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Densification behaviour of Aluminium reinforced with Tungsten Carbide particulate Metal Matrix Composite processed by P/M

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ABSTRACT: *There is a huge demand for Aluminium matrix based composites (AMC) as they offer high specific strength and wear resistance as compared to pure Aluminium. In this study the densification effect of tungsten carbide (WC) particulate reinforcement in the Aluminium (Al) matrix was investigated. The Al composite was prepared by P/M process with tungsten carbide particulate of 2.5%, 5%, 7.5% and 10% on mass fraction basis. The preforms were prepared for the aspect ratios of 0.5, 0.75 and 1.0. The theoretical density of the preforms was calculated using rule of mixture. Compaction was carried out in UTM machine by applying load of 80 to 98KN. The preforms were sintered at 640°C for 60 minutes in a muffle furnace. The densities of the sintered samples were measured using Archimedes principle. The measured values were plotted for unreinforced Aluminium and the composite preforms. The experiment indicated that increase in WC particulate increases density of the preforms and a relative density of 93.73% is achievable. For aspect ratio 0.5 the progress in densification is linear indicating further densification is possible with addition of WCp more than 10%.*

Keywords - *Al composites, metal matrix composites, Tungsten carbide, Densification, Powder Metallurgy*

I. INTRODUCTION

1.1 Composites

Composite materials have attractive properties for use in Automobile, Aerospace, marine industries [1]. Composite is a mixture of soft & hard material to improve the mechanical, thermal & electrical properties [2,3]. Composite materials are broadly classified as Polymer matrix composites (PMC), Metal Matrix composites (MMC) and Ceramic Matrix composites (CMC) [4]. More research work was carried out in PMC compared to MMC & CMC.

For engineering applications MMC plays a vital role. For MMC, aluminium is the excellent material in non-ferrous family. Comparison of important properties of Al, Cu, Fe & Zn is given below in the Table 1.

Table 1

Properties	**Al**	**Fe**	**Cu**	**Zn**
Density g/cm3	2.7	7.9	8.9	7.1
Melting point ^{0}C	658	1540	1083	419
Thermal Capacity, J/kg,^{0}C	900	450	390	390
Thermal Conductivity W/m^{o}C	230	75	390	110
Coeff. of Linear expansion x10^{-6} ^{o}C	24	105	16	26
Modulus of elasticity GPa	70	220	120	93

Source:NICT

1.2 Aluminium Composites

Aluminium composites are the forerunners of material development during the last century. They are continually being explored by material design engineers and metallurgist to replace various conventional materials for optimal performance and economic feasibility. Besides having high specific strength, Aluminium composites show high specific stiffness, electrical and thermal conductivity, low coefficient of thermal expansion, and wear resistance [4].

The high ductility of aluminium is overcome by densifying with ceramic materials for increasing the ultimate strength and high temperature application. The author reviewed various literatures on aluminium composites and found SiC & Al_2O_3 reinforced composites are common. As alternative to these ceramics, this paper has been prepared on densifying Aluminium by reinforcing it with Tungsten carbide (WC) [5].

1.3 Particulate composites

Particulate composites are widely used in composites development because they are cheap and of manufacturing ease [4]. Particulates of SiC, Al_2O_3, Si_3N_4 & B_4C are common reinforcement used in preparing composites. Physical properties of the above ceramics are given in Table 2 below.

Table 2

Properties	WC	SiC	Al_2O_3	B_4C	Si_3N_4
Density g/cm^3	13-15.3	3.21	3.7-3.97	2.51	3.31
Compressive Strength MPa	3100-5860	1725-2500	2070-2620	2900	689-2760
Modulus of Rigidity GPa	483-641	476	393	445	317

Source: NICT

Very few experiments have been carried using tungsten carbide (WC) as reinforcement. The mechanical properties of Al reinforced by ceramic particulates are greatly depended on particulate size and its mass and volume fraction [5]. Particulate of WC at mass fraction of 2.5%, 5%, 7.5% & 10% for 3 aspect ratios 0.5, 0.75 & 1.0 are used in this experiment.

1.4. Powder Metallurgy

Particulate composites are largely prepared by stir casting method or P/M process. Though stir casting is a better approach for manufacturing composites of Al as Al oxidizes readily, P/M process was chosen for this experiment because of the following reasons,

- Due to wide gap difference in their density and thermal expansion coefficient, It is difficult to synthesise Al & WC.
- Wetability of molten Al & WC is very poor in stir casting technique.
- Possibility of undesirable reaction between the constituents may occur.

