FORMABILITY OF METAL-MATRIX COMPOSITE BASED ON ALUMINIUM ALLOY 6061 - REINFORCED WITH SILICON CARBIDE PARTICULATES

L.HEGDE* AND S.N.PRASAD**

**NMAMIT, Nitte, Karnataka - 574 110, **NIFFT, Hatia, Ranchi - 834 003.*

Abstract

Aluminium alloy reinforced with hard ceramic materials has improved specific strength, specific modulus and wear resistance. Increasing amount of these reinforcing materials decreases ductility and CTE values. Many of these properties are desirable in aerospace, marine and automotive applications. There is no substantial data available as regards to forming characteristics of newly developed composite alloy.

The present work has been undertaken with a view to assess quantitatively the forming behavior of 6061-Al/SiC_p composites developed through conventional casting routes.

The cast composites were upset tested and drawn during study of formability. Ring compression tests developed by Male and Cockcroft have been used for determining the friction factor during upsetting of rings. The reduction capacity test was modelled using Avitzur's equations for forging of thin discs to estimate friction factor during upset forging a solid cylindrical disk under dry conditions. Friction factor has been estimated using a computer based on equation developed by Venugopal et al.

Increasing silicon carbide content from 10 vol% to 20 vol% resulted in decreased formability based on upset test. Initially this decrease was of the order of 20% which later decreased by 25%. The rate of decrease of formability was more pronounced beyond 15 vol% of silicon carbide particulate addition. Paper reports the systematic investigation carried out with composite rings of geometry 6:3:2 (OD:ID:Height) under different lubricating conditions to estimate co-efficient of friction. Interfacial frictional value decreased on changing the lubricating conditions from dry to 220 grade lubricant, and this was of the order of 20-25%. Lubricant 220 and furnace oil were foun to have similar characteristics between 25-45% deformation in height. Paper also reports the results of reduction capacity test during upset forging of samples with aspect ratio of 2 and 2.5. It was revealed that the friction factor has strong dependence on deformation percentage. The friction factors determined by

means of ring compression test and reduction capacity test with aspect ratio 2 are not in good agreement in cast Al 6061-SiC_p composite, however, they are very close when aspect ratio was increased to 2.5. Further work on forming behaviour of the composite is in progress and it is expected that these will fill up the existing gap in the development of metal matrix composites.

Introduction

Metal matrix composites are engineered combinations of two or more materials one of which is matrix and the other consisting of dispersoids of continuous or discontinuous fibres, whiskers, or particulates in the matrix. These materials are gaining importance because of improved properties such as, high specific strength, specific stiffness, high temperature properties, damping properties, machinability, friction wear and seizure resistance, low coefficient of expansion etc., that are found to be difficult in achieving collectively in conventional monolithic materials. Many of these properties are desirable in aerospace, marine and automotive applications. However, reinforcing of heavy material matrix (iron or steel) is not that much promising as that of light material (aluminium or its alloys) because, the improvement in properties is not substantial and that much can not be achieved by heat treatment or by alloying at economical cost of production.

Aluminium silicon carbide composites in which Al base alloy containing SiC as dispersoid have shown improved specific strength, specific modulus and wear resistance with increasing volume fraction of dispersoids. These composites have specific strength upto 50% higher than aluminum, specific stiffness 50% higher than steel and wear resistance ten times higher than aluminium. Co-efficient of thermal expansion of these composites decreases linearly with volume fraction of dispersoids. At elevated temperatures mechanical properties of these composites do not degrade as rapidly as those of unreinforced aluminium alloys.

Experimental details

The alloy chosen for the experiments is precipitation hardenable Al-Mg-Si (6061) alloy. Silicon carbide particles of average size of 43 μm were used as reinforcing material.

The base alloy was melted in crucible type resistance furnace and stirred with the help of motor driven stirrer. Silicon carbide particles were added to the rotating melt. Mg was added to the melt to improve the wettability of the particles with the matrix. The melted composite with different volume fractions (10, 15 and 20 vol.%) of silicon carbide were cast in the permanent mould. The final composition of magnesium was observed to be 1.5%. The casting was carried out at Regional Research Laboratory (CSIR), Trivandrum.

