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Evaluation of Various Properties of Al_2O_3-Al Metal Matrix Composites through Powder Metallurgy Technique

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Abstract: *Aluminium metal matrix composites are potential materials for various applications due to their good physical , mechanical, and chemical properties. Reinforcing phases are incorporated into the metallic matrix to improve the properties compare to the matrix materials. The effect of Al_2O_3 wt% on the Physical, mechanical and corrosion properties for Al metal matrix composites has been undertaken. The weight% of the reinforcement was varied systematically from 5 to 15wt% in 5 wt% intervals. The powder metallurgy composites were compacted and then heat treated. The paper presents the effect of different wt% of Al_2O_3 addition in Al metal.*

Key words: *Metal matrix, reinforcing phase, powder metallurgy, compacted.*

I. Introduction

For the last few years, metals and alloys matrix, particularly light metal based composites have taken a great place in the world of materials and has become a keen competitor to the conventional materials.[1,2]. Particulate composites are fabricated using many methods, including powder metallurgy process. Powder metallurgy develops materials with properties relatively easy to control by mixing materials with different properties in various proportion. The metal matrix composite can be reinforced with hard non-reactive particles, dispersoids or fibres. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their physical, tribological, mechanical and chemical properties by selection of the amount, size, and distribution of the reinforcing particles in the matrix [3]. Ceramic reinforced metal matrix composites are used more often, due to the wide range of their properties, and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials [4,5].

Reinforcements are usually incorporated to improve the properties of the base matrix like strength, hardness, stiffness, conductivity, etc[6]. Aluminium based composites are widely used in aircraft, aerospace, automobiles, electrical, electronic and various other fields [7]. In metal matrix composites, the reinforcements should be stable in the given working temperature and non-reactive too. The most commonly used reinforcements are Silicon Carbide (SiC) and Aluminium Oxide (Al_2O_3) and recently SiO_2. SiO_2 reinforcement increases the tensile strength, hardness, wear resistance with lowering density of Al and its alloys [8]. In this study, the effect of second phase particle Al_2O_3 with temperature on the physical, mechanical and corrosion properties of Al_2O_3-Al composites was studied

Experimental Procedure

Sample Preparation

Al – Al_2O_3 composite samples were prepared with different weight % of Al_2O_3 powder such as Al-5%wt% Al_2O_3, Al-10%wt% $Al_2O_3$and Al -15%wt% Al_2O_3 by milling using mortar pastel. The cylindrical pellets of powder with nominal dimension of 10mm dia. were made from the ground powder by pressing at a pressure of 5 ton / sq. inch with the help of hydraulic press uniaxially. The samples are then isothermally heated at the temperature of 400^{o}C, 500^{o}C, 600^{o}C in a horizontal tube furnace for 30 minutes respectively. The heating rate employed to reach the desired temperature is 6^{o}C/min.

SEM Image analysis

Image analysis of pure Aluminum and Al_2O_3- A1composite samples was carried out by SEM,GEOL made with different magnifications such as 200X, 400X and 100X.

Micro structural analysis

Micro structural study of pure Aluminum and Al_2O_3- A1composite samples was carried out by image analyzer with different magnifications 20X and 50X.

Bulk density measurement

The bulk density of the samples were measured taking weighing of the samples by a electronic weight measurement machine and volume of the sample which was measured from diameter & height of the sample digital Vanier Calipers.

Porosity measurement

The apparent porosity of the samples were measured by taking weight of dry samples (W_d), suspended in water (W_s) and after removing from water (W_w) and using the formula as given in below.

$$\textbf{Apparent Porosity} = \frac{(W_w - W_d)}{(W_w - W_s)} \times 100\ \% \qquad (1)$$

Apparent porosity of pure Aluminium and Al_2O_3- A1 composite samples for both before and after sintering were measured.

Hardness

Hardness of the mirror like polished with fine emery paper (2/0) samples were measured for the applied load of 15.625 kgf and dwell time 30 second using Brinell Hardness Tester.

