Processing and properties of composites Al/SiC Produced by powder metallurgy

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Abstract: The aim of the present work was the production of Al/SiC metal matrix composite by powder metallurgy. The material was produced by hot extrusion of aluminium ASTM 1100 reinforced with particulated silicon carbide. The reinforcement volumetric fraction was 5 %, 10 % and 15 %. The powders mixture were homogenized in a type "V" mixer, followed by compaction in aluminium cans. Each can was sealed, heated and rapidly transferred to a vertical hydraulic press where they were hot extruded. The mechanical properties such as yield strength, ultimate tensile strength, elongation and hardness were evaluated. The hydrostatic density after extrusion was also measured. The samples were microstructural characterized by metallography. It was found that the hot extrusion powders process is a suitable method for the production of metal matrix composites.

1. INTRODUCTION

The powder metallurgy (P/M) technique has some specific features which makes it an interesting metal matrix composite (MMC) fabrication process. The preparation of aluminium powders by the atomization process allows an increase in the alloying elements content and minor segregation effects. Silicon carbide particles can be homogeneously added to the composite. The aluminium oxide coming from the aluminium powder surface provides an additional reinforcement. This technique also presents good reproducibility. Another major advantage is the possibility of adding large reinforcement quantities (up to 55 %).

The presence of the aluminum oxide layer on the powder surface is a drawback in aluminium powder forming. Its thickness ranges from 0.01 µm to 1 µm and it is very stable at conventional sintering temperatures. Although it is very difficult to disrupt the oxide layer in conventional press and sintering processes, the hot extrusion technique can overcome this problem.

In this work, the processing of an aluminium reinforced with particulated SiC composite by P/M, is presented. The processing route was evaluated by mechanical properties measurements and by microstructural characterization.

2. EXPERIMENTAL

The aluminium powder used was an ASTM 1100 produced by air atomization. The use of a commercially pure aluminium permitted to investigate the process without the interference of other major alloying elements. The granulometric distribution and chemical analysis of the ASTM 1100 aluminium and SiC powders are shown in Table 1. Batches (2.5 kg) containing 5 %, 10 %, and 15 % volume fraction of SiC were prepared. One batch was prepared without SiC.

The powders were mixed in a "V" type blender for 4 hours to ensure a homogeneous blend. The mixtures were transferred to an ASTM 6063 aluminium can and then they were compacted at 100 tonne load (pressure ~ 60 MPa). A conical cover was pressed against the can and next was heated at 450 °C for 5 hours. This temperature is conventional for extrusion of commercially pure aluminium. The canning was used to decrease the powder air exposition, since no atmosphere protection was used during the extrusion preheating.

Table 1. *Granulometric distribution and chemical analysis of the ASTM 1100 aluminium and SiC powders used.*

aluminium powder			SiC powder		
particle size distribution		chemical composition	particle size distribution		chemical composition
under (%)	high size µm	(wt. %)	under (%)	high size µm	(wt. %)
2.7	10	Fe = 0.25	6.1	3	Fe = 0.18
16.5	20	Si = 0.17	23.6	6	Cu = 0.20
37.3	30	Mg + Cu < 0.005	48.7	10	$Si + SiO_2$ = 0.60
57.2	40	Al balance	72.8	15	Al = 0.15
71.4	50		89.3	20	SiC balance
88.8	70		98.2	30	
median	37		median	10	

The extrusion was performed in a vertical hydraulic press of 1500 tonne capacity. The extrusion ratio was 17:1. The maximum press load during the extrusion was in the range of 450 to 500 tonne. The extrusion speed spanned 23 to 25 mm/s. The extruded sections were round with 31 mm diameter and about 1 m of length.

The samples for optical metallography were sectioned, ground and polished following conventional metallographic procedures. The samples were subsequently eletroliticaily etched (700 ml ethyl alcohol, 100 ml butyl glycol, 68 ml perchloric acid and 100 ml water), at 1 A/cm^2 for 5 s.

