Experimental Investigation of Tribological Properties of AZ31 with MWCNT as Reinforcement – Taguchi Approach

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***Abstract*—** **Wear property of pure Magnesium alloy AZ31 nano-composites improved by means of Multi-Walled Carbon Nano Tube (MWCNT) reinforcement were studied through conducting experiments on pin-on-disc wear equipment. The composites are made-up by powder metallurgy method by evenly reinforcing into Magnesium alloy AZ31 matrix. The result of varying percentage MWCNT on the wear property of AZ31 composites and the method behind to facilitate are investigated from end to end by Scanning Electron Microscopy (SEM) examination. The categorization reveals, the wear rate & coefficient of friction of AZ31 & varying wt% of MWCNT significant improvement. SEM investigation confirms that for AZ31 & wt% MWCNT composite surface are having less cracks & defects.**

Keywords—Wear, SN ratio, MWCNT, AZ31, Composites

I. INTRODUCTION

The design of lightweight vehicles and aircrafts, is considered one of the most effective strategies for improving fuel efficiency and reducing anthropogenic climate change. As a result, this area of research has attracted an increasing amount of attention in recent years. However, some inherent weaknesses, such as low absolute strength and stiffness, low wear resistance, and inferior creep resistance often restrict the scope of their applications. The addition of discontinuous reinforcements, especially nano-sized particles, into the magnesium matrix can significantly improve the physical, mechanical, and damping properties of magnesium alloys beyond the limits dominated by traditional alloying.

Over the past few years, MWCNT-reinforced Mg matrix composites have received much attention, and several methods have been proposed to fabricate these composites with a uniform distribution of MWCNT in the matrix, including powder metallurgy with ball milling.

In the recent years the usage of magnesium alloy is drastically increased due its light weight and high strength [6]. Because of its advanced high strength to light weight has made them eye-catching in the implementation in medical implant, aerospace, automotive, electronic [7].

In current days the graphene is one of the most widely investigated allotropes of carbon [1, 2]. Graphene has the identical properties in provisions; it is high young’s modulus at the same time its membrane is soft and superior thermal and electric property [3]. The graphene have mutual amazing physical and chemical properties, as well as broad research in super capacitors, electronics, medical implant, fuel cells.[4,5]. The graphene properties are responsive to the structural defects and the quantity of layers [3].

The growth of metal matrix composite (MMC) is due its good strength and stiffness property the composites shows amazing ductility and strength. And due to reinforcement the stiffness and strength of the composite are enhanced that is either a metal or metal matrix composite based particulate or a fiber. The metal matrix composite are processed in such a way to have low coefficient of friction and thermal expansion behavior build for the application of electronic packing and automobile purpose [8]. Many investigations have carried out on magnesium and the result of study showed a very poor mechanical properties and less wear resistance from the past decades [9].

II. MATERIALS AND METHODS

a. Materials

AZ31 magnesium alloy with the composition of varying 0.5%, 0.75% & 1% of MWCNT was used as the raw material, and was prepared by the metal powders. The specifications of these metal powders are shown in Table 1. The reinforcements, multi-walled MWCNT (30–50 nm in outer diameter, 1-2µm in length, and 98% purity) were used.

b. Fabrication of AZ31–MWCNT Composites

The composites and matrix were fabricated by powder metallurgy method. The reinforcements (0.5 wt. %, 0.75% & 1.0 wt. % MWCNT) and 99 wt. % metal powders (AZ31) were added into a stainless steel container and mixed under the protection of argon atmosphere in a glove box to minimize the oxidation. The mixture was then milled in a ball mill process at 400 rev/min for 2.5 hrs at room temperature using stainless steel balls of 5 mm and 10 mm as the grinding medium, and a ball to powder ratio of 10:1. The mill was turned off for 8 min after every 20 m of work to avoid overheating

c. Wear Test

Dry sliding tests were conducted using Ducom pin-on-disc tester according to ASTM G99-05. Pin specimens machined from the as AZ31 & incorporation MWCNT of varying percentage of diameter 10 mm and length of 25 mm were worn against an grey cast iron (Grade 4E) counter body with a bulk hardness of 82 ± 1 HRB. Before the commencement of each wear test, the pins and counter body surfaces were degreased by acetone and dried to remove surface contaminants. The tribological performance of the composites were studied as a function of reinforcement content (wt. %), applied load (N), sliding speed (m/s) & sliding distance (m). The worn surface morphology has been analyzed through SEM.

