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Comparison of Wear Behaviour of Mg, Mg-4Zn, Mg-4Zn-3MnO$_2$ & Mg-4Zn-3MnCl$_2$ Systems

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ABSTRACT: Study involves the comparison between wear properties of commercially pure Mg, Mg-4Zn, Mg-4Zn-3MnO$_2$ and Mg-4Zn-3MnCl$_2$ by addition of Zn and Mn (by changing their sources). The wear behaviour of all systems investigated under applied loads of 5, 10, 15, 20, 25 and 30 N at the room temperature. The wear tests carried out by pin-on-disk type wear testing machine at sliding speed of 0.25 m/s for a total sliding distance of around 452 meter. The result shows that the wear property of pure magnesium improved by addition of 4.0% zinc but by addition of manganese in improvement of wear properties is not noticeable. At lower load condition (5N & 10N) the highest wear resistance obtained in Mg-4Zn-3MnCl$_2$ system. At higher load (20N, 25N & 30N) wear resistance remain almost equal in all systems (Mg-4Zn, Mg-4Zn-3MnO$_2$ & Mg-4Zn-3MnCl$_2$).

KEYWORDS: Mg-4Zn Mg-4Zn-3MnO$_2$, Mg-4Zn-3MnCl$_2$, Wear, Wear rate,

I. INTRODUCTION

Use of magnesium alloys are rapidly expanded in the automobile sector due to light weight, high specific strength, good damping capacity, small casting shrinkage, high dimensional stability and easy to recycle [1-3]. However, the poor wear resistance extensively limits their practical applications. It appears that while extensive studies have been carry out on wear of aluminium alloys, no such detailed work has been undertaken regarding the wear of different magnesium alloys. Various techniques developed to improve the tribological behaviour of magnesium alloys through surface hardening or strengthening [4, 5]. The study of wear behaviour magnesium alloys reveals that wear rate greatly affected by applied loading and sliding conditions. Wear rate of the alloy depends upon the hardness of the alloy. Harder material has more wear resistance property. In this research activity, the idea was to check addition of zinc, MnCl$_2$ and MnO$_2$ in pure magnesium to compare the wear properties. Wear resistance can be evaluated by using "Pin on Disc" type wear testing machine.

II. EXPERIMENTAL WORK

2.1 Materials and Methods

Magnesium melting done by using flux-melting method in an electrical resistance furnace and Zn added in solids forms. Flux 220 used for melting of the magnesium in graphite crucible [7, 8]. 3 weight % MnO$_2$ or 3 weight % of MnCl$_2$ was added to the molten Mg-4Zn alloy by gentle stirring method. The molten alloy poured in to a metallic mould with dimensions of 20×70×100 mm.

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Wear tests were performed using a pin-on-disc type machine as presented in figure 1. The machine was standardized by using ASTM standard G99. It is manufactured by Ducom Instruments Pvt. Ltd., Bangalore. The wear test performed at room temperature using carbon steel disc with a hardness of 64 HRC. The arrangement of disc, pin and loading condition easily observed in figure 1. The discs were 165 mm in diameter and 8 mm in thickness. The pins, 8 mm diameter and 40 mm height machined from casting and polished. The wear tests are conducted under normal loads of 5, 10, 15, 20, 25 and 30 N at a constant sliding speed of 0.25 m/s for a sliding distance of 452 meter.

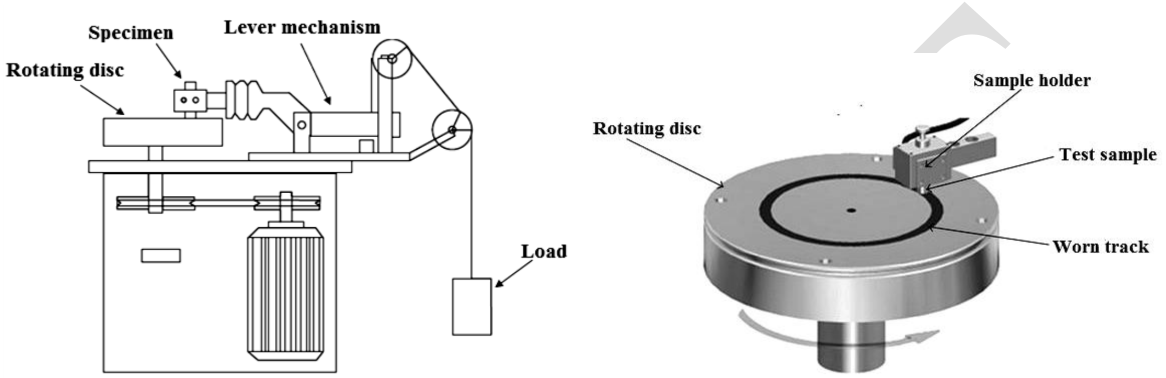

Fig. 1. Experimental set-up of pin on disc wear testing machine

The microstructure of samples and the worn surface profile are studied by using JEOL JSM5610LV scanning electron microscope (SEM) with Backscattered mode operated at 15 kV.

