

Investigation and Assessment of Mechanical Properties of Al-Fly Ash



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1 Introduction

The blend of two or more materials known as composite material exhibits improved properties than the individual constituents when used alone. Individual materials in metallic alloys, on the other hand, retain their unique physical, chemical, and mechanical properties. Reinforcement and matrix, on the other hand, are two distinct elements of MMCs. Composites have stronger strength, stiffness, and low density than bulk materials, allowing for weight reduction in finished parts. Researchers have extensively investigated composites' unrivalled the performances [1–3]. The wear-resistant particulate-filled MMCs are used in applications such as vehicle segments such as piston blocks, cylinders, cylinder rings, calipers, impellers, space structures, contactors, and vibrator segments [4]. Al-based composites shown exceptional mechanical characteristics among MMCs [5, 6]. The wear resistance of Al6061 and Al6061-TiO₂ MMCs is influenced by sliding distance, weight % of reinforcement, and normal load [7, 8]. Prakash Rao [9] experimental results presented that the increasing content of fly ash as reinforcement content in the composites reduces cutting tool failure by reducing built up edge formation. Ankush Sachdeva [10] checked possibility by means of using different reinforcement materials fly ash, silicon carbide (SiC), and the graphite (Gr) to empower properties of A15020 alloy. Different test specimens were fabricated using Al with different reinforcements and studied mechanical properties such as strength and hardness. Udaya Prakash [11] fabricated the hybrid composites using Al as matrix material, boron carbide (B₄C)

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and fly ash as the reinforcement materials. They have investigated the effects reinforcements like surface roughness, gap voltage, and pulse on and off time, by means of wire electro-discharge machining process. Ramachandra et al. [12] fabricated the MMCs using liquid metallurgy route with Al–Si 12 wt% alloy as matrix material and 15 wt% fly ash fine particulates-reinforced composite. Results exhibited that the resistance to wear of the composite reinforced with fly ash material increases with increasing fly ash content but declines with the increasing applied sliding velocity and normal load. Manoj Singla et al. [13] fabricated MMCs using Al as base metal and reinforcement with varying weight fractions of SiC from 5 to 30% in the steps of 5%. The results showed that as the weight percent of SiC increases, so does the hardness and impact strength. At 25 wt% SiC, the extraordinary results (maximum impact power of 36 nm and maximum hardness of 45.5 BHN) were achieved. Yigezu et al. [14] used a full factorial design plan to evaluate abrasive wear of in-situ produced Al–12% Si/TiC MMCs. The percentage of TiC in the coating and the sliding distance had a bigger impact on coefficient of friction (COF), according to findings. Considering the aforementioned, the current research effort intends to develop and test AA1050-fly ash-reinforced MMCs. In this study, fly ash particles were used to strengthen the Al-1050 matrix material at varied weight percent. The mechanical and tribological characteristics of Al-fly ash composites that have been manufactured have been characterized and investigated.

2 Materials and Fabrication

2.1 Material

The material being Al-1050 ingots from was supplied by Fenge Metallurgical, Bangalore, India.

Al alloy AA1050 because of its low density, limited capacity to be strengthened via precipitation, strong thermal and electrical conduction, superior corrosion resistance, and good damping capacity, was chosen as the metal matrix in this investigation. The chemical compositions of AA1050 alloy are shown in Table 1. The properties of AA1050 and the reinforcing fly ash are shown in Table 2. Reliance Industries Limited provided injection grade HDPE (M60075), and NTPC of West Bengal, India provided fly ash. Fly ash was selected as a reinforcement alloy because it is a byproduct of coal combustion and is inexpensive, as well as having high electrical resistivity, poor thermal conductivity, and low density. In the current work, three different proportions of fly ash (1, 2, 4%) are taken. For 1%, 500 gm of Al and 5 gm of fly ash are taken. For 2%, 500 of Al and 10.5 gm of fly ash are taken, and finally, for 4%, 500 gm of Al and 21 gm of fly ash are taken.