Thin foils of the extruded aluminium without SiC were examined. The samples were mechanically cut and subsequently thinned by moist grinding on SiC emery paper down to 100 µm. The final perforation was done with the same electrolyte mentioned above in a twin jet electropolisher.

Cylindrical samples were used to determine the hydrostatic density after extrusion. A dried sample was weighed using an analytical balance. The sample volume was determined by weighing the sample immersed in water. The sample density was calculated by the dry weight divided by the volume.

The composite Brinell hardness (62.5 kgf, preload 10 kgf, sphere 2.5 mm) was measured at the centre of the sample and near the borders. Vickers microhardness measurements (20 gf load) were taken from the aluminium matrix. These measurements were performed in order to verify hardness difference across the transversal section.

Composite extruded specimens were tension tested at room temperature. The specimens were smaller than standard samples, and were prepared according to ASTM B557 M-81 recommendations. A universal testing machine was used and the strain was measured using an extensometer.

3. RESULTS AND DISCUSSION

During the composite mechanical polishing SiC was pulled out very often causing scratches in the sample. As the aluminium matrix is very soft and easily scratched, the final polishing was achieved by a 5 s electrolytic polishing. This procedure impaired artifact errors during microhardness measurements. The higher the SiC content, the more difficult the metallographic preparation.

Fig. 1 shows optical micrographs of the composite with 5 %, 10 % and 15 % SiC volume fraction, as extruded. It can be seen from this figure that the SiC particles agglomeration increases with the SiC content. Reinforcement agglomeration is often found in composites and the following procedures are recommended in order to minimize agglomeration in P/M produced MMCs: dry the powder before mixture since moisture influences agglomerations; apply high extrusion ratios; use thermomechanical treatments after extrusion; mixture by mechanical alloying[1,2].

The microstructure of the ASTM 1100 aluminium usually shows intermetallic phases containing Al-Fe-Si[3]. Second phases were observed in the aluminium matrix, which could be intermetallics and/or aluminium oxide. Transmission electron microscopy of the extruded material without SiC showed the presence of 0.1 µm to 0.3 µm particles in the matrix.

Fig. 2 shows the measured and calculated composite density. For the theoretical density calculation, density values corresponding to 2.71 g/cm^3 and 3.18 g/cm^3 for the aluminium matrix and SiC reinforcement, respectively, were used. As the alumina content was not known, the calculated aluminium density should be higher since the density of the Al_2O_3 is 3.8 g/cm^3 [4]. Fig. 2 show that the calculated and measured densities are very similar, however the measured densities are always lower than the calculated. Holes were observed by optical and electron scanning metalography, in the middle of some agglomerates. This could be the reason for the small difference between calculated and measured densities.

a) b) c)

Fig. 1 *Optical micrographs of the as extruded composite. a) 5 % SiC volume fraction. b) 10 % SiC volume fraction c) 15 % SiC volume fraction*

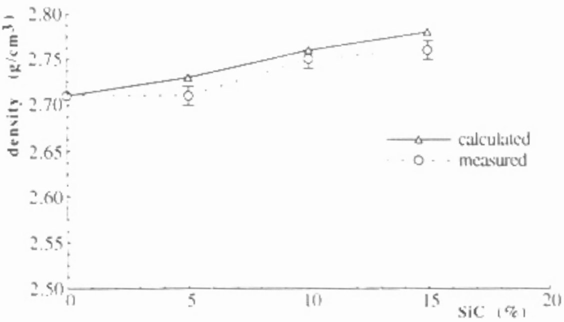

Fig. 2 *Comparison of calculated and measured composite densities for different SiC content*

Table 2 presents the mean values of Brinell and Vickers hardness obtained as function of the SiC volume fraction. The measurements were taken at the centre, between centre and border, and nearby the border. No significant hardness difference were found at different locations. This is confirmed by the low standard deviation.

The results show that Brinell hardness and Vickers microhardness, are similar for both composites, as extruded and annealed. This fact suggests that dynamic recrystallization might have occurred during extrusion. The Brinell hardness increased with the SiC volume fraction, as would be expected.