III.RESULTS AND DISCUSSION

3.1 Chemical analysis of Mg, Mg-4Zn, Mg-4Zn-3MnO_2 and Mg-4Zn-3$MnCl_2$ systems by EDS

The overall chemical analyses of final ZM system along with addition of Mn in the form of $MnCl_2$ & MnO_2 are present in following table 1. System 1, Mg-4Zn represent the presence of zinc 4% with 0.05 % manganese. The upper layer of magnesium immediately converts into the oxide hance oxygen presence is also confirmed with a value of around 5 wt%. System 2, Mg-4Zn-3$MnCl_2$ along with the zinc present, the wt. % of manganese obtained is around 1.29%. From 3 wt.% $MnCl_2$ only 1.29 wt. % of recovery of manganese observed. Similarly, in case of system 3, Mg-4Zn-3MnO_2 where 3% of MnO_2 was added and recovery of manganese observed is 1.14%.

Table 1: The overall chemical analysis of all system obtained from EDS analysis

System No.	Types of system	Mg	Al	Zn	Mn	O
Standard	Mg	97.19	-	-	-	2.81
System 1	Mg-4Zn	90.47	0.4	4	0.05	5.07
System 2	Mg-4Zn-3$MnCl_2$	89.46	-	3.64	1.29	5.61
System 3	Mg-4Zn-3MnO_2	85.84	1.25	3.78	1.14	7.99

3.2 Wear measurement

Figure 2 indicate maximum wear variation by change load of 5, 10, 15, 20, 25 and 30 N after 30 minute. As shown in figure 2, wear is increases with increasing load. It is highest in pure magnesium case compare to other systems. At lower load (5 & 10 N) Mn containing system offers highest wear resistance than pure Mg & Zn containing system. At moderate load (15 & 20 N) the wear resistance offer in presence of Zn & Mn is almost equal in values. At higher load

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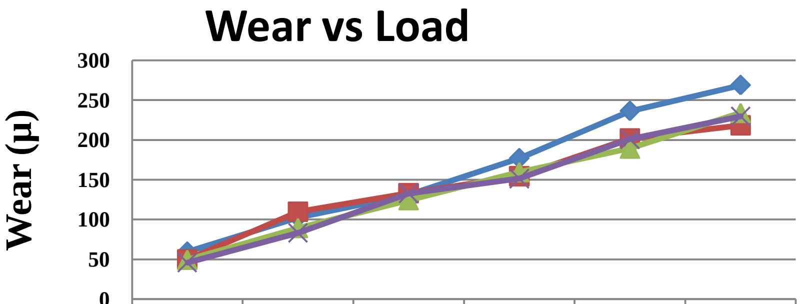
the chances of generation of heat and friction is also high and hence Zn containing system offers highest wear resistance than complex Mn containing system. The reason behind such phenomena may be due to higher thermal conductivity of presence of pure Zn in Mg compare to complex Mn & Zn containing phase in Mg-4Zn-3MnO_2 and Mg-4Zn-3$MnCl_2$.



	5	10	15	20	25	30
Pure Mg	59.78	102.83	131.35	177.15	236.55	269
Mg-4Zn	50.23	110.16	133.39	154.62	202.09	218.5
Mg-4Zn-3MnCl2	49.52	89.42	124.43	159.6	189.23	234.04
Mg-4Zn-3 MnO2	45.92	83.15	132.95	151.51	200.92	229.63