All tests were performed at ambient temperature (24^0C) and relative humidity (52-65%) under applied normal load of 10N, 20N & 30N with three different sliding velocities 0.5, 1.5 and 3.5m/s corresponding to travelling distance of 2500m, 3000m & 3500m. Three samples were tested for each test condition and temperature change of the pin throughout the test was measured using chromel-alumel thermocouple contacting very close to the tip of the pin. The worn pin surfaces and collected wear debris were then examined using Scanning Electron Microscope (SEM) to characterize wear surface morphology.

III. RESULTS AND DISCUSSION

In this analysis, to reduce the wear rate of composite, the Taguchi technique adopted to get signal to the noise ratio. L9 orthogonal array were used. S/N ratio indicated in the response table 1 demonstrations that the signal to noise ratio could be maximized at the position and wear could be minimized at these position in the level rank for S/N ratio response table 2 & table 3 shows level rank for AZ31 + 0.5% MWCNT. Figure 1 shows that, means effect plot for AZ31 + 0.5% MWCNT.

Table 1. S/N ratio for AZ31 + 0.5% MWCNT

Sl. No.	Load on Specimen (L)	Sliding. Distance (m)	Sliding. Velocity (m/s)	volume loss	S/N ratio (db)
1	10	2500	0.5	12	-21.5836
2	10	3000	1	15	-23.5218
3	10	3500	1.5	17	-24.6090
4	20	2500	1	22	-26.8485
5	20	3000	1.5	25	-27.9588
6	20	3500	0.5	20	-26.0206
7	30	2500	1.5	36	-31.1261
8	30	3000	0.5	29	-29.2480
9	30	3500	1	34	-30.6296

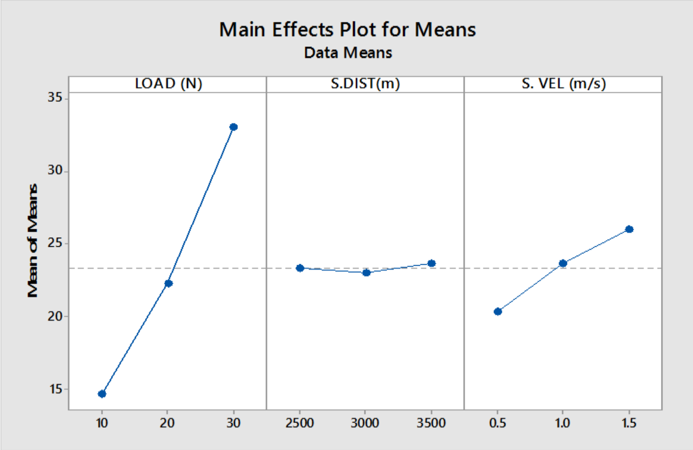

Fig.1 Means effects plot for AZ31 + 0.5% MWCNT

The investigation of variance (ANOVA) is adopted to examine the influence of wear factors like Load, sliding distance, sliding velocity. The ANOVA support to create or build comparative impact or influence of respective constituent in particular of their degree of involvement to the response. The ANOVA experimentation conducted out at the 5% implication level (i.e. at a position of 15% confidence) [14]

Table 2 Level rank for S/N ratio of AZ31 & 0.5% MWCNT

Level	L	S	S.D
1	**-23.24**	**-26.52**	**-25.62**
2	-26.94	-26.91	-27.00
3	-30.33	-27.90	-27.90
Delta	7.10	0.57	2.28
Rank	1	3	2

Table 3 Level rank for Means of AZ31 & 0.5% MWCNT

Level	L	S	S.D
1	**14.67**	**23.00**	**20.33**
2	22.33	23.33	23.67
3	33.00	23.67	26.00
Delta	18.33	0.67	5.67
Rank	1	3	2

