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Study of Tribological Properties of Al 6061 Reinforced MnO_2 Metal Matrix Composites

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Abstract: The present study deals with investigations relating to dry sliding wear behaviour of the Al 6061 alloy, reinforced with MnO_2 particles in 3, 6, 9, and 12 wt.% in four steps in stir casting process. The tests were conducted at varying loads from 0 to 15 N, track radius of 30 mm and constant speed of 1000 rpm. Effect of normal load are discussed and the wear resistance of the composite increased on increasing the MnO_2 particles thus wear rate is significantly less for the composite compare to matrix material. Tribological results reveals that wear rate is directly related with the load. The results show that the tribological behaviour of metal matrix composites (MMCs). The results indicate that the wear resistance of the Al6061 reinforced material increased with increase in MnO_2 content, but decreases with increase in normal load.
Key words: Al 6061, MnO_2, Stir casting process, Tribological behaviour, MMCs, normal load.

I. INTRODUCTION

Many methods have been engaged to synthesize the aluminium matrix composites (AMCs), out of all the methods stir casting is the best encouraging route for synthesizing discontinuous reinforcement AMCs. Stir casting of AMCs implicates generating a melt of the particular base material, trailed by the fusion of a reinforcing material into the melt and attaining a proper dispersion by stirring [1]. Due to the poor wettability issues between particles and molten alloy attaining a uniform dispersion of the reinforcement into the liquid matrix is a challenging task several techniques have been employed to prepare the composites [2]. Reinforcements like particulate alumina, manganese dioxide, silicon carbide, graphite, fly ash, etc can easily be incorporated in the melt using cheap and widely available stir casting method [3]. The various fabrication procedures for MMCs, which are generally produced using two major methods, namely, solid and liquid modes of fabrication [4]. It has been reported that the abrasive wear resistance of particle reinforced MMCs increases with the volume fraction of particles, under both high and low stress abrasive wear conditions [5]. Reviews were indicating the tribology of AMMCs as a function of the applied load, reinforcement volume fraction, sliding velocity, distance and nature of the reinforcing phase [6]. In present study stir casting method is used for manufacturing of aluminium matrix composite [7]. The structure and the properties of these composites are controlled by the type and size of the reinforcement and also the nature of bonding [8].The attempt has been made on the tribological properties of aluminium matrix composites reinforced with manganese dioxide consolidate some of the aspects of wear behaviour, such as effect of load [9].

II. EXPERIMENTAL DETAILS

A. Test Materials

Al 6061 was chosen as the matrix of the composite in the current study because of its properties, such as density which make it more lightweight component, low melting point which make it easier for casting purpose, high thermal conductivity, which increases its commercial usage, easily available which make it more advantages for the experimentation and low cost which make its use available for the experimentation and for the industrial purpose. Here Al 6061 have a purity of 99.674% and commercial magnesium of purity 99.92%.

TABLE 2.1 Chemical composition of Al 6061and magnesium used for the investigation

Chemical Element	Al-ingot	Mg-ingot
Manganese (Mn)	0.0 - 0.15	0.002
Iron (Fe)	0.0 - 0.70	0.020
Magnesium (Mg)	0.80 - 1.20	Balance
Silicon (Si)	0.40 - 0.80	0.006
Copper (Cu)	0.15 - 0.40	0.016
Zinc (Zn)	0.0 - 0.25	0.002
Titanium (Ti)	0.0 - 0.15	0.001
Chromium (Cr)	0.0 - 0.15	0.001
Aluminum (Al)	Balance	0.023

