THE USE OF POWDER METALLURGY ROUTES FOR MANUFACTURING ALUMINIUM ALLOY 6061 AND ALUMINIUM ALLOY 6061 BASED MATRIX - SiC COMPOSITES

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ABSTRACT

Powder metallurgy routes have been used to manufacture unreinforced aluminium alloy 6061 (AA6061) and aluminium alloy 6061 based metal matrix composites (MMCs). The materials were composed from elemental aluminium based 6061 powders. The composites were reinforced by 15\%SiC with an average size of 23 µm. The materials were vacuum degassed at 470°C and continuously vacuum sintered at 610°C and 620°C for AA6061 and MMCs, respectively. Samples were cut from the as sintered billets to examine the quality of the materials through microstructures observation. Residual porosity was found in all materials and the density was 93 - 95\% from the theoretical value. A relatively good dispersion of SiC was achieved and the SiC clustering was shown unlikely to occur.

The as sintered billets were solution homogenised at 330°C for 1.0 h and directly hot rolled at 500°C and 520°C for AA6061 and MMCs, respectively. The overall sectional reduction was designed 3\% - 7\%, and to avoid a temperature drop the billets were reheated for each pass. A total reduction of 32\% in cross sectional area was achieved for AA6061 after 15 passes and surface cracks started to appear. However, only a total reduction of 28\% can be achieved for MMCs after 5 passes and edge cracks started to occur. From the microstructures observation showing that the porosity was significantly reduced, the SiC reinforcements were aligned in the rolling direction, and a near theoretical density was achieved. The hardness of the as sintered billets was 55 HV20 and 60 HV20 for AA6061 and MMCs, respectively, and increased by 58 HV20 and 62 HV20 after a hot rolling treatment.

The ageing behaviour of the above materials was then investigated. Samples were solution homogenised at 540°C for 0.5 h in argon gas environment, directly quenched in liquid nitrogen, and aged in an oil bath at 175°C. It was shown that a peak aged reached at 3 to 5 h and 1.0 to 2.0 h with a peak hardness of 120 HV20 and 136 HV20 for AA6061 and MMC, respectively.
1. INTRODUCTION

It has been proven that aluminium alloys have relatively good mechanical properties at room temperature, but their strength decreases significantly at elevated temperatures. By using reinforcements such as SiC or Al2O3 particulates or whisker forms, which is so-called metal-matrix composites (MMCs), the reinforced aluminium alloys have shown better properties even at elevated temperatures. Recently, MMCs have been applied in aerospace and other industries because of their superior mechanical and physical properties to most of conventional alloys (McDaniels, 1985). The mechanical properties of MMCs can be enhanced significantly by incorporating a stronger and stiffer phase as reinforcement in such matrix (Cooper & Kelly, 1969). In addition, the physical properties of these MMCs can also be improved as a result of the incorporated reinforcements. The advantages of MMCs may be summarised as (1) increased stiffness, strength and stiffness, which reduces structural weight and increases performance; (2) a decrease in the thermal coefficient expansion, which reduces thermal strain in structural undergoing thermal cycles; (3) increased creep strength, wear resistant, corrosion resistant.

The majority of MMC production is discontinuously reinforced with particulate or whisker forms of SiC or Al2O3 in aluminium, magnesium and other matrix alloys. These materials are processed using methods that are similar to conventional deforming processes, or casting of metallic alloys, and consequently are considerably less expensive than continuous fibre reinforced composites of the lower costs of reinforced metal and the lower cost of processing (Ghosh, 1995). There are several methods available for fabricating composites (Ghosh, 1989). However, these are generally used in liquid state processing and solid state processing. Both methods require that the powder metallurgy techniques, in which the amount of processing temperature will determine whether of using solid or liquid state processing.

In the present work, a liquid phase sintering process has been used in which surface of elemental particles melted, while inside of them remained a solid state. The sintered billets were subsequently hot rolled to reduce porosity, to obtain smaller good sizes, and to allow matrix flowing between reinforcement particles so that any contiguity or pore can be avoided. The quality of the billets was examined using a microstructure observation and a Vickers hardness tester.