Formability :-

Upset Test :- The cast composites were cut to the sizes of 80 mm dia. and 60mm length for upset tests. The samples were heated to 470 ± 5°C in a muffle furnace for 30 minutes, subsequently forged for different reductions in height on 150 ton hydraulic press. The pressure applied during the tests was 85 ± 15 kg/cm^2. Dies of the press were maintained at 150 to 200°C to avoid chilling.

Ring Compression test for determination of Coefficient of friction :-

Rings of cast composite were prepared by machining having a geometry of 6:3:2 (OD:ID:Ht). The machined rings were heated in an electric furnace upto 450 ± 10°C and held for 15 min for uniform heating. The rings were upset to different heights from 10% to 50% in steps of 10% on a 150 ton hydraulic press, under three different lubricants, with the help of stoppers. The change in internal diameter with reduction in height has been taken as criteria to evaluate the co-efficient of friction μ and friction factor m.

Reduction capacity test :-

This test involves the upset forging of a solid cylindrical disk, where the percentage reduction in height of disk was used to estimate the friction factor.

Cylindrical specimens of 6061-Al/10 vol% SiC(p) composites of diameter 10 mm and 12.5 mm having aspect ratio 2 and 2.5 were taken for this test. These were compressed using 150 ton hydraulic press at constant strain rate under dry conditions. Friction factor 'm' has been estimated using computer routine to solve equation.

Mechanical properties :-

Tensile samples were machined and testing was done on Instron testing machine (model 1195) at RDCIS, SAIL, Ranchi. Due to poor machinability of the composite, carbide tools were used for machining.

Hardness were measured under 1000 kg load and with 10 mm dia ball on standard Brinell hardness tester. Average of 3 values have been taken.

Metallographic study was carried out on NIKON make optical microscope. The samples were ground and polished using different grades of emery papers and then cloth polishing was done using diamond paste and Hi-Fin oil at a speed of 300 to 600 rpm for 4 to 6 min. Metallographic study was carried out at magnifications of 100 x and 250 x.

Results and Discussions

Results are given in Tables 1 to 4, Figs. 1 to 4 and Plate 1 to 4.

Mechanical properties :-

Fig. 1, table 1 & 2 give mechanical properties of the metal matrix composites in as-cast condition as well as in forged condition. Increasing amount of carbide particulates increases hardness continuously. In case of 10% SiC the hardness increased by over 33% after upset forging. 1% increase in volume fraction of SiC in the matrix results in to 5 to 7% increase in the hardness values in as-cast condition.

The tables also indicate the UTS values in as cast as well as forged conditions. Forged samples have higher UTS values compared to cast samples. In case of upset forged samples the UTS values in the radial direction were better than those in the longitudinal direction. UTS value obtained in the case of composites with 20 vol.% SiC when upset forged to 30% reduction is almost same as that of composite with 10 vol. % SiC when upset forged to 50% reduction.

Formability test :-

Fig.2 gives the result of formability of the cast samples. It is evident from this figure that increase in SiC content resulted in decreased formability based on upset test. Initially 5% increase in SiC content decreased the formability by 20%. Further increase in the SiC content by same amount decreased the formability to 25%. For particular size of SiC particles it is observed that increase in volume percentage decreases the formability.

Coefficient of friction by ring compression test :-

In the case of 6061-Al/10 vol% SiC(p) composites study has been made to find out the co-efficient of friction and to grade the three lubricants based on ring compression test.

From table 3, it can be seen there is a decrease in interfacial frictional values on changing lubricating conditions. The maximum values of co-efficient of friction (μ) has been found under dry conditions. The minimum value of 'μ' has been obtained with proprietary lubricant 220 grade. The decrease in 'μ' with changing lubricants is of the order of 20 to 25%. The value of 'μ' with furnace oil as a lubricant is 0.28. Fig. 3 and Fig. 4 show that lubricant 220 and furnace oil have almost similar characteristics before 25-45% deformations and can safely be used for free forging or impression forging for simpler shapes. For the lubricants tested, dry condition is suited for deeper impression forging because of high co-efficient of friction.

Co-efficient of friction obtained in dry condition is 30 to 40% less for composites than co-efficient of friction for Al-Mg alloys under the same condition with similar ring dimensions. This decrease can be attributed to the presence of reinforcing material within the matrix.