B. Methodology

The process of stir casting starts with placing empty crucible in the furnace. The heater temperature is then gradually increased up to 800°C. Aluminium alloy is cleaned to remove dust particles, weighed and charged in the crucible for melting. Required quantities of reinforcement powder and magnesium powder are weighed on the weighing machine. Reinforcements are heated for 45 minutes at a temperature of 500°C. When matrix was in the semisolid stage condition at 650°C, 3 % by weight of pure magnesium powder is used as wetting agent. After five minutes the scum powder is added which forms a scum layer of impurity on liquid surface which to be removed. At this heater temperature stirring is started and continued for five minutes. Stirring rpm is gradually increased from 0 to 300 rpm with the help of speed controller. Preheated reinforcements are added during five minutes of stirring. Reinforcements are poured manually with the help of conical hopper. Stirrer rpm is then gradually lowered to the zero. Then molten composite slurry is poured in the metallic mould without giving time for reinforcement to settle down at crucible bottom. Mould is preheated at 500°C temperature for one hour before pouring the molten slurry in the mould. This is necessary to maintain slurry in molten condition throughout the pouring. Then it is left to solidify in mould.

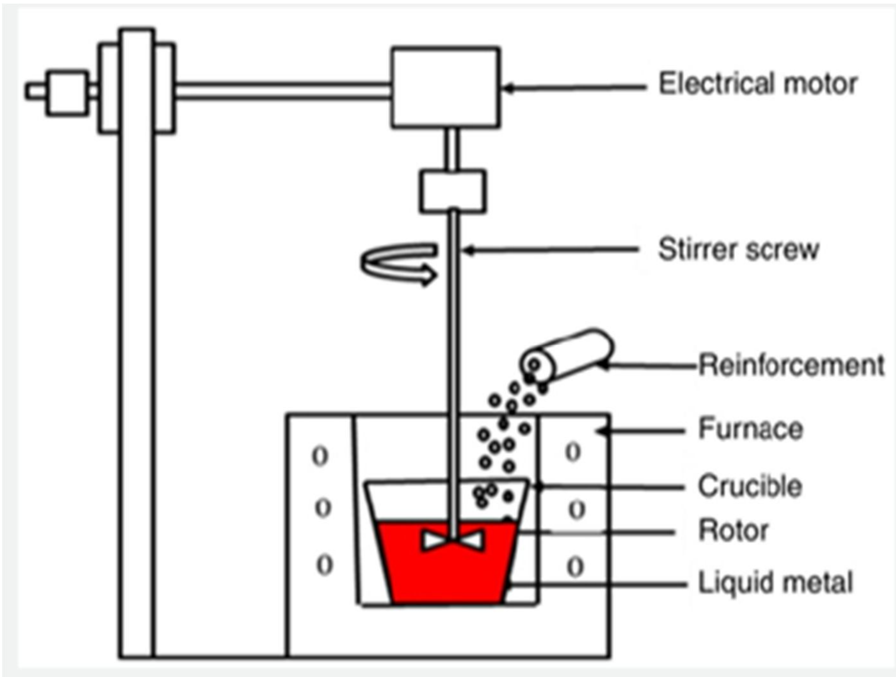

Fig 1.1 stir casting process

Different designation of compositions are shown in Table 4.1 and these composition have been designated on the basis of its constituents, and the first letter 'A' indicates the base metal aluminium 6061 and a next letter 'M' indicates allowing element magnesium which is kept constant at 3 wt.% then AM is followed by a letter 'P' indicates the manganese dioxide (MnO_2) powder.

TABLE 2.2
Normal composition of the composites

Designation of composites	Magnesium (wt.%)	Particle (wt.%)
AM	3	0
AMP3	3	3
AMP6	3	6
AMP9	3	9
AMP12	3	12

Al 6061-Mg alloy has been prepared by adding of 3 wt.% of magnesium into Al 6061 melt and these alloys are designed as AM, and similar to all other alloy by varying of 3, 6, 9 and 12 wt.% of manganese dioxide they are designed as AMP3, AMP6, AMP9 and AMP12 respectively.

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III. RESULTS AND DISCUSSION

A. SEM Microstructure and X-ray Diffraction Analysis of MnO_2 Particles

Cast composites have been synthesized by using Al 6061 as the matrix material and it was alloyed with 3 wt.% of magnesium to impart wetting to the MnO_2 particles, and MnO_2 particles are added as reinforcements in amount of 3, 6, 9 and 12 wt.%.