2. MATERIALS PREPARATION

There were two different materials have been used in the present work, namely unreinforced AA6061 and MMC. The MMC was reinforced by 15% SiC particles with average size of 23 µm. Commercial elemental powders equivalent to AA6061 were composed to produce unreinforced AA6061 and MMC billets. Both material alloys were fabricated using the same route, namely powder metallurgy techniques. The compositions of the material alloys are presented in Table 1.

![Table 1: Chemical composition of unreinforced AA6061 and MMC alloys produced by elemental powders, wt%](image)

<table>
<thead>
<tr>
<th>Powder Type</th>
<th>Mg</th>
<th>Si</th>
<th>Cu</th>
<th>Al</th>
<th>SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA6061</td>
<td>1.0</td>
<td>0.4</td>
<td>0.25</td>
<td>balance</td>
<td></td>
</tr>
<tr>
<td>MMC</td>
<td>1.0</td>
<td>0.4</td>
<td>0.25</td>
<td>balance</td>
<td>15</td>
</tr>
</tbody>
</table>

![Figure 1: Setting of temperature controller for drying aluminium powders](image)

Before manufacturing these alloys, aluminium powders were dried to remove moisture contents which may affect the quality of material alloys. The drying process was carried out in a vacuum furnace at a temperature level of 470°C and maintained for approximately 6 hours. To achieve the above temperature, the furnace controller was set as shown in Figure 1. The remaining of powder alloys were added according to the percentage of weight composition as shown in Table 1.

3. MANUFACTURING PROCESS

The processing procedure in the present work is shown in Figure 2. The elemental powders, which have been composed according to Table 1, were mixed. A Turbula mixer (11°C) was used for dry blending the mixture of matrix powders and SiC particles as necessary. After blending, the powders were formed into rectangular shape using a mould made of a soft polymer material. To avoid handling of the powders on the mould, the mould was coated by silicon fluid. The shaped alloys were then cooled isothermally at a rate of about 280 K/min followed by vacuum degassing at 470°C for 1.5h and vacuum sintering at 615°C and 800°C for AA6061 and MMC, respectively for 1.5h. The furnace controller was set as shown in Figure 1. The as
Sintered billets were examined their specific densities and showing the values of 2.46 and 2.59 for AA6061 and MMC, respectively. These values are substantially below a theoretical value, which is about 2.6. This indicates that some pores exist in the as sintered billets.

Figure 2. Diagram of PM fabrication route in the present work

Figure 3. Setting of temperature controller for degassing and sintering

To reduce the porosity, the as sintered billets were rolled using a two high rolling mill with 140 mm diameter rolls, with a constant speed of 150 mm/s. The billets were solution homogenised at temperature of 530°C for about 1.0 h and were subsequently rolled at temperature of 500°C and 520°C for AA6061 and MMC, respectively. Roll reduction per pass was designed approximately 3% - 7% in cross sectional area. After 15 passes the rolling process for AA6061 was stopped due to surface cracks starting to appear and the final reduction is approximately 52% of its original cross sectional area. The rolling process for MMC was stopped after 5 passes due to edge cracks and the final reduction is approximately 28% in cross sectional area. The density after rolling is 2.59 and 2.62 or increased by 4.91% and 1.27% for AA6061 and MMC, respectively, which is close the theoretical value.

The microstructures at each stage of processing were examined via an optical microscopy observation. Samples were cut from the billets and were mounted on epoxy resins by curing them in cylindrical shapes with a standard size provided by the Buehler company. The samples were then polished using a procedure recommended by the Struers company for AA6061, while for MMC, it was adopted from the procedure for polishing ceramics and finally the samples were polished similar to the procedure of final stage of polishing AA6061. It is important to note that MMC samples have to be polished using diamond particles on a napkin pan.

The as sintered billets were also examined their hardness using a 20 kg load on a Vickers hardness tester to see the hot rolling effect of the material properties. An average of 5 indentations was taken for each sample. For the hot rolled billets, only on the rolling direction was examined.