Reduction capacity test :-

The table 4 shows the results of reduction capacity test with different reductions of samples of aspect ratios of 2 and 2.5. The shear friction factor (m) is determined by means of the tests and by using Computer routine. It can be revealed from the table that the friction factor has strong dependence on deformation percentage for both the l/d ratios of 2 and 2.5. But the friction factor determined by means of ring compression test and reduction capacity test with aspect ratio 2 is not in good agreement for 6061-SiC composites. However, with aspect ratio of 2.5, difference in the friction factor obtained from this test and that of ring test is less compared to that of with aspect ratio 2.

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Table 1
Mechanical properties of as-forged 6061-Al/SiC$_p$ composites

	Condition	UTS kg/mm^2	Elongation (%)	YS kg/mm^2	Hardness BHN
10 vol% SiC$_p$	Upset forge (50% Redn.)	10.93	1.00		50.00
		10.07	0.35		50.00
20 vol% SiC$_p$	Upset forge (30% redn.)	10.50	0.95	10.43	65.50
		10.24	0.55	10.21	

Table 2
Hardness values of 6061-Al/SiC composites at different conditions

	Condition	Hardness BHN
10 vol% SiC$_p$	As cast	37.5
	Upset forged	50.7
15 vol % SiC$_p$	As cast	47.5
	Cast + Upset	56.8
20 vol % SiC$_p$	As cast	63.9
	Cast + Upset	65.5

Table 3
Coefficient of friction from ring compression test

Sl. No.	Lubricating condition	Percentage deformation	% change in internal dia.	Coefficient of friction μ	Friction factor m
1	Dry	11.25	7.8	0.29	0.49
2	-do-	30.00	20.0	0.35	0.60
3	-do-	36.00	20.8	0.24	0.46
4	-do-	45.62	42.5	0.40	0.67
5	-do-	51.25	50.5	0.34	0.58
6	-do-	54.37	50.8	0.27	0.46
		Average 'μ'	= 0.31		
1	Furnace Oil	12.50	1.6	0.08	0.14
2	-do-	33.12	21.6	0.31	0.53
3	-do-	35.00	25.0	0.35	0.60
4	-do-	47.50	31.66	0.21	0.36
5	-do-	51.20	41.66	0.25	0.43
6	-do-	56.2	45.83	0.21	0.36
		Average 'μ'	= 0.28		
1	Lubricant 220	12.5	1.6	0.08	0.13
2	-do-	32.5	16.6	0.28	0.48
3	-do-	37.5	20.8	0.22	0.38
4	-do-	46.8	25.5	0.17	0.29
5	-do-	47.7	29.16	0.19	0.33
6	-do-	56.2	35.00	0.15	0.26
		Average 'μ'	= 0.17		

Table 4
Reduction Capacity test

Shear friction factors for 6061/10vol%SiC_p specimen of different l/d ratios at different deformation percentage.

Sl. No.	Deformation	l/d Ratio	
		2.0	2.5
1	10-16	0.21	0.21
2	20-25	0.17	0.25
3	26-30	0.02	0.29
4	45-50	0.06	0.41