Wear Resistance

Holder-on-disc type Friction and Wear monitor (DUCOM; TR-20LE-M2) with data acquisition system was used to evaluate the wear behaviour of the composite, against hardened ground steel disc. The load(9.8N) with 320 rpm for track diameter of 30 mm and sliding speed of 1 m/s were used for all composite samples. The load was applied on the sample by dead weight through pulley string arrangement. From the wear (micrometer) Vs time (second) data (excel data), the wear rate (micrometer / second) by cumulative summation of wear (micrometer) for each point from the excel data was calculated and then divided it by the total time duration i.e. by 600. The average coefficient of friction by cumulative summation of all coefficient of friction from excel data for every point of reading was determined and then divided it by total number of readings / points.

Corrosion rate

Corrosion behaviour of the samples was studied in 3% KCL solution by Garmy instrument. From the voltage Vs current graph obtained by potentiometer, the corrosion rate using Linear Polarization Method was calculated.

II. Results & Discussion

SEM images of composite samples showing that the Al_2O_3 particles are uniformly dispersed over the sintered Al matrix. Typical SEM images of the pure aluminium and 15wt % Al_2O_3-Al samples are shown in the Fig 1-2

Typical Micro structural images of sintered Al and 15 wt% Al_2O_3-Al composites are shown in the Fig.3-4. Fig. 3 showing clearly the grain and grain boundary which are formed due to sintering.

Bulk density of the samples after sintering is summarized in the Table1 From the table and corresponding Fig. 5, it is observed that the bulk density values increases with both Al_2O_3 and temperature and maximum values was obtained with 15wt% of Al_2O_3 and 600^oC.

Apparent porosity of Al_2O_3-Al composites for both before and after sintering is summarized in the Table 2, The results and corresponding Fig.6 showing that the apparent porosity of Al_2O_3-Al composites after sintering decreases as temperature increases with compare to unsintered compact and gives the lower values at 600^oC.

Hardness values of Al_2O_3-Al composite samples were measured and summarized in the Table 3. From the table and corresponding Fig. 7, it is observed that hardness value increases with Al_2O_3 content and maximum hardness was obtained at 15wt% Al_2O_3 because of the uniform distribution of hard reinforcing phase Al_2O_3 and work hardening effect of the matrix A1 due to the impeding the motion of dislocation caused by the external stress.

The wear rate of Al_2O_3-Al composites is summarized in the Table 4 and corresponding Fig. 8 showing wear rate of Al_2O_3-Al with the increasing temperature and minimum wear was achieved in 15wt% Al_2O_3 at 600^oC for a period of 10minutes than unreinforced Al matrix. The Fig. 9-11 showing the wear, co-efficient of friction and % of contact with time respectively.

Corrosion rate of the composite samples is summarized in the Table-5. From the table and corresponding Fig.12 it is observed that minimum corrosion rate was obtained with 15wt%.$A1_2O_3$ sintered at 600^{o}C for a period of 30 minutes due to the presence of low porosity.

Table-1 Bulk density of Al_2O_3-Al composites

Materials	Bulk density
Pure Al	2.52
5 wt% Al_2O_3 – Al composite	2.56
10 wt% Al_2O_3 – Al composite	2.74
15 wt% Al_2O_3 – Al composite	2.919

Table-2 Porosity (%) as a function of wt% of Al_2O_3 content before sintering & after sintering

Materials	Apparent porosity	
	Before sintering	After sintering
Pure Al	8.59	3.55
5 wt% Al_2O_3 – Al composite	10.27	3.5
10 wt% Al_2O_3 – Al composite	13.37	5.2
15 wt% Al_2O_3 – Al composite	15.28	7.8

Table-3 Brinell hardness of Al_2O_3- Al composites sintered at 600° C temperature

Material	Hardness(BHN)
Pure Al	21.5
5 wt % Al_2O_3 – Al composite	26.4
10 wt % Al_2O_3 – Al composite	28.7
15 wt % Al_2O_3 – Al composite	35.05

Table-4 Wear rate of Al_2O_3-Al composites sintered at 600° C

Material	Wear rate
Pure Al	50.77
5 wt% Al_2O_3 – Al composite	46.01
10 wt % Al_2O_3 – Al composite	35.51
15 wt% Al_2O_3 – Al composite	13.6

Table-5 Corrosion rate of Al_2O_3-Al composites sintered at 600^{o}C

Sample	Corrosion Rate ($I_{corr.}$) ($\mu A/cm^2$)
Pure Al	330.2
5 wt% Al_2O_3 – Al composite	259.1
10 wt % Al_2O_3 – Al composite	70.73
15 wt % Al_2O_3 – Al composite	6.785