Table 4 ANOVA signal to noise ratio for AZ31+0.5% MWCNT

Source	DF	Seq SS	Adj SS	Adj MS	F P	P	%P
L	2	75.5869	75.5869	37.7935	1277.88	0.001	89.9
SD	2	0.5050	0.5050	0.2525	8.54	0.105	0.60
SV	2	7.9188	7.9188	3.9594	133.88	0.007	9.41
Residual Error	2	0.0592	0.0592	0.0296			0.07
Total	8	84.0698					100

Table 4. Show the consequences of the ANOVA examination for AZ31+0.5% MWCNT composites. It is noticed out of variance examination that the, sliding velocity and load exhibit the higher implication on the wear of AZ31+0.5% MWCNT composites substantial future more or correspondingly The end column of table 4 indicates the demonstrates. The percentage involvement of respective parameters on the total variation displays the degree of

implication on response value. It can be noted from the table 4 that the, load, (89.9) sliding velocity (9.41) and value have important implication on the wear properties of AZ31+0.5% MWCNT. Table 5 shows that mean effect plots for AZ31+0.75% MWCNT.

Table5. Means effects for AZ31 + 0.75% MWCNT

Sl. No.	Load on Specimen (L)	Sliding. Distance (m)	Sliding. Velocity (m)	volume loss	S/N ratio (db)
1	**10**	**2500**	**0.5**	**10**	**-19.91**
2	10	3000	1	12	-21.85
3	10	3500	1.5	14	-22.93
4	20	2500	1	21	-26.44
5	20	3000	1.5	21	-26.28
6	20	3500	0.5	20	-26.02
7	30	2500	1.5	32	-30.10
8	30	3000	0.5	26	-28.29
9	30	3500	1	28	-28.95

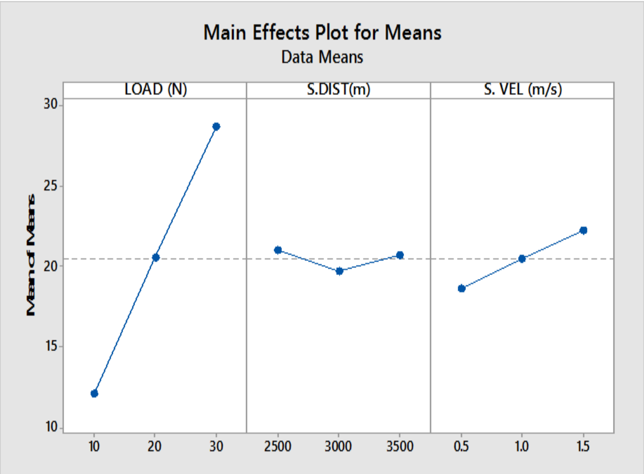

Fig.2 Means effects plot for AZ31 + 0.75% MWCNT

Table 6 Level rank for S/N ratio of AZ31 + 0.75% MWCNT

Level	L	S	S.D
1	**-21.57**	-25.49	**-24.74**
2	-26.25	**-25.48**	-25.75
3	-29.12	-25.97	-26.44
	7.55	0.49	1.70
Delta Rank	1	3	2

Table 7 Level rank for Means of AZ31 + 0.75% MWCNT

Level	L	S.D	S.V
1	**12.10**	20.97	**18.63**
2	20.54	**19.67**	20.47
3	28.68	20.69	22.22
	16.58	1.30	3.58
Delta Rank	1	3	2

The wear rate of AZ31+ 0.75% MWCNT composite, maximize the signal to the noise ratio indicated by bold letters in the response table 6 & table 7 shows that level rank for S/N ratio & Means respectively. Table 8 shows the result of ANOVA for S/N ratio for the AZ31 + 0.75 % MWCNT

Table.8 ANOVA signal to noise ratio for AZ31 + 0. 75% MWCNT

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F P**	**P**	**%P**
L (N)	2	87.2210	87.2210	43.6105	54.61	0.018	93.11
S.D	2	0.4791	0.4791	0.2395	0.30	0.769	0.511
S.V	2	4.3782	4.3782	2.1891	2.74	0.267	4.674
Residual Error	2	1.5972	1.5972	0.7986			1.705
Total	8	93.6756					100

Table no 8. Show the outcomes of the variance examination for AZ31+0.75%mwcnt alloy. It is noticed out of variance examination that the, sliding velocity and load exhibit the higher implication on the wear of AZ31+0.75% MWCNT substantial future more or correspondingly The end column of table 8 indicates the demonstrates. The percentage involvement of respective parameters on the total variation displays the degree of implication on response value. It can be noted from the table 8that the, load, (93.11) sliding velocity (4.674) and value have important implication on the wear properties of AZ31+ 0.75% MWCNT alloy. Table 10 & table 11 shows that level rank for S/N ratio & Means respectively.