The mean Vickers microhardness for the composite matrix in the annealed condition was 36 ± 1 kgf/mm^2. This value is higher than that reported for the same aluminium obtained by ingot metallurgy (I/M), 23 kgf/mm^2 and 32 kgf/mm^2 in the annealed and cold worked condition (H14), respectively[3]. This difference is likely due to the dispersion of aluminium, intermetallics or a high dislocation density.

Table 2. *The mean hardness values measured for different SiC volume fractions*

SiC	Brinell hardness		Vickers microhardness	
(%)	as extruded	annealed	as extruded	annealed
0	36 ± 1	31 ± 2	35 ± 1	34 ± 1
5	38 ± 2	34 ± 2	36 ± 1	36 ± 1
10	44 ± 2	38 ± 3	37 ± 1	37 ± 1
15	49 ± 3	42 ± 3	37 ± 1	38 ± 1

The tension tests are presented in Fig. 3. These data show that an increase in the SiC content enhances the strength of the composite and diminishes its ductility and toughness. The ultimate tensile strength increases continuously with the SiC content. The yield strength shows a slight increase with the SiC content. The decrease in ductility was not significant, so the values are compatible with those corresponding to aluminium ASTM 1100 produced by I/M. elongation around 35 % and 9 % for the annealed and cold worked conditions, respectively. In Fig. 3, the mechanical properties of the aluminium ASTM 1100 in the annealed and cold worked H14 condition are also shown. It can be seen that the mechanical properties of the as extruded samples without SiC have both yield and ultimate strength. between that of annealed and cold worked aluminum produced by I/M. This difference in behaviour can be accounted for the presence of aluminium oxide and intermetallics in the aluminium matrix.

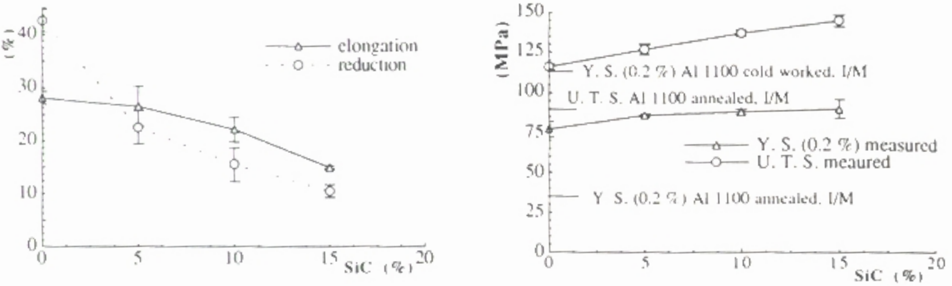

Fig. 3 *Mechanical properties of the composites as extrude as function of the SiC volume fraction. a) elongation and area reduction. b) yield strength (0.2 %) and ultimate tensile strength.*

4. CONCLUSIONS

1- The extrusion process of composites Al/SiC$_p$ (extrusion ratio 17:1) provides good particles distribution. However some, SiC agglomeration was observed and its number increased with the SiC content.
2- The mechanical properties varies with the SiC volume fraction. The yield strength, ultimate tensile strength and hardness increase with the SiC content whereas the ductility decreases.
3- The production of Al/SiC$_p$ composite for use at room temperature can be accomplished by hot extrusion of powders mixture, bearing in mind that the expensive degassing step can be avoided.

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REFERENCES

[1] Bacon M., Metal matrix composites - engineering materials solutions. *Mat. Edge* July/Aug. (1989) 33-41.
[2] Hunt Jr. W. H., "A perspective on the development of metal matrix composites", Meeting of the Detroit Section of the Metallurgical Society. Detroit-USA March (1988).
[3] Hatch J. E. Aluminium, properties and physical metallurgy. ASM Publication, USA. (1984) 25-57.
[4] Cotrell A. H. The mechanical properties of matter. John Willey. (1964) 112-115.