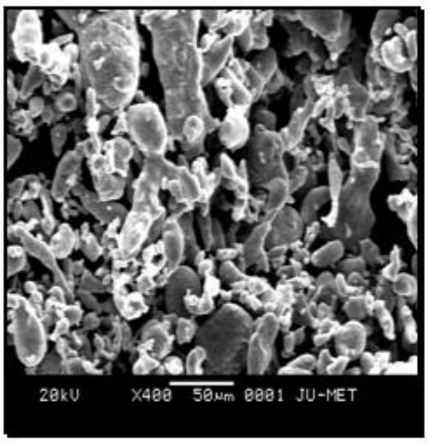


Fig.1 Typical SEM image of **Pure Al** powder at 400X

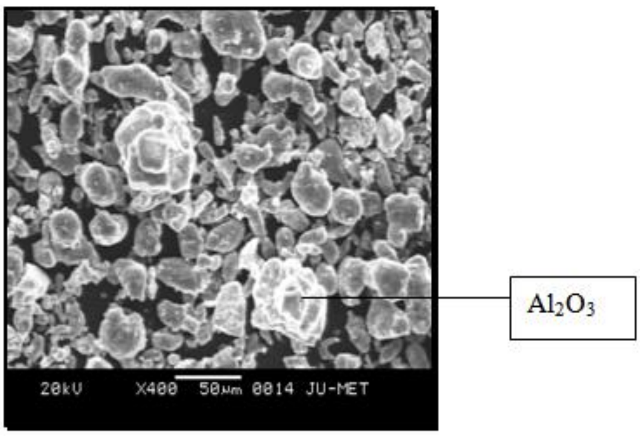


Fig.2 Typical SEM image of **15%Al_2O_3– Al** powder at 400X

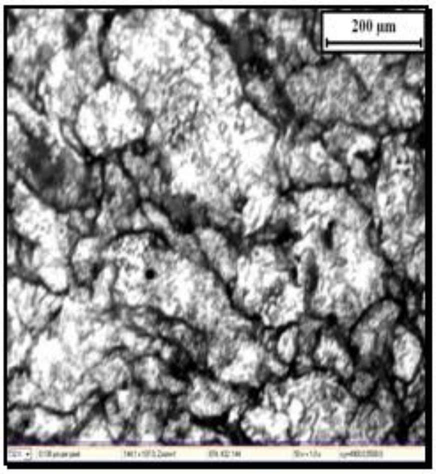


Fig. 3 Typical Microstructure of **Pure Al** sintered at **600° C** at 50X

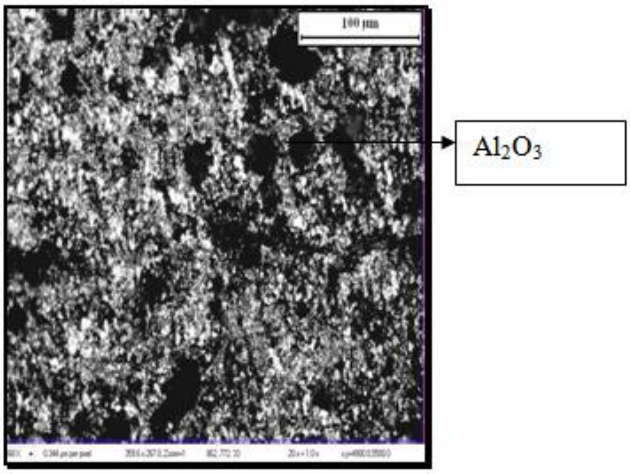


Fig. 4 Typical Microstructure of **15% Al_2O_3 – Al** composite sintered at **600° C** at 50X.