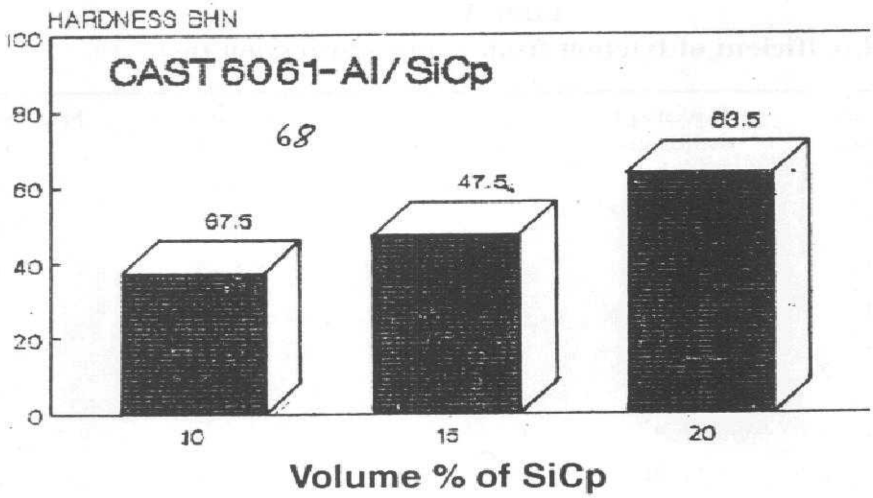

Fig. 1 - Hardness vs volume percentage of SiCp

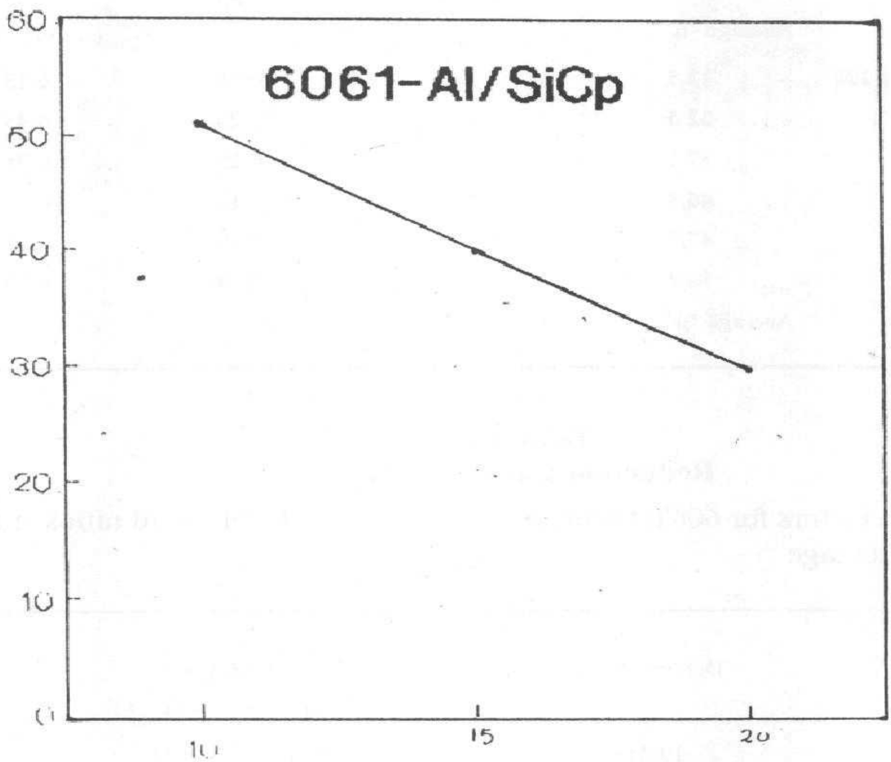

Fig. 2 - Deformation % vs volume % of SiC

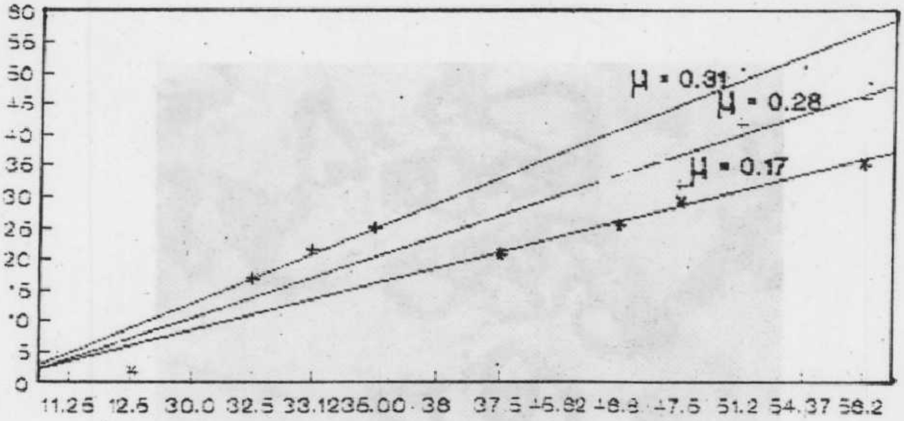

Fig. 3 - Change in internal diameter vs deformation %

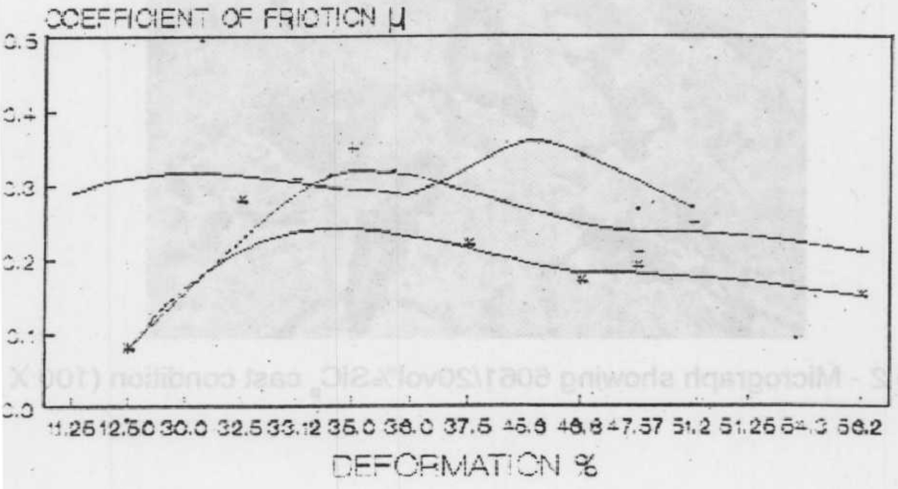

Fig. 4 - Coefficient of friction vs deformation %