Table 1 Chemical composition of AA1050 [15]

Element	Cu	Mg	Si	Fe	Mn	Zn	Ti	Al
Percentage	0.001	0.003	0.123	0.259	0.004	0.008	0.01	Balance

Table 2 Physical and mechanical characteristics of the base alloy AA1050 [15] and reinforcement fly ash

Materials	Hardness (HB500)	Density (g/cc)	Tensile strength (MPa)
AA1050	34	2.71	78
Fly ash	500	2.17	450

2.2 Fabrication and Testing

The fabrication of Al-fly ash MMCs via stir casting procedure was selected; crucible is heated up to 720 °C, and then, Al is placed in crucible; the temperature was maintained till the Al is melted. The fine powder particles of fly ash were selected as the reinforcement material and were added in molten Al after effective degassing with hexachloroethane degassing tabled, and it will be mixed continuously by stirring continuously at 400 rpm for about 10 min simultaneously about 5 g of Mg chips were added to molten mixture to improve the wettability of reinforcement in the matrix material. In the meanwhile, the molds were cleaned and preheated up to 300 °C. After effective stirring of the molten mixture of AA1050 and fly ash MMCs can be poured into the preheated circular-shaped permanent mold box made of cast-iron. After solidification, specimen should remove from the molds, and the excess material from the specimen will be removed by using filing and by using emery papers. Using a CNC lathe machine, the cast MMCs obtained from stir casting were machined to the requisite specifications in accordance with ASTM standards. Mechanical qualities are tested, such as tensile strength, hardness, and wear resistance. The UTM model TUE-C-600 was used according to ASTM standard E8M-04, at JNTU Hyderabad. Hardness test machine model VH-1, SR. No: 27497 was used specimens were prepared according to ASTM standard E384-11. Hardness test is made by using Vickers micro-hardness tester. ASTM-G99 standards were used in this wear experiment. The sliding speed is maintained at 3.14 ms⁻¹. The pin-on-disk device is used to perform the wear test. The pin-on-disk tribometer is used to simulate friction as well as investigate and investigate wear mechanisms under sliding circumstances. The speed was selected from 0 to 500 rpm, temperature control, normal force, wear rate, number of turns, frictional coefficient, speed, and other parameters are registered and then displayed. The weight of the specimen will be carried out by using digital microscope weighing machine. Then, the pin will be rotated on the disk at given speed for 5 min. Wear test is carried out at four different loads (9.81, 19.62, 29.43, 39.24 N). After conducting the test, obtained values are tabulated as below (Figs. 1, 2 and 3).