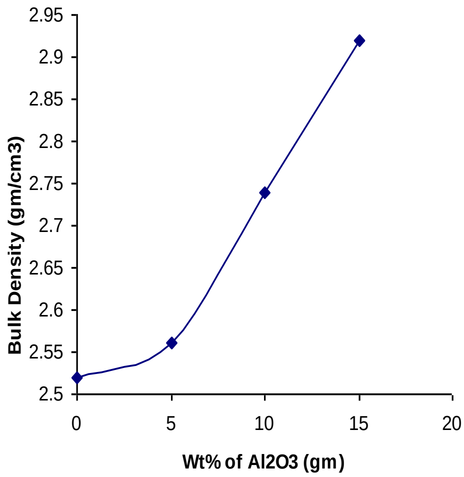


Fig. 5 The bulk density as function of wt% of Al_2O_3 content for Al_2O_3-Al composites

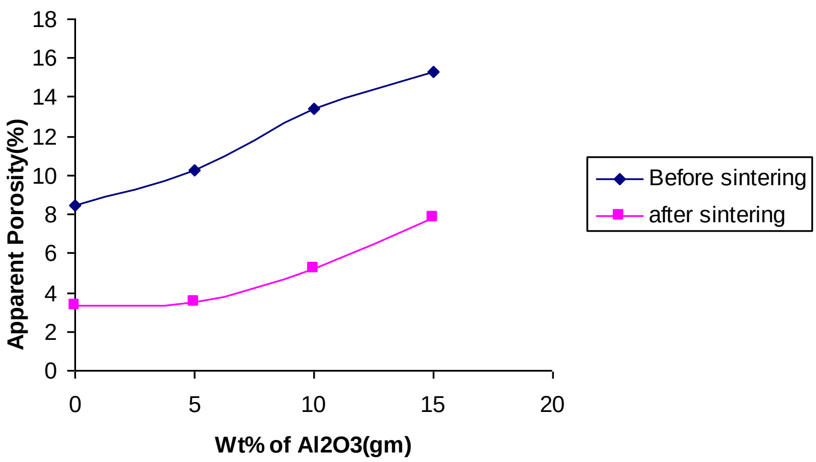


Fig. 6 Apparent porosity(%) as a function of wt% of Al_2O_3 content before and after sintering

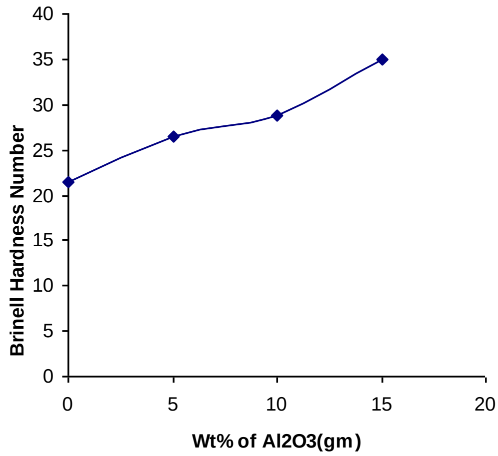


Fig. 7 Brinell hardness with wt% of Al_2O_3content sintered at 600° C temperature

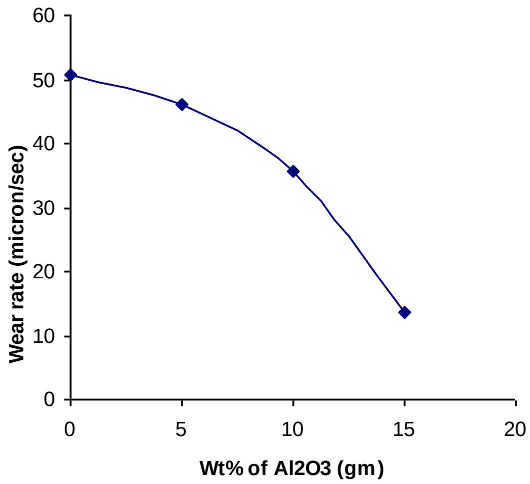


Fig. 8 Wear rate with wt% of Al_2O_3 content sintered at 600° C

WEAR, COEFFICIENT OF FRICTION & % OF CONTACT

Sample: 15% Al_2O_3 – Al composite sintered at 600°C, **RPM:** 320.00, **Load:** 9.80 N, **Track Diameter**: 30 mm, **Samples / Min :** 60