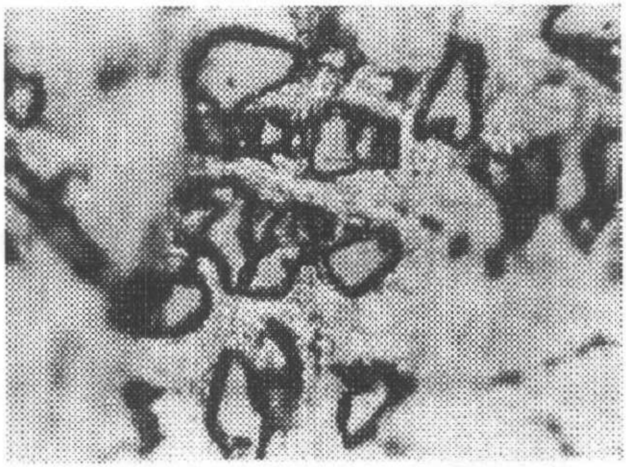

Plate 1 - Micrograph showing 6061/10vol%SiC_p cast condition (100 X)

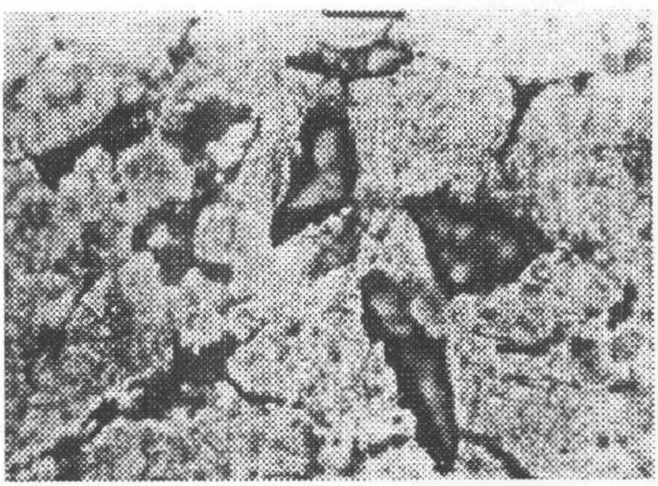

Plate 2 - Micrograph showing 6061/20vol%SiC_p cast condition (100 X)

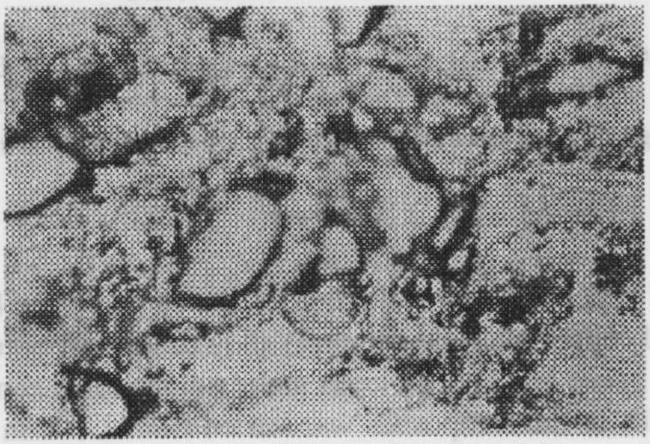

Plate 3 Micrograph showing forged (50% redn.) 6061/10vol%SiC_p

Plate 4 Micrograph showing forged (30% redn.) 6061/20vol%SiC_p