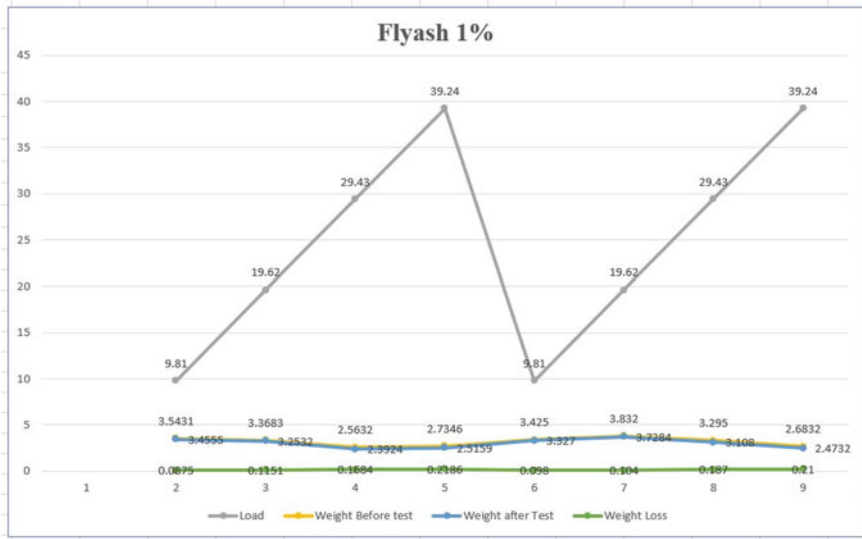


Fig. 1 Wear characteristics of Al-flyash 1 wt% composite

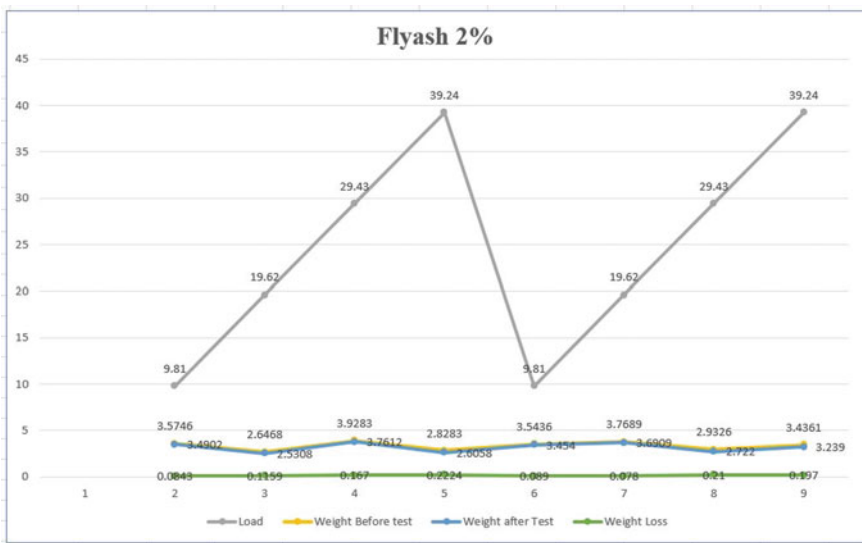


Fig. 2 Wear characteristics of Al-flyash 2 wt% composite

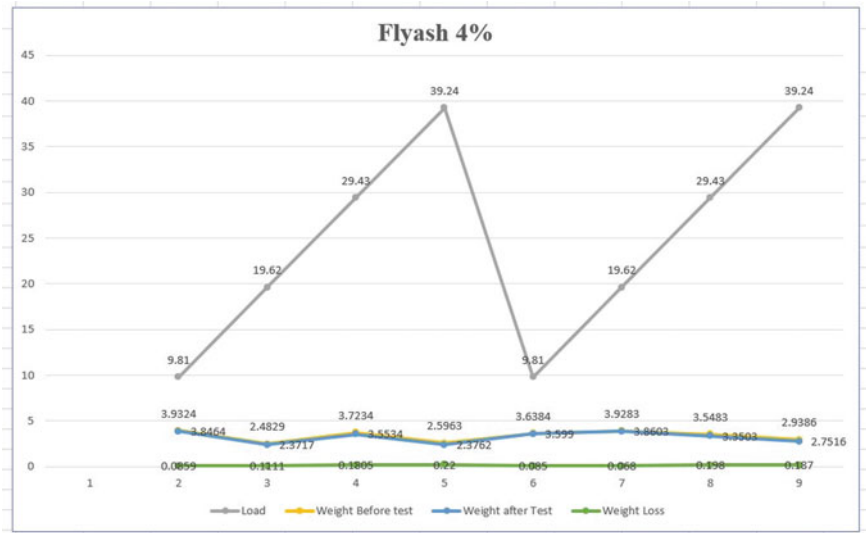


Fig. 3 Wear characteristics of Al-flyash 4 wt% composite

2.3 Factorial Design Methodology

In this case, a 2² factorial design was employed to investigate four components. Compression, hardness, bulk density, and permeability were the four parameters chosen. Investigational work based on two levels and two factors was evaluated and carried out to assess the influence of factors studied on Al castings. The weight loss has an impact on the wear rate, as shown by the ANOVA technique. Table 3 shows the corresponding design parameters. The 2² designs for weight loss are shown in Table 4 (Figs. 4 and 5).

Factors : 2 Base designs : 2, 4
 Runs : 4 Replicates : 1

Table 3 For design parameters

S. No.	Factors	Low (-)	High (+)
1	(Al-fly ash%)	2	4
2	Load	9.81	39.24

Table 4 For 2² design for weight loss

A	B	Replicates		Total	Avg.	Labels
		I	II			
-	-	0.0843	0.0890	0.1733	0.466	(1)
+	-	0.0859	0.0850	0.1709	0.0854	A
-	+	0.2224	0.1970	0.4194	0.2097	B
+	+	0.2200	0.1870	0.4070	0.2035	AB
Total				1.9293	0.9646	