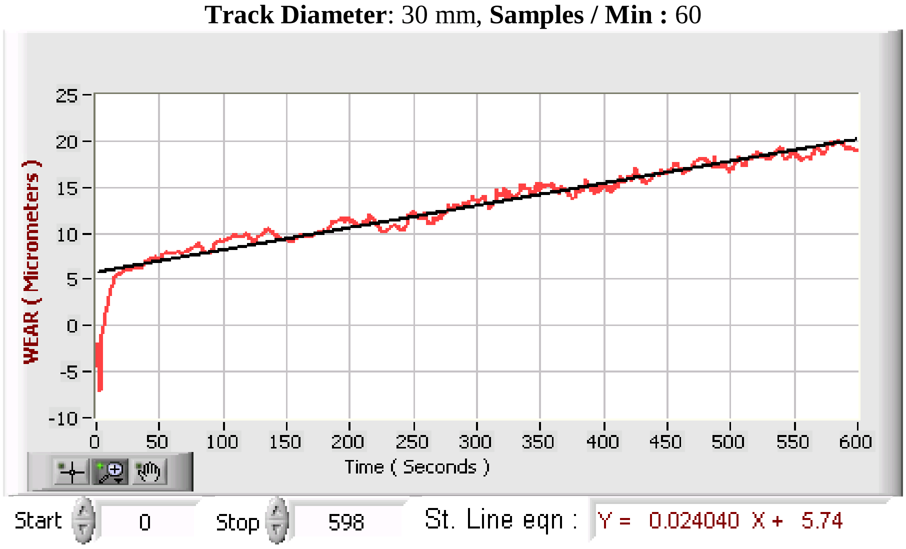
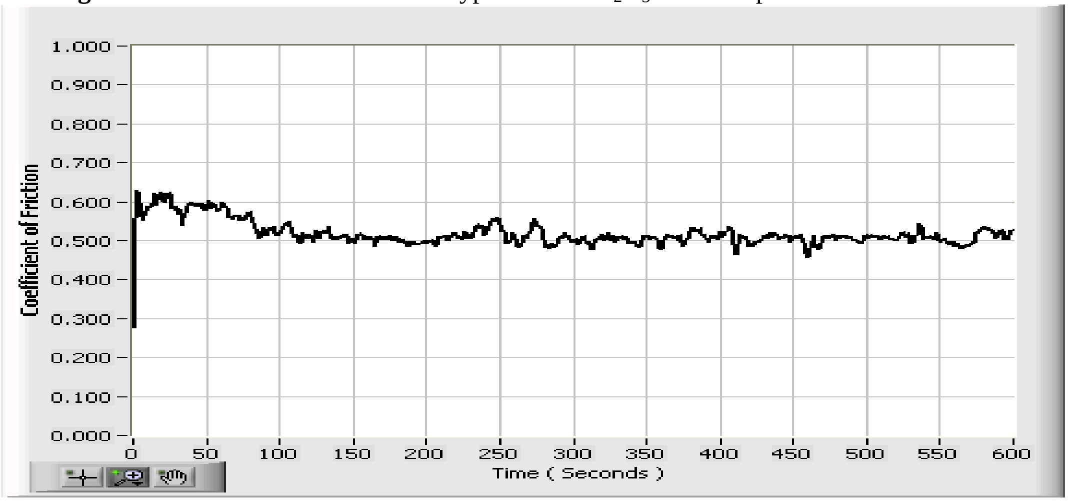


Fig. 9 Wear as a function of time for typical 15% Al_2O_3 – Al composite sintered at 600°C



Mean: 0.518 S.D.: 0.032 Variance : 0.001

Fig. 10 Co-efficient of friction as a function of time for typical 15% Al_2O_3 – Al composite sintered at 600°C