The size and shape of the MnO_2 particles in the powder have been observed under SEM and the results are shown in Figure 4.1. The output of an EDAX analysis is an EDAX spectrum. The EDAX spectrum is just a plot of how frequently an X-ray is received for each energy level. An EDAX spectrum normally displays peaks corresponding to the energy levels for which the most X-rays had been received. Each of these peaks are unique to an atom, and therefore corresponds to a single element. The higher a peak in a spectrum, the more concentrated the element is in the specimen.

The size of particles is in the range between 10 µm and 120 µm and the shape of the larger particles are nearly spherical shape but the smaller particles have irregular shape. The MnO_2 particles in the powder have been observed under SEM (Scanning Electron Microscope) and the result are shown in the Fig 4.2 along with the EDAX analysis.

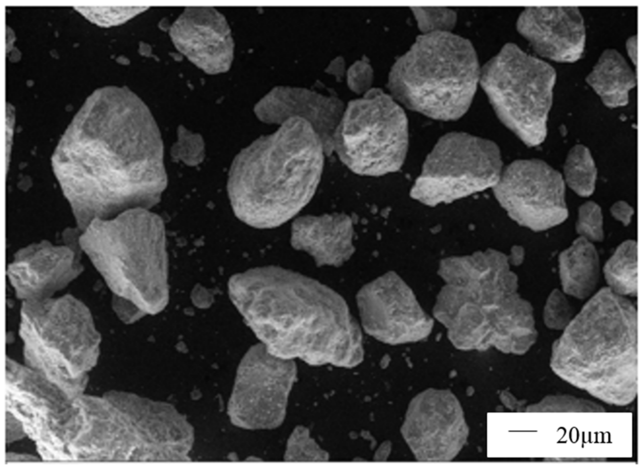
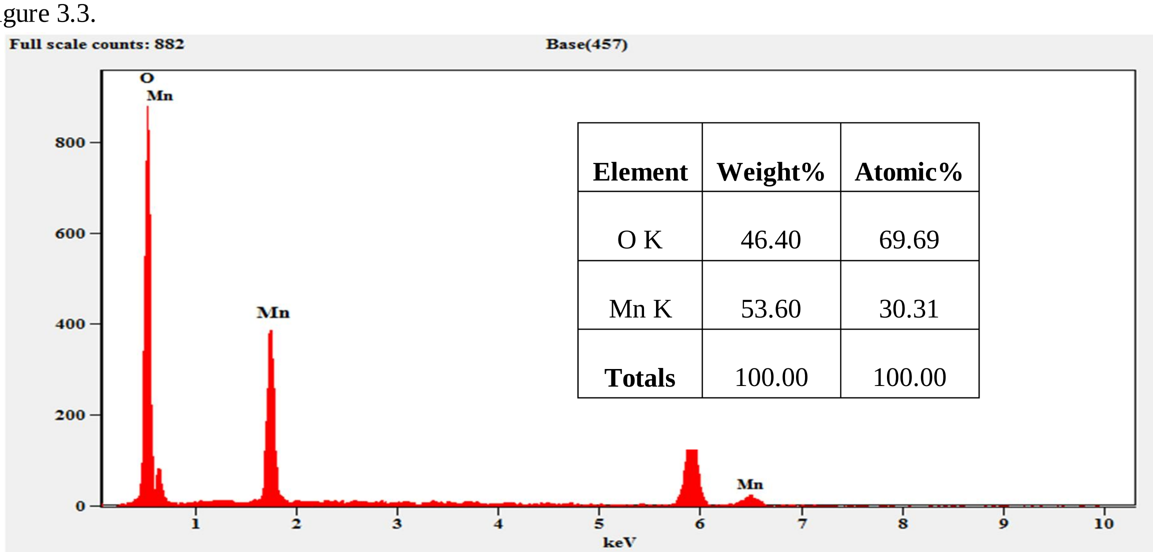


Fig 3.1: SEM micrographs showing size and shape of the MnO_2 powder

The powder has been examined for their X-ray diffraction (XRD) pattern using X-ray diffractometer in the two theta range of 10 to 80^o using Cu as a target material, K_α radiation and nickel filter. The step size and the dwell time were suitably adjusted, which was used for identification of various phases with the help of inorganic JCPDS (Joint Committee on powder diffraction Standards) X-ray diffraction data card available from the International Centre for Diffraction Data as the Powder Diffraction File (PDF), which shows the MnO_2 particles are fairly pure. XRD pattern of MnO_2 particles used in the synthesis of Al 6061 (Mg)-MnO_2 composites and is shown in Figure 3.3.