4. EXPERIMENTAL RESULTS

4.1. Microstructure

The microstructures of the as sintered billets are shown in Figures 4a-6b for AA6061 and MMC, respectively. Residual porosity was present in all materials and the density was about 92 - 94% of the theoretical value. Most of the pores in MMC were associated with the close proximity of SiC particles. The prior particle boundaries of the aluminium powder are clearly visible, especially in AA6061 and are decorated with the remaining fragments of the aluminium oxide skin. It was not shown a tendency to form chillies.

Figures 5a-6b represent the microstructures of AA6061 and MMC hot rolled material in longitudinal direction, respectively. The porosity was minimised significantly compared to the all sintered materials and a near theoretical density was reached. Oxides and precipitates appeared as stringers in the direction of rolling. The SiC particles having a high aspect ratio were also partially aligned in the hot rolling direction. However, the matrix material showed to be unable to flow around the reinforcements, which may be caused by the low applied temperature; especially far from the surface. The grain boundaries under optical microscopy were found to be refined.

The hardness of the as sintered billets was 55 HV20 and 60 HV20 for AA6061 and MMC, respectively, and increased by 58 HV20 and 62 HV20 after a hot rolling treatment.
Figure 4. Microstructures of materials after sintering process

Figure 5. Microstructures of materials after sintering process

Figure 6. Aging curves of AA6061 and MMC containing 15%SiC

5. DISCUSSION

5.1. Microstructural Studies

The high density of the billet materials is primarily resulted from parameters such as dryness of the powders, magnitude of the isostatical compaction pressure, and temperature and time applied during liquid phase sintering. During the liquid phase sintering stage the oxide decoration would be disrupted and dispersed and the original particle boundaries were no longer traced. However, massive particle movement would not be occurred via liquid phase sintering. If clustering of SiC particles occurred during previous processing stage, it would persist into the as sintered microstructure.

The presence of large size pores associated with the close proximity of SiCp in the as sintered materials could be related to the inability to create sufficient (or any) liquid phase in these regions or to cause liquid phase to penetrate. It is well established that for densification to take place during liquid phase sintering it is essential to have an appreciable liquid phase, appreciable solubility of the solid in the liquid, and wetting of
the solid in the liquid (Kingery et al., 1976). The driving force for densification is derived from the capillary pressure on the liquid phase located between the fine solid particles. For the Al alloy - SiCp composites the first and the last of these conditions are important as is the high viscosity of the liquid during the processing. When clustering or contacting of SiC particles occurs there is high probability of little or no matrix powder being incorporated with them and the above conditions are therefore difficult to meet. A slowing or ceasing of densification will be induced, which results in the retention of voids in these areas.

From an examination of the microstructure of the as sintered composites, Figure 5, it would be expected that via liquid phase sintering, optimum mechanical properties unlikely to be achieved. Hot rolling was therefore selected as the second processing stage of these sintered materials, which aim of consolidating and improving their homogeneity.

Upon hot rolling of the as sintered billets, the Al 6061 matrix grains elongated and SiC particles were rearranged in the rolling direction. The elongated Al alloy particles undergo large-scale plastic flow and the clusters of SiC would be separated by the shear stress and redistributed. Previous vacuum sintering encouraged the removal of porosity in the rolling stage. Generally, the problem arises from hot rolling of these composite materials was caused mainly incomprehensibility of deformation characteristics of the matrix and the reinforcement, and the interface between the two (Mahajir et al., 1990).

Surface cracks may be caused the applied strain exceeds the critical strain in the related temperature. According to Raj (1981) and Humphreys et al. (1987), during deformation, when the applied strain rate is lower that a critical strain rate, which is a function of deformation temperature, reinforcement size, and volume fraction, the build-up of dislocation pile-up resulting from the limited plastic relaxation of the matrix will not occur. Therefore, the fracture of the reinforcement, or the forming of cavities around non-deformable particles, may be avoided (Stanford et al., 1989).