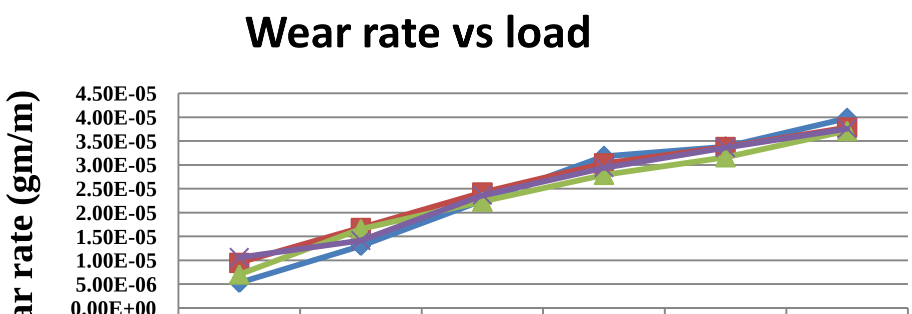
Fig. 2. Maximum wear vs load graph of pure mg and all systems (after 30 min)

3.3 Wear rate

Figure 3 indicate the wear rate for all systems. Wear rate checked by varying the different amount of load conditions like 5, 10, 15, 20, 25 and 30 N. Idea is to find out at what load higher wear rate are observed or whether by increasing the load wear rate can increase or not. Wear rate is find by following formula,

$$\text{Wear rate} = \frac{\Delta W}{\text{Sliding distance}}$$

where, $\Delta W = W_1 - W_2$ = Change in weight



	5	10	15	20	25	30
Pure Mg	5.30E-06	1.30E-05	2.25E-05	3.18E-05	3.38E-05	3.98E-05
Mg-4Zn	9.50E-06	1.68E-05	2.42E-05	3.03E-05	3.37E-05	3.78E-05
Mg-4Zn- 3MnCl2	7.07E-06	1.66E-05	2.23E-05	2.79E-05	3.16E-05	3.71E-05
Mg-4Zn-3MnO2	1.06E-05	1.41E-05	2.36E-05	2.94E-05	3.36E-05	3.76E-05

Fig. 3. Wear rate vs load graph of pure mg and all systems

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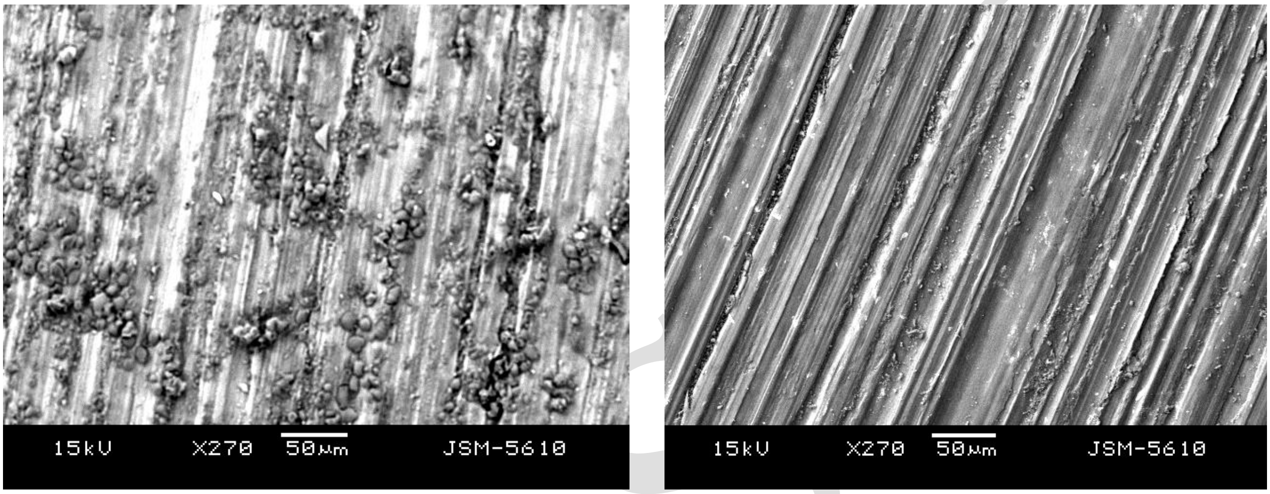
The following figure 3 confirms that wear rate is strongly depends on applied load. It also follows the linear relationship by changing the load. At lower load mild wear rate is observed where as intermediate and sever wear observed at higher load. Sever wear is characterize by massive surface damage and production of large metallic debris particles which were readily identify by SEM analysis.