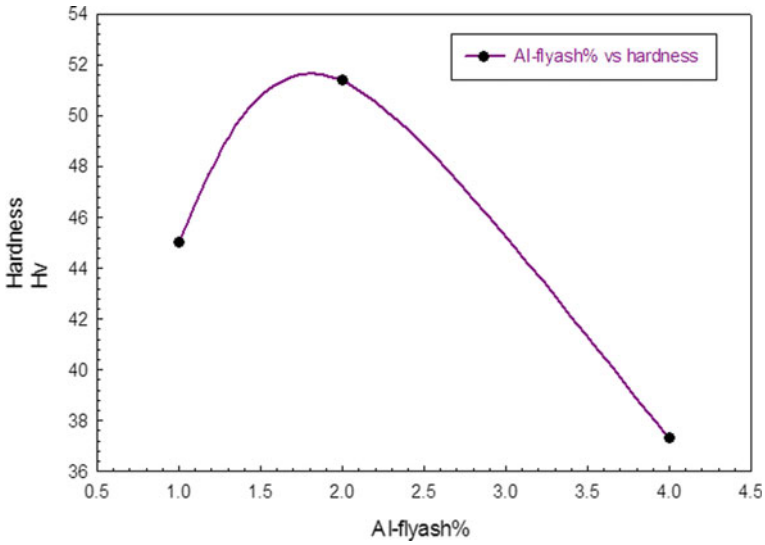


Fig. 4 Variation of hardness for Al-fly ash%

3 Results and Discussion

3.1 Tensile Strength Test

The AA1050 and fly ash MMCs were subjected to evaluate tensile, yield strength, and percentage elongation shown in Table 5. The reduction in mechanical properties of the MMCs is attributed to the decrease in solid solution strengthening.

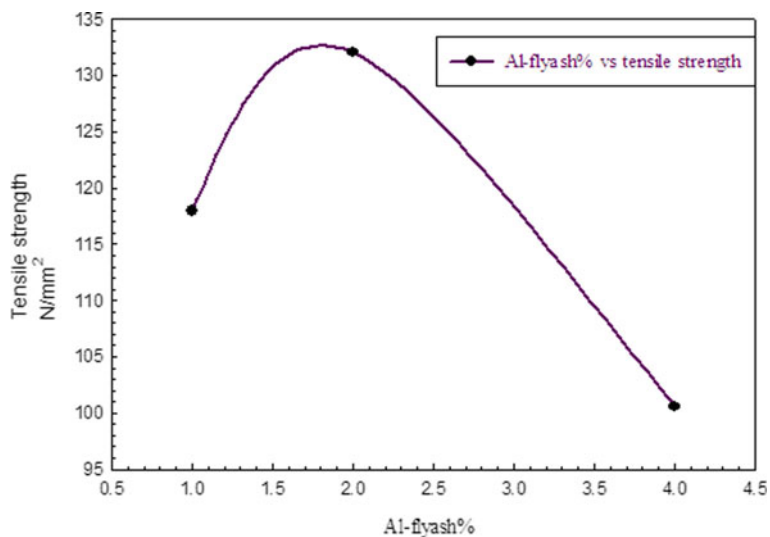


Fig. 5 Variation of tensile strength for Al-fly ash%

Table 5 Tensile test results

S. No.	Al-fly ash% (%)	Tensile strength (MPa)	Yield strength (MPa)
1	0	100	–
2	1	117.955	93.357
3	2	132.090	108.731
4	4	100.599	79.346

3.2 Hardness Test

Hardness test has done for 3 different proportions of Al-fly ash%. From those, different values are obtained for hardness values as mentioned in Table 6.