Element	Weight%	Atomic%
O K	46.40	69.69
Mn K	53.60	30.31
Totals	100.00	100.00

Fig.3.2 SEM image and EDAX Spectrum of MnO_2 used in the synthesis of Al 6061 (Mg)-MnO_2 composites

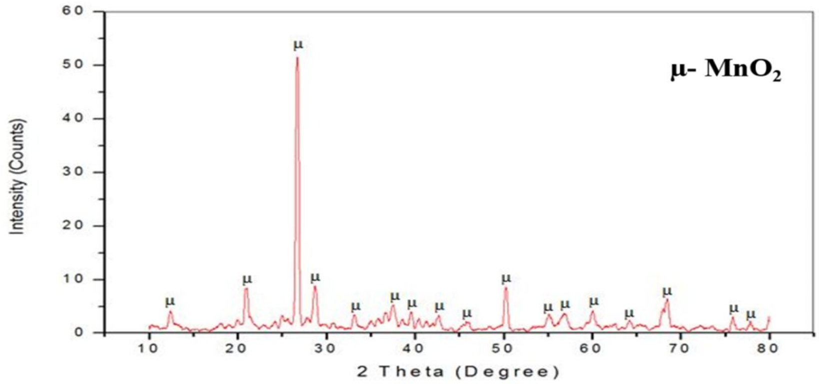


Fig.3.3 XRD pattern of Manganese dioxide particles used in casting

B. *Mechanical Properties of Al1100 (Mg)-ZrO2 Composites*

1) *Effect of Normal load:* The wear behaviour of the composite is studied at room conditions and applied loads ranging from 5 N to 15 N at an equal interval of 5 N, 10 N and 15 N and with sliding speeds of 1000 rpms, using a pin-on-disk wear testing machine. The weight loss was measured using a weighing machine. The track diameter was held constant at 30 mm and speed is 1000 rpm and the experiment is run for 15 minutes and sliding distance of 2827.43 m and sliding velocity of 3.14159 m/s. Variation of weight loss with different load for 0 wt.% of manganese dioxide added is designated as AM as shown in Table 3.1. Weight loss increases with increasing with different load for Al 6061 alloy as shown in Figure 4.11. Variation of weight loss with different loads 5 N, 10 N, and 15 N for different weight percentage of 3 wt.%, 6 wt.%, 9 wt.% and 12 wt.% of MnO_2 added composites designated as AMP3, AMP6, AMP9, and AMP12 shows that weight loss increases with increasing load as shown in Figure 3.4 respectively.

Table 3.1 illustrate the variation of weight loss with normal load, it can be observed from the Figure 3.4 that the weight loss increases with increasing the load for Al 6061 alloy almost linearly. The weight loss increases marginally (almost stabilized) in the composite AMP3, AMP6, AMP9, this may be attributed to the fact that manganese dioxide particles which are exposed to the counter surface and by increasing the contact area between the meeting surface as well as train earning of the surface because of increased dislocation density this result in relatively large number of smaller particle contact area between the matrix and reinforcement faces will be more and so that is a interface between two phases this increased interface region would result in better stiffening and increase strength of composite structure resulting in reduced wear of the material.