Table 9. S/N ratio for AZ31 + 1% MWCNT

Sl. No.	Load on Specimen (L)	Sliding. Distance (m)	Sliding. Velocity (m)	volume loss	S/N ratio (db)
1	**10**	**2500**	**0.5**	9	-19.0457
2	10	3000	1	11	-20.9839
3	10	3500	1.5	13	-22.071
4	20	2500	1	18	-25.1055
5	20	3000	1.5	19	-25.4209
6	20	3500	0.5	16	-24.0824
7	30	2500	1.5	29	-29.236
8	30	3000	0.5	20	-26.0206
9	30	3500	1	25	-28.0916

Table 10. Level rank for S/N ratio of AZ31 + 1% MWCNT

Level	L	S	S.D
1	**-20.70**	-24.46	**-23.05**
2	-24.87	**-24.14**	-24.73
3	-27.78	-24.75	-25.58
Delta	7.08	0.61	2.53
Rank	1	3	2

Table 11 Level rank for Means of AZ31 + 1% MWCNT

Level	L	S	S.D
1	**10.95**	18.64	**14.99**
2	17.56	**16.62**	18.19
3	24.78	18.03	20.11
Delta	13.83	2.02	5.12
Rank	1	3	2

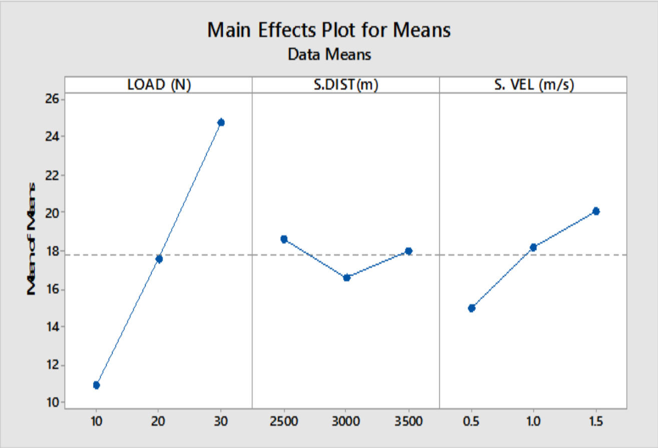

Fig.3 Means effects plot for AZ31 + 1% MWCNT

Table no 12. Show the outcomes of the variance examination for AZ31+0.1% MWCNT. It is noticed out of variance examination that the, sliding velocity and load exhibit the higher implication on the wear of AZ31+0.1% MWCNT substantial future more or correspondingly The end column of table 8 indicates the demonstrates.

Table.12 ANOVA signal to noise ratio for AZ31 + 1% MWCNT

Source	DF	Seq SS	Adj SS	Adj MS	F P	P	%P
LOAD(N)	2	76.0326	76.0326	38.0163	146.48	0.007	87.37
S.DIST	2	0.5525	0.5525	0.2763	1.06	0.484	0.6349
S.VEL	2	9.9172	9.9172	4.9586	19.11	0.050	11.396
Residual Error	2	0.5191	0.5191	0.2595			0.596
Total	8	87.0213					100

The percentage involvement of respective parameters on the total variation displays the degree of implication on response value. It can be noted from the table 12.that the, load, (87.37) sliding velocity (11.39) and value have important implication on the wear properties of AZ31+1% MWCNT.

CONCLUSION

The following results are concluded below,

1. A novel approach applied to fabricate the AZ31 with incorporation of MWCNT as a reinforcement
2. A robust design approach Taguchi’s method followed to the required values.
3. L9 orthogonal array were adopted as Load (L) in N, Sliding Velocity (SV) in m/sec & Sliding Distance (SD) in m.
4. For three wt% of MWCNT characterized to get the wear rate
5. As increase the wt% of MWCNT wear rate has been significantly improved.
6. As ANOVA results revels that, same representation of the wear rate.

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