Using P/M process, composite can be prepared in room temperature using cold compaction. The advantages of using this process are,

- Minimal residual voids
- Avoidance of dissolved gases
- Good bonding between the interfaces
- Near final shape compacts [5]

II. MATERIALS & METHODOLOGY

2.1 Material preparation

12 samples of Al powder were blended with WC powders at mass fractions of 2.5%, 5%, 7.5% and 10% for the aspect ratio of 0.5, 0.75 & 1.0. Three samples of unreinforced Al was prepared for each aspect ratio for comparison with Al-WCp composites.

The amount of powder required was calculated based on the mass fraction. WC was procured from Alfa Aesar USA, 99.9% purity of size -100+270 mesh size & fine Al powder was supplied by Lobe Chemi, Mumbai.

Theoretical density was determined using micro-mechanics approach termed "Rule of Mixture"[6] . The rule of mixture formula (1) for particulate composites is given as

$$\rho_c = f_m \rho_m + f_r \rho_r \quad (1)$$

Where ρc is the density of the composite
ρ_m is the density of the matrix
ρ_r is the density of the reinforcement
f_m=Mass fraction of the matrix=mass of matrix/(mass of matrix+mass of reinforcement)
fr=Mass fraction of reinforcement=mass of reinforcement/(mass of matrix+mass of reinforcement)

2.2 Composite Fabrication

Preforms were prepared by cold compaction in a UTM using a hardened fabricated die with 25.4 mm bore. Compressive load of 80 to 98KN was applied depending on their aspect ratio [7-8].

Table 3

Aspect Ratio	Load Applied KN
1.0	98.1
0.75	88.29
0.5	80.44

Figure 1

Table 3 shows the compaction load applied for each aspect ratio. The Green density of the preforms was measured analytically and also by using Archimedes principle. Fig. (1) shows the preforms prepared by powder metallurgy by cold compaction process.

2.3 Composite Sintering

Sintering is a most critical part when it comes to Al composites processing, as Al readily oxidizes forming Al oxide preventing sintering [9-13]. Before sintering for protection from oxidation at high temperature, as a low cost method the samples were given an Aluminium coating (2 coats & dried for 24 hrs/coat) as a sacrificial layer for oxidation.

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Figure 2

Fig (2) shows the photograph of preforms arranged in a muffle furnace for sintering. Sintering was carried out in the muffle block furnace and was soaked at 640°C for 60 minutes increasing the rate of heating by 15°C/min.

The preforms were cooled in the furnace itself at the normal rate. It took nearly 12 hours for the reforms to reach atmospheric temperature. The preforms were removed from the furnace and then machined to remove oxidized layer maintaining the aspect ratios. The sintered density was measured for analysis.

III. RESULTS & DISCUSSION

3.1 DENSIFICATION BY COLD COMPACTION

After densification by cold compaction the green density was compared with theoretical density (calculated by rule of mixture). A consolidated graph of all three aspect ratio (Fig 3) was drawn based on the measurements.

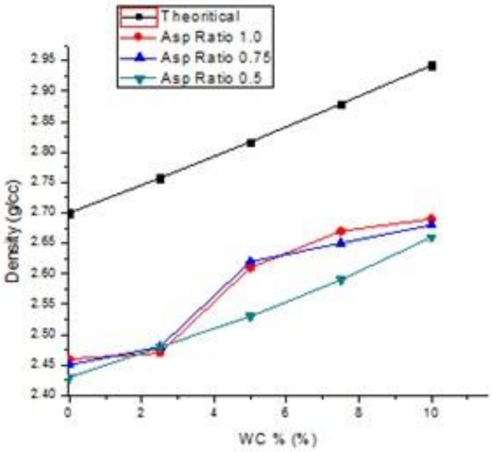

Figure 3

The graph (Fig 3) indicates that for aspect ratio 0.5 the increase in green density is linear. Further increase in green density is possible with increase in WC particulate increase. For aspect ratio 0.75 & 1.0 the progress is almost identical. There is progressive raise in density till 7.5% addition of WCp reinforcement after which they show stabilization in green densification.

