface cavities to regular size and shape but the amount of lubricant has exceeded the requirement for 10 vol.% Al_2O_3/Al 6061 MMCs. Excess lubricant that has accumulated at the grain boundaries, during delubricating process of the ZnS burned off and leave empty spaces (pores) at the grain boundaries of the MMCs.

CONCLUSION

In PM processing using hot pressing technique, lubricant plays a very important role especially for producing homogeneous grain size structure, good particle distribution and high mechanical strength. For this study using 10 vol.% Al_2O_3/Al 6061 MMCs, the optimum amount of ZnS is in the range of 0.5 to 1.0 wt.%.

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