3.4 Wear behaviour

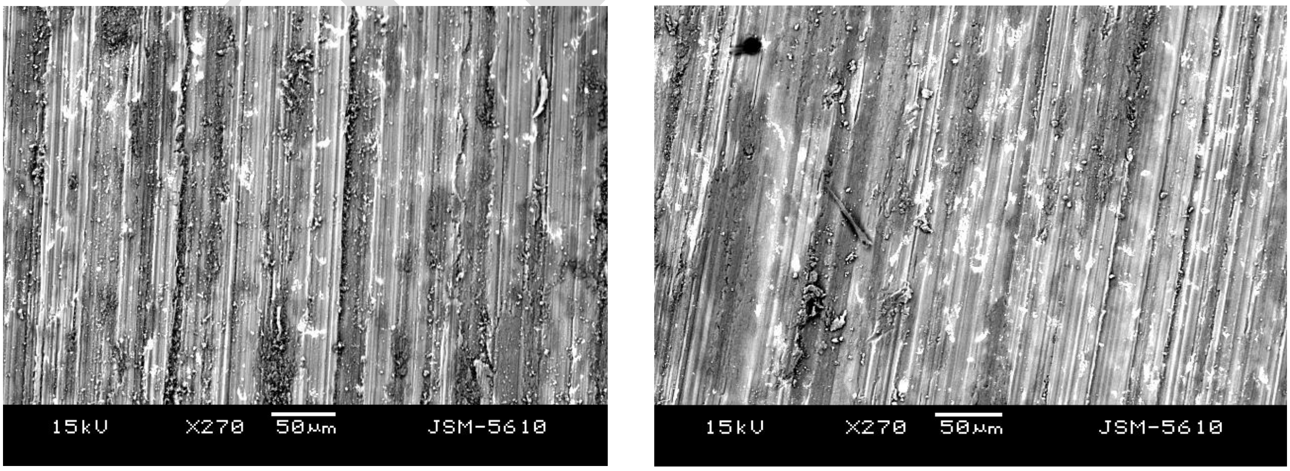
Figure 4 & 5 shows SEM analysis of all systems for 5N and 30 N load respectively at 270X magnification.



Pure Mg **Mg-4Zn**

Fig. 4. SEM analysis of pure Mg and Mg-4Zn after wear testing at 5 N load

As shown in figure 4, at 5 N load indicate the wear pattern along with the wear debris. In case of pure magnesium the amount of wear is more and hence generations of debris are also more. In case of 4% Zn containing wear is less and debris are also less. Only the presence of wear scars is observed in case of 4% Zn containing system. The scars are also not very deep in nature. The presence of oxides in Mg-4Zn system is almost nil compare to pure magnesium.



Mg-4Zn-3MnO$_2$ **Mg-4Zn-3MnCl$_2$**

Fig. 5. SEM analysis of Mg-4Zn-3MnO$_2$ & Mg-4Zn-3MnCl$_2$ all systems after wear testing at 5 N load