3.2 Densification by sintering

After sintering all the preforms in a muffle furnace and subsequent cooling the density of the preforms were measured and graphically represented in fig 4 below.

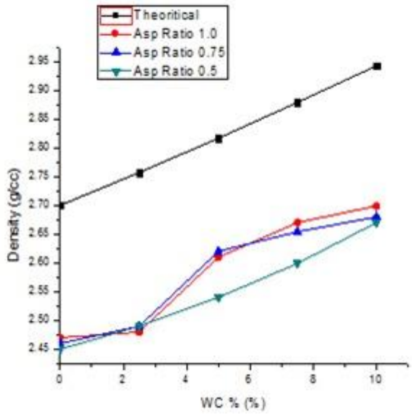

Figure 4

WCp composition against theoretical & sintered densities indicates that for aspect ratio 0.5 the increase in sintered density is linear as in case of green density. Densification for aspect ratio 0.75 shows decline when compared with aspect ratio 1.0. Though the maximum densification achieved in 0.5 aspect ratio is lesser than 0.75 & 1.0 it is progressing upwards indicating further increase in densification is possible with addition in reinforcement.

3.3 Comparison of aspect ratios after densification

The densification post cold compaction and sintering was studied for each aspect ratio 1.0, 0.75 & 0.5 and graphically represented in the fig 5, 6 & 7 and inferred.

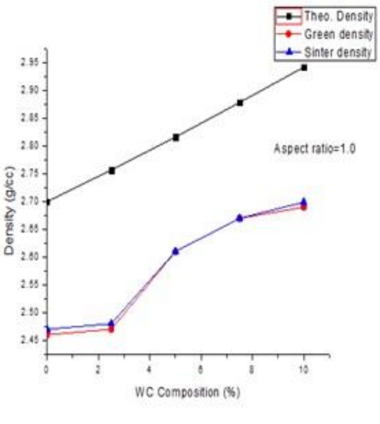

Figure 5

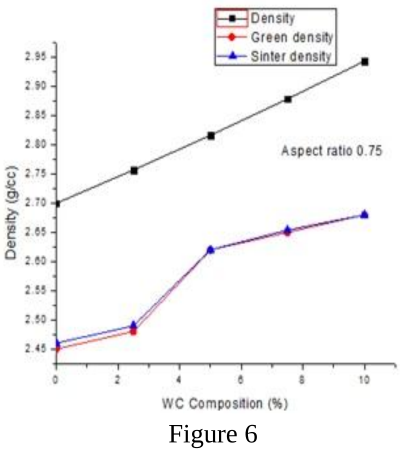

Figure 6

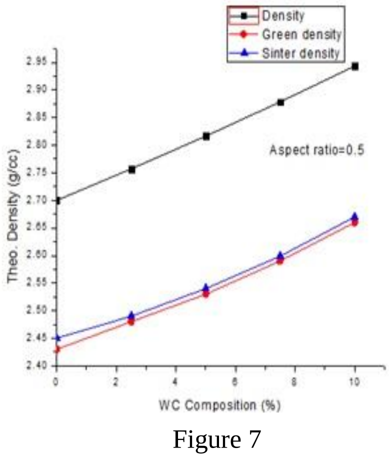

Figure 7

In fig 5 the graph indicates that for aspect ratio 1.0 there is no significant change in green and sintered density. Only at the beginning and at the end they show some variation. The sintering densification is poor.

For aspect ratio 0.75 in fig 6 the density has almost stabilized around 2.68 g/cm3. Both green density and sintered density coincide after 7.5% addition of reinforcement. This indicates that no densification has taken place after sintering.

For aspect ratio 0.5 in fig 7 the green density and sintered density are parallel with theoretical density. The sintered density line is above green density line. This indicates that densification after sintering has taken place though not significant. As already observed on further increase in addition in reinforcement WCp by 2.5 to 5% will improve increase density further.

IV. CONCLUSION

It is observed that increase in WCp composition invariably increases the density of Al. Green density of 2.69g/cm^3 and sintered density of 2.7g/cm^3 was achieved for Sample A (aspect ratio 1.0) with a relative density of 93.73%. For aspect ratio 0.5 the maximum sintered density achieved was 2.67g/cm^3. Further densification is possible for aspect ratio 0.5 with increase in WCp by another 2 to 5% mass fraction.

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