TABLE 3.1
Amount of weight loss for different load conditions

Designation of composites	Load in N	Initial weight of the sample W_1 in grams	Final weight of the sample W_1 in grams	Difference in weight W_1-W_2 in grams
AM	5	5.2327	5.1312	0.1015
	10	5.2905	5.1703	0.1202
	15	5.2304	5.1779	0.1261
AMP3	5	5.3295	5.2303	0.0992
	10	5.3397	5.2307	0.1035
	15	5.3724	5.2616	0. 1095
AMP6	5	5.3023	5.2085	0.0938
	10	5.3495	5.2489	0.1006
	15	5.38445	5.2837	0.1008
AMP9	5	5.4397	5.3487	0.0970
	10	5.4295	5.3311	0.0984
	15	5.4450	5.3462	0.0988
AMP12	5	5.4376	5.3535	0.0841
	10	5.4533	5.3624	0.0927
	15	5.4778	5.3851	0.0969

The composite developed by addition of 12 wt.% of MnO_2 powder have higher wear resistance compare to all other composition, the weight loss increases up to 10 N load and weight loss decreases from 10 N load to 15 N load that may be due to the presence of both courser and fine particle size together appear beneficial for improvement of bonding with matrix that leads to increase wear resistance property.

The wear rate increases steeply with the addition of normal force. As the normal load increases, the coefficient of friction also increased which led to more wear rate. This is quite a common phenomenon in most of the material. Further, the size of the wear debris increased with increasing loads and thereby, resulting in large wear loss at higher loads.