Table 6 Shows the results for hardness test

S. No.	Al-fly ash% (%)	Hardness values HV
1	0	30HV
1	1	45.0HV0.5
2	2	51.4HV0.5
3	4	37.3HV0.5

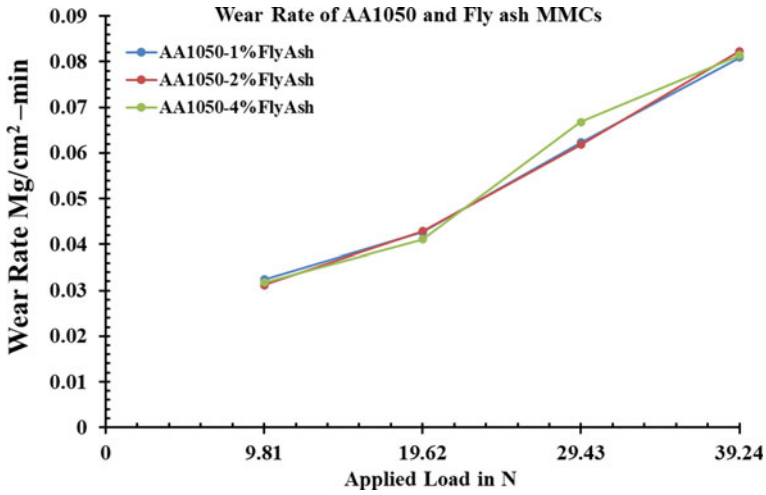


Fig. 6 AA1050-flyash results for wear rate

3.3 Wear Test

Pin-on-disk wear tests were performed for three different amounts of Al-fly ash percent. The results of the testing for wear rate are given in Fig. 6.

3.4 Factorial Design

The estimated effect and coefficient of weight loss will be $R\text{-sq.} = 98.31\%$ and $R\text{-sq. (pred)} = 88.00\%$. The estimated and coefficient of the design matrix were shown in Table 7

The predicted values of pipe volumes are determined from the formula given below.

$$\text{Weight loss (Y1)} = 0.14575 - 0.002775A + 0.0659B + 0.000125AB \text{ (Table 8).}$$

Table 7 Shows the estimated and coefficient of design matrix

Term	Effect	Coefficient	SE coefficient	T	P
Constant		0.146325	0.004591	31.87	0.0000
Block		0.006825	0.004591	1.49	0.234
A	-0.003700	-0.001850	0.004591	-0.40	0.714
B	0.120550	0.0620275	0.004591	13.13	0.001
A * B	-0.002500	-0.001250	0.004591	-0.27	0.803

Table 8 Shows ANOVA of variance

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Blocks	1	0.0003726	0.0003726	0.0003726	2.21	0.234
Main effects	2	0.0290290	0.290290	0.0145460	86.26	0.002
A	1	0.0000274	0.0000274	0.0000274	0.16	0.714
B	1	0.0290646	0.0290646	0.0290646	172.36	0.001
2-way interactions	1	0.0000125	0.0000125	0.0000125	0.07	0.803
Residual error	3	0.0005059	0.0005059	0.0001686		
Total	7	0.0299830				

3.5 Main Effect Plots and Interaction Plots

3.5.1 Main Effect Plot

The principal effect is a plot of the means at each level of a component. When the mean response changes across values of a factor, the main effect plot is used to analyze the relative strength of the effects across the components. When the line is horizontal (parallel to the *x*-axis) in this graph, there is no major effect; nevertheless, there is a main effect when the line is not horizontal. Al-fly ash% (A) climbs from low to high levels in the principal impact graph, whereas loads (B) decrease. The load has the biggest influence on lowering the wear rate of all the factors (Fig. 7).