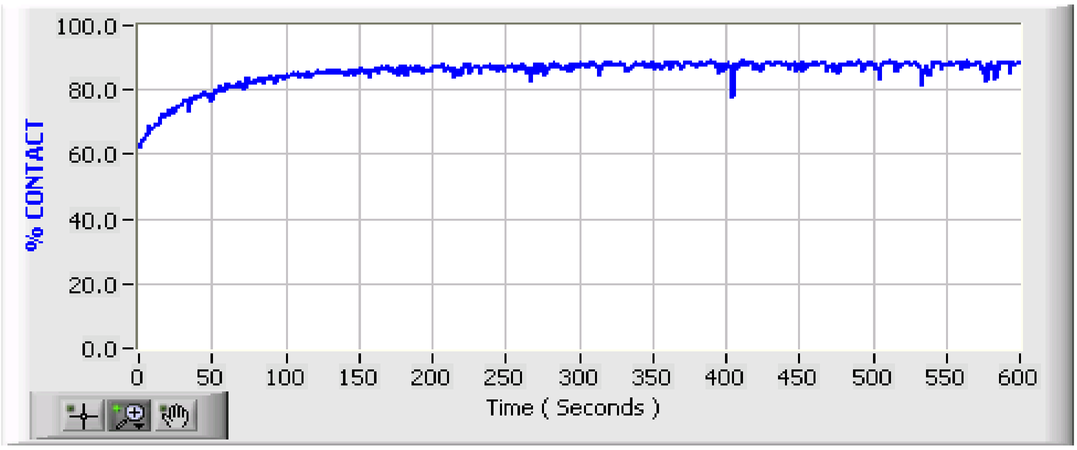


Fig. 11 % of contact with time for typical 15% Al_2O_3 – Al composite sintered at 600°C

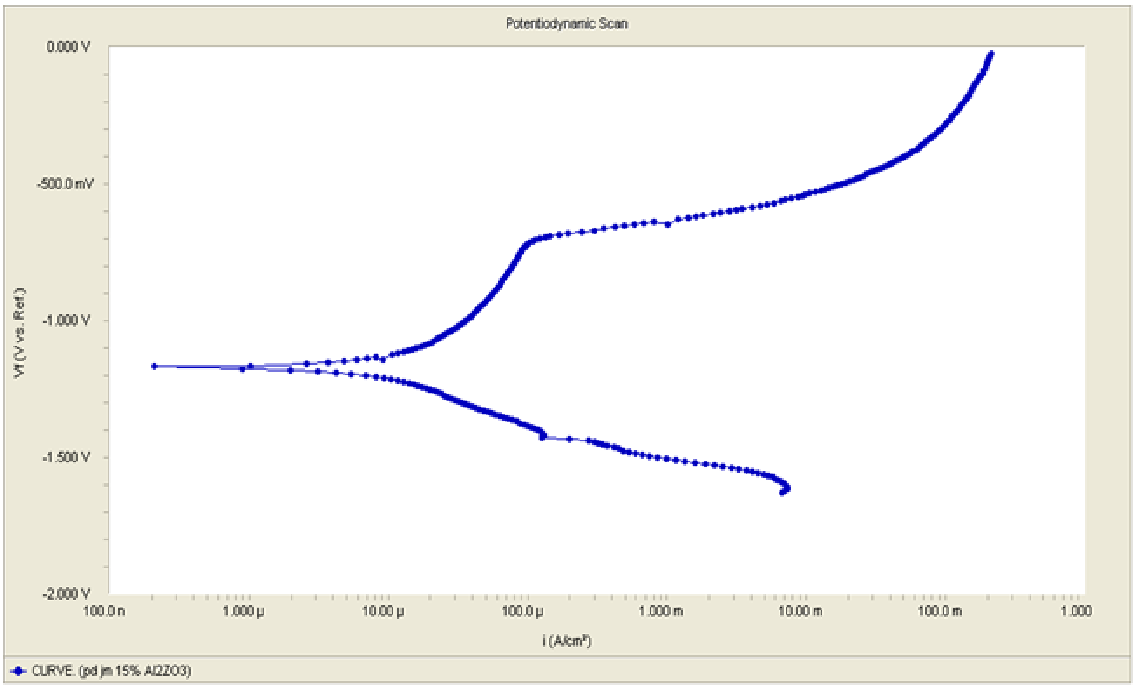


Fig. 12 Corrosion behavior for typical 15% Al_2O_3 – Al composite sintered at 600°C

III. Conclusions:

1. The bulk density of Al_2O_3 – Al metal matrix composites progressively increases with Al_2O_3 content following increasing sintering temperature.
2. Porosity of Al_2O_3 – Al metal matrix composites decreases with increasing sintering temperature but increases with Al_2O_3 content.
3. The hardness (BHN) value of Al_2O_3 –Al metal matrix composites significantly increases with increasing amount of wt % addition of Alumina as well as by increasing sintering temperature and maximum value obtained at 600^oC with 15wt% $Al_2O_{3.}$
4. Wear resistance of Al_2O_3 –Al metal matrix composites showing significant increase with addition of Al_2O_3 as well as by increasing sintering temperature.
5. Corrosion resistance of Al_2O_3 –Al metal matrix composites showing better than unreinforced aluminium.
6. Al_2O_3 –Al metal matrix composites exhibit better physical, mechanical and chemical properties than unreinforced aluminium.

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