5.2. Ageing Behaviour

The accelerated ageing behaviour observed in the present study has been reported by several investigators (Rack et al., 1977; Rack, 1987; Appendino et al., 1991; Song, 1994; Ni, 1994), and has been ascribed to the increased dislocation density in the MMC matrix which results from the thermal contraction mismatch between the Al matrix and SiC particles during quenching (Vo-Duc et al., 1986). Therefore, the gap between solution and quenching temperatures will affect the dislocation density. The present results indicate that by using liquid nitrogen which is at -196°C, the hardness was higher than by using ice water quenching such as reported by Song (1994) and Ni (1994). In addition, a peak ageing was also achieved in shorter time than by using ice water quenching. However, a peak hardness did not change significantly and is the present work even gave a lower value.

6. CONCLUSION

Powder metallurgy routes using liquid phase sintering and hot rolling have been demonstrated to produce AA6061 and MMC from elemental 6061 based powders. Residual porosity in the as sintered billets was present in all materials and the density was about 92 - 94 % of the theoretical value. Most of the pores in MMC were found in the close proximity of SiC particles. The prior particle boundaries of the aluminium powder are clearly visible, especially in AA6061, and are decorated with the remaining fragments of the aluminium oxide skin. It was not shown a tendency to form clusters in MMC.

The porosity was minimised significantly after hot rolling and a near theoretical density was achieved. Oxides and precipitates appeared as stringers in the direction of rolling. The SiC particles having a high aspect ratio were also partially aligned in the hot rolling direction. However, the matrix material showed to be unable to flow around the SiC particles. The grain boundaries under optical microscopy were found to be refined. The hardness of the as sintered billets was 55 HV20 and 60 HV30 for AA6061 and MMC, respectively, and increased by 58 HV20 and 62 HV20 after a hot rolling treatment.

For the ageing behaviour, it was shown that a peak aged was reached at 3-5 h and 1-3 h with a peak hardness of 120 HV20 and 136 HV20 for AA6061 and MMC, respectively.

7. ACKNOWLEDGEMENT

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8. REFERENCES


MENCAKI KORELASI JUMLAH KENDARAAN YANG LEWAT DENGAN TINGKAT KEBISINGAN LALU LINTAS

Subbagi

ABSTRACT

Measurements of the traffic noise level and traffic density have been done. The obtained data can be used to develop a semi-empirical equation which shows the relation between the traffic volume and the noise level. This equation can be used for predicting the traffic noise level.

1. PENGANTAR

Kebisingan merupakan hasil sampingan pemanfaatan teknologi oleh manusia dan kadang-kadang disebut juga sebagai "bunyi yang tidak dikehendaki".

Sumber kebisingan dapat berupa apa saja, tetapi sumber utama kebisingan di daerah pemukiman adalah lalu lintas darat, yaitu kendaraan bermotor (Pride, 1982). Pengukuran kebisingan untuk mengetahui tingkat kebisingan di suatu daerah telah sangat dilakukan, tetapi data yang diperoleh pada umumnya merupakan data yang sisat, yaitu data yang diperoleh hanya sesuai dengan kondisi lalu lintas pada saat pengukuran dilakukan. Apabila salah satu faktor, misalnya tingkat kepadatan lalu lintas berubah, maka data yang telah didapat tidak sesuai lagi. Oleh karena itu perlu dicari hubungan matematis antara volume arus lalu lintas dengan tingkat kebisingan. Dari hubungan tersebut diharapkan dapat diprediksi tingkat kebisingan lalu lintas apabila jumlah kendaraan yang lewat per jam diketahui.


Berbeda dengan di negara maju, lalu lintas kendaraan bermotor di kota-kota di negara berkembang termasuk Indonesia sangat kompleks dan terdiri dari berbagai jenis kendaraan yang masing-masing menghasilkan tingkat kebisingan rata-rata yang sangat berbeda pula. Penelitian tentang tingkat kebisingan berbagai jenis kendaraan di India telah dilakukan (Rao, 1988) dan dari data yang didapat dapat dianalisis persamaan matematis untuk memprediksi tingkat kebisingan lalu lintas.

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