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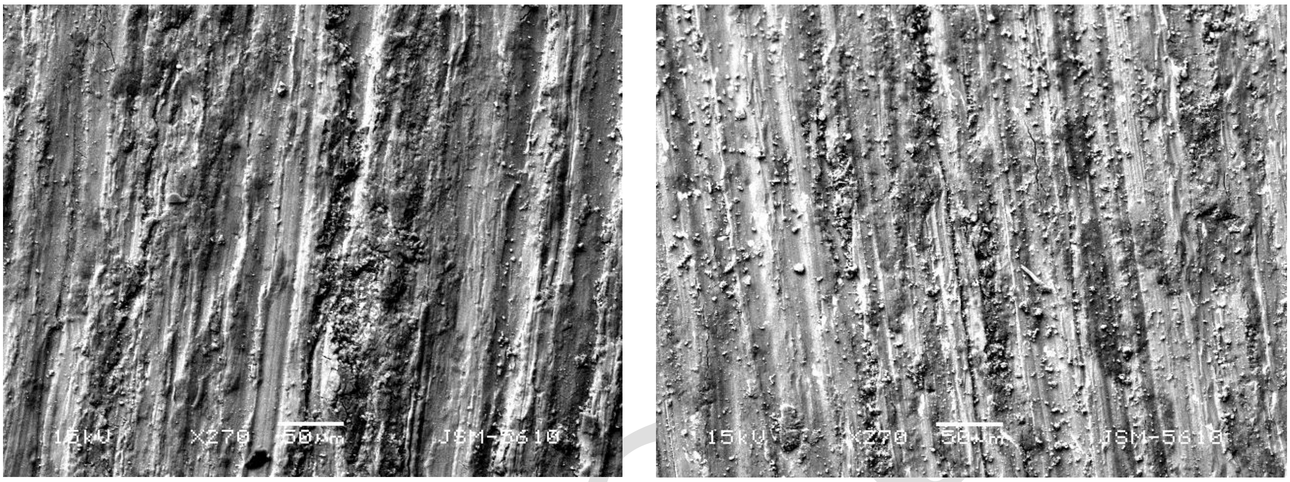
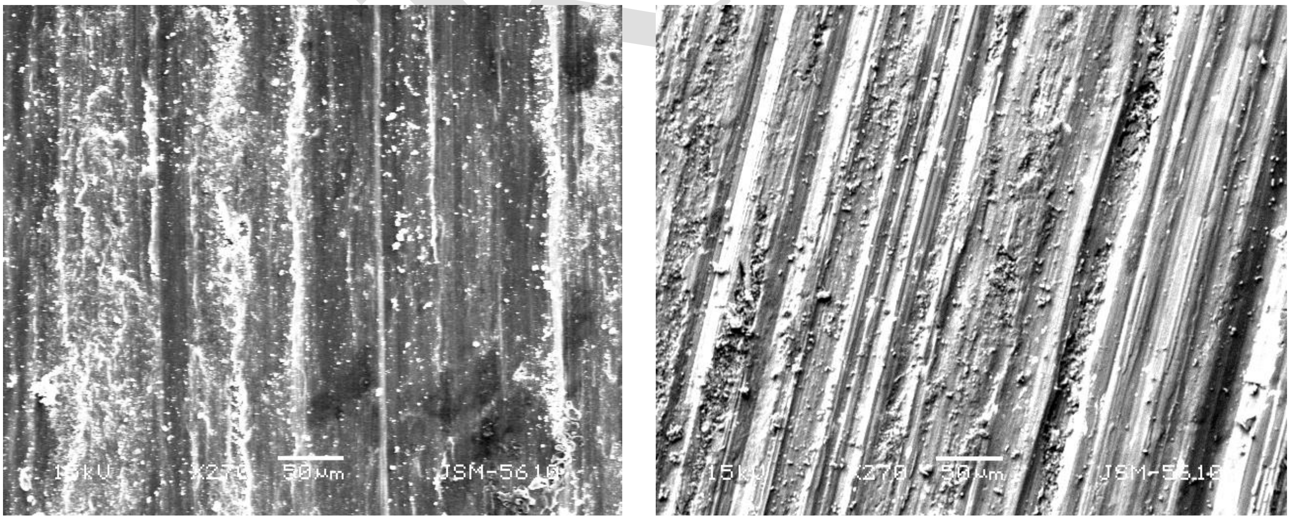
In case of Mn containing system the wear pattern indicate less amount of wear with less amount of debris compare to MnO_2 system in case of $MnCl_2$ system amount of debris generated are quite less, the smear surfaces are quite smooth in most of the region. Wear scars are totally different compare to pure Mg and zinc containing system. The surfaces of wear scar appear to be oxidized but quantity of oxidation is less compare to pure magnesium. At certain place delamination of oxide films easily seen in the form of debris at certain locations. But in both the case SEM images are almost equal in appearance by changing the Mn form.



Pure Mg **Mg-4Zn**

Fig. 6. SEM analysis of pure Mg and Mg-4Zn after wear testing at 30 N load

With increasing load from 5 N to 30 N (6 times more) friction generated in Mg and Zn containing system are quite higher and uniform presence of debris are there throughout the micro photograph. In case of pure magnesium more surface roughness are observe than zinc containing system.



Mg-4Zn-3MnO_2 **Mg-4Zn-3$MnCl_2$**

Fig. 7. SEM analysis of Mg-4Zn-3MnO_2 & Mg-4Zn-3$MnCl_2$ all systems after wear testing at 30 N

For 30 N load the MnO_2 containing system shows maximum smooth area along with very fine debris compare to $MnCl_2$ containing system.

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IV. CONCLUSIONS

(i) By changing the load from 5, 10, 15, 20, 25, 30 N wear amount increases in all systems. (Pure Mg, Mg-4Zn, Mg-4Zn-3MnO_2, Mg-4Zn-3$MnCl_2$).
(ii) Compare to pure Mg, addition of 4wt% Zn increases the wear resistance by 20%, while in case of MnO_2 and $MnCl_2$ addition wear resistance increases by almost same percentage.
(iii) Wear rate decreases by addition of 4wt% Zn, Mn (1wt %) from MnO_2 and $MnCl_2$.
(iv) After analysis by SEM it is concluded that at lower load (5 N) amount of wear and debris are more in pure Mg compare to other systems. At higher load (20 N to 30 N) wear marks impression and amount of debris generation are also increase in all the system.

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