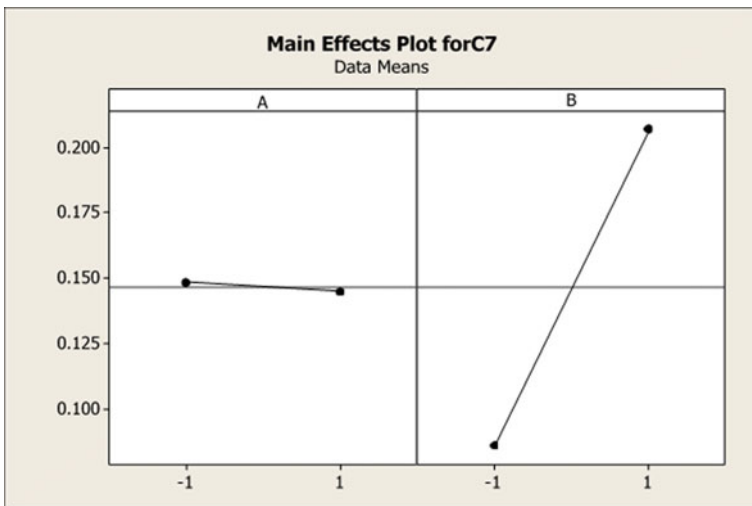


Fig. 7 Main effect plot

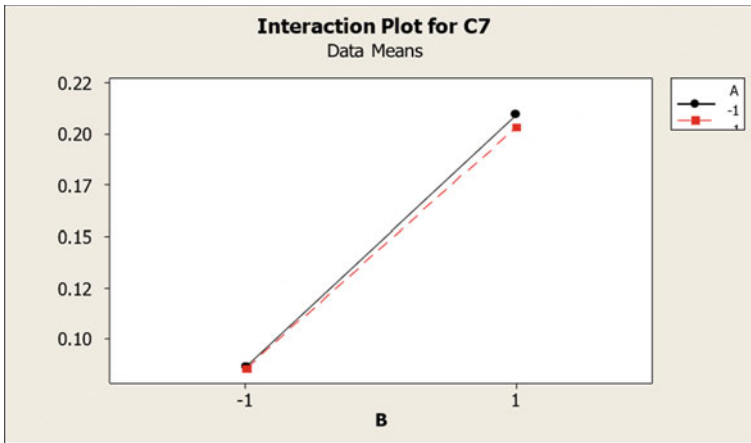


Fig. 8 Interaction plot

3.5.2 Interaction Plot

For two variables, it creates a single interaction map. Interaction plots can be used to determine whether there is interaction; if the interaction plot has a parallel line, there is no interaction (Fig. 8).

3.5.3 Residuals Plots

In regression and ANOVA, residual plot is used to measure the degree of goodness of model. The probability plot, histogram, versus fits, and versus order are all available in Minitab (Fig. 9).

3.5.4 Residuals Versus Fitted Value

This graphic should show a random distribution of residuals on both sides of 0. An outlier is a point that deviates significantly from most other points. In the residual plot, there should be no noticeable patterns.

3.5.5 Histogram of the Residual

General residual attributes such as typical values, distribution, and shape are displayed with this exploration tool. A skewed distribution could be indicated by long tail on one side. Outliers are points that stand out from the rest of the bars in some way.

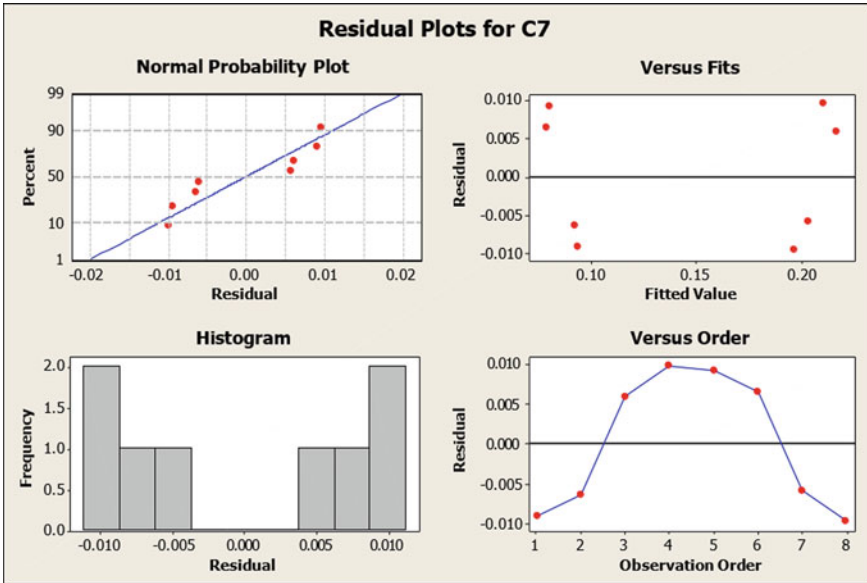


Fig. 9 Residuals plots

3.5.6 Residual Versus Order of Data

This is a plot of all residuals in the order in which they were collected, and it may be used to identify non-random errors, particularly time-related effects. This graph serves in the verification of the uncorrelated residuals assumption.

3.6 Discussion

The results of this study indicate how reinforcing affects the mechanical characteristics of stir-cast Al alloy composites. The results of mechanical parameters like as hardness and ultimate tensile strength are provided in Table 9.

Table 9 Shows the results

S. No.	Al-fly ash%	Tensile strength (N/mm ²)	Hardness HV	Wear rate (mg/cm ² -m)
Al (AA1050)		100	30	9.81
1	1	117.955	45.0	0.2186
2	2	132.090	51.4	0.2224
3	4	100.599	37.3	0.2200

Hence, from the above table, we can clearly say that there is a higher value at 2% reinforcement.