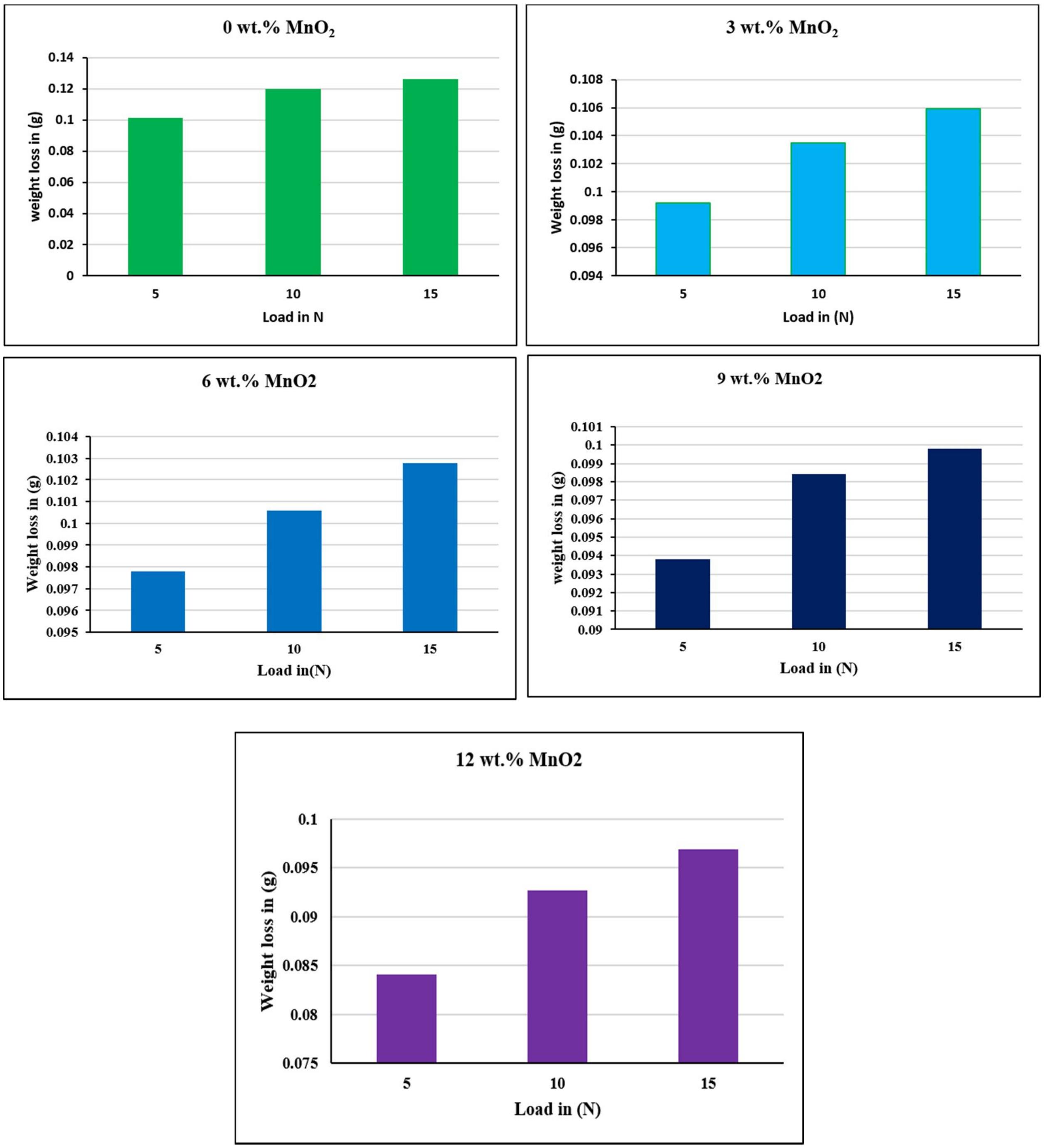


Fig 3.4 The variation of weight loss for different load for 0, 3, 6, 9, and 12 wt.% of MnO_2 added composite designated as AM, AMP3, AMP6, AMP9, and AMP12

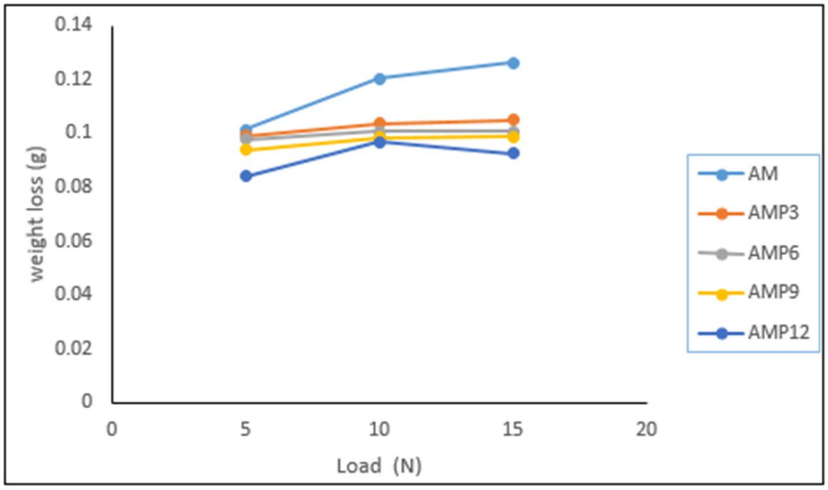


Fig 3.5 The variation of weight loss for different load for 0, 3, 6, 9, and 12 wt.% of MnO_2 added Composites designated as (a) AM, (b) AMP36, (c) AMP6, (d) AMP9, (e) AMP12 respectively

IV. CONCLUSIONS

The aluminium metal matrix composites have been fabricated successfully by the addition of 0, 3, 6, 9 and 12 wt.% of Manganese dioxide (MnO_2) powder to molten Al 6061 alloy by liquid stir casting method followed by casting in permanent mould. The influence of increasing amount of MnO_2 powder addition on evolution of cast microstructure and their impact on the hardness and tribological properties of the resulting composite has been investigated. The conclusions of the present study are outlined below.

A. Stir casting technique (Liquid Metallurgy) was successfully adopted in the fabrication of Al 6061 (Mg) - MnO_2 alloy and composites containing reinforcement 0, 3, 6, 9 and 12 wt% of MnO_2 powder.
B. EDAX and XRD analysis shows MnO_2 particles are fairly pure.
C. The resistance of the composite increased on increasing the MnO_2 particles. Tribological results reveals that weight loss is directly related with the load.
D. At constant speed and track radius the weight loss increases with increasing load, the highest weight loss observed at a maximum load of 15 N.

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