4 Conclusions

In this work, Al-MMCs test samples were prepared using fly ash as reinforcement in various weight percentages 1, 2, and 4 into the AA1050 base metal and performed various tests. From the tests carried out, it may be concluded that the tensile strength can be increased with adding fly ash in aluminum metal matrix. The hardness of MMCs of Al-fly ash increased by adding the fly ash. Wear rate decreased by adding fly ash in the wear melt. Up to 20% of weight, fly ash can be used in stir casting to produce composite. It may be concluded that fly ash may be used to produce Al-MMCs which can be used to turn industrial waste to wealth.

References

1. Pramod, R., Veeresh Kumar, G.B.: Influence of WC particulate reinforcement on the mechanical properties and sliding wear of Al6061 alloys. *Appl. Mech. Mater.* **813/814**, 67–73 (2015)
2. Oghenevweta, J.E., Aigbodion, V.S.: Mechanical properties and microstructural analysis of Al–Si–Mg/carbonized maize stalk waste particulate composites. *J. Eng. Sci.* (2014)
3. Sujan, D., Oo, Z., Rahman, M.E., Maleque, M.A.: Physio-mechanical properties of aluminium metal matrix composites reinforced with Al₂O₃ and SiC. *World Acad. Sci. Eng. Technol.* **6** (2012)
4. Veeresh Kumar, G.B., Rao, C.S.P., Selvaraj, N.: Mechanical and tribological behavior of particulate reinforced aluminum metal matrix composites—a review. *J. Miner. Mater. Charact. Eng. (USA)* **10**(1), 59–91 (2010)
5. Sidesh Kumar, N.G., et al.: Mechanical and wear behavior of Aluminium and hybrid composites. In: *International Conference on Advances in Manufacturing and Material Technology*, vol. 5, pp. 908–917 (2014)
6. Koli, D.K., Agnihotri, G., et al.: Properties and characterization of Al–Al₂O₃ composites processed by casting and powder metallurgy routes. *J. Latest Trends Eng. Technol.* **2** (2013)
7. Elango, G., Raghunath, B.K.: Tribology behaviour of hybrid (LM25A1 + SiC + TiO₂) metal matrix composites. In: *International Conference on Design and Manufacturing*, vol. 64, pp. 671–680 (2013)
8. Veeresh Kumar, G.B., Rao, C.S.P., Selvaraj, N., Bhagyashekar, M.S.: Studies on Al6061-SiC and Al7075-Al₂O₃ metal matrix composites. *J. Miner. Mater. Charact. Eng. (JMMCE) (USA)* **9**(1), 47–59 (2009)
9. Prakash Rao, C.R., Bhagyasekhar, M.: Machining behavior of Al60061-flyash composites. In: *International Conference on Advances in Manufacturing and Material Technology*, vol. 5, pp. 1593–1602 (2014)
10. Sachdeva, A., Narayan, R.: Evaluation and comparison of mechanical properties of aluminium alloy 5052 reinforced with siliconcarbide, graphite and fly ash hybrid metal matrix composites. *Int. J. Eng. Sci. Tech.* **5**, 0975–5462 (2013)
11. Udhay Prakash, J., et al.: Experimental investigation on machinability of aluminium alloy (A413)/flyash/B4 C hybrid composites using wire EDM. In: *International Conference on Design and Manufacturing*, vol. 5, pp. 1344–1353 (2013)

12. Ramachandra, M., Radhakrishna, K.: Effect of reinforcement of flyash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite. *J. Wear* **262**, 1450–1462 (2007)
13. Singla, M.: Development of aluminium based silicon carbide particulate metal matrix composite. *J. Miner. Mater. Charact. Eng. Technol.* **8**, 455–467 (2009)
14. Yigezu, B.S., et al.: On modeling the abrasive wear characteristics of in situ Al–12%Si/TiC composites. *J. Mater. Des.* **50**, 277–284 (2013)
15. Avcu, Y.Y., Gönül, B., Yetik, O., Sönmez, F., et al.: Modification of surface and subsurface properties of AA1050 alloy by shot peening. *Materials* **14**(21), 6575 (2021). <https://doi.org/10.3390/ma14216575>