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Experimental and Simulation of Mechanical and Wear Behaviour of Metal Matrix Nano Composites

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Abstract. The Bayer process, which converts bauxite into alumina, results in the primary waste product being a rusty- colored mud called "red mud." In addition to a few other insignificant chemicals, it is made up mostly of oxidesof the elements iron, titanium, aluminum, and silica. Concerns about the economy and the environment have motivated enormous work on a worldwide scale to find solutions to problems associated with red mudmanagement. These problems include usage, storage, and disposal. Even though there are a lot of diverse applications for red mud, none of them have been shown to be commercially or economically viable as of now.It is well knowledge that MMCs are strengthened to increase their resistance to wear, and that the wear characteristics may be significantly enhanced by including a tough intermetallic compound into the aluminum matrix. The purpose of the present research project is to investigate the low-cost alternative of making use of redmud as a material for reinforcing structures. This is because red mud is not only readily available but also has allof these different components that are good for strengthening. Experiments have been carried out in a laboratorysetting with the purpose of determining the wear characteristics of an aluminum red mud composite when subjected to a variety of various operating situations using a pin-on-disc machine in pure sliding mode. Additionally, the samples were heated in order to improve their wear properties. Under an optical microscope, the worn surfaces of the samples that had already been used were analyzed in order to get a better understandingof how the particle reinforcement influences the wear behavior of the composite. The wear resistance and tensile strength of the composite are both enhanced when red mud particles are dispersed throughout the aluminum matrix. If the cooling medium and heat treatment are chosen appropriately, the composite may have higher wearresistance. In addition, an artificial neural network prediction model (ANN) is used in order to reproduce the correlation that exists between the property parameters. As a consequence of this, the values that were seen experimentally and those that were projected match up incredibly well. These results may serve as a springboardfor researchers and industrial designers to make MMC components from industrial waste for use in wearable settings. These components may be made from trash from many industries.

Keywords: artificial neural networks (ANN), aluminum matrix, red mud composite, pin-on-disc machine, MMCcomponents.

1. Introduction

Since the early 1940s, when radome structures were made of E glass and phenol, sophisticated composites have come a long way. A fantastic illustration of this development is the usage of graphite and polyamide composites in the space shuttle orbiter. This advancement in the technology of reinforcements, matrices, and composite manufacturing was brought on by the realization that adopting advanced composites might potentially result in weight reductions, which in turn implies lower cost and improved efficiency.

The awareness of the potential weight reductions that may be obtained by adopting advanced composites was the primary driver of this expansion. The 1960s saw a focus on the rigorous examination of features and fracture mechanics, in contrast to the preceding two decades, which saw breakthroughs in production techniques. Since then, there has been a growing need for brand-new materials that are lighter in weight while also being more stiff, stronger, and flexible. Construction, transportation, and the aviation sectors are just a few examples where this need is present. The creation of composite materials is, in large part, a response to the tremendous demands that the aviation, aerospace, and automotive industries are placing on technology. Because of their low specific gravity, the qualities of these materials, particularly in terms of their strength and modulus, are considerably superior to those of many conventional engineering materials such as metals. This is especially true in terms of how well they perform. It isnow possible to create one-of-a-kind composite materials that have superior physical and mechanical properties as a result of extensive research into the fundamental nature of materials and an improved understanding of the relationship between structure and property among various kinds of materials. These two topics have been the focus of a great deal of attention in recent years. Some examples of these cutting-edge materials are high- performance composites such as polymer matrix composites [1, 2], ceramic matrix composites [3, 4], and metal matrix composites [5, etc.]. It is possible that the steady flow of technological progress that has occurred in the most recent decades is to blame for the increasing prevalence of applications that make use of composite materials. As a result of the significance of composites as engineering materials, there are already more than 200 various types of composites that can be purchased on the market [6]. This number is based on the fact that there are now more than 1600 different types of engineering materials available.

According to Jartiz's definition of composites they are multifunctional material systems that provide properties that cannot be acquired from a single material.] The physical fusion of two or more materials that are compatiblewith one another and that may differ in composition, characteristics, or even form results in cohesive constructs. Kelly [8] makes it very clear that composites shouldn't be seen as a combination of the two components that makethem up. When viewed in a broader context, the combination has characteristics that are distinctively its own.It has more strength, heat resistance, or any other desirable quality than any of the components alone, and it differsfundamentally from both of the components in terms of its composition.

In order to create a better material, Berghezan defines composites as "compound materials that differ from alloysby the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their shortcomings." "Compound materials that vary from alloys by the fact that the separate components maintain their features" is how composites are characterized.Van Suchetclan defined composite materials as heterogeneous materials made up of two or more solid phases thatare in microscopic contact with one another. According to this definition, composite materials are as follows: They may also be considered homogeneous materials at the microscopic level, meaning that no matter where a portion is located, it will always have the same physical characteristics.

According to some reports, just 5% of the energy required to produce aluminum from scratch is consumed in the recycling process However, there are certain problems with recycling aluminum, one of which is the presence of contaminants, which significantly affects the mechanical properties of the recovered material. The components and the manufacturing technique must both be carefully chosen in order to avoid this problem since they may induce the development and buildup of hazardous intermediate phases].

There are several variables to consider that are interdependent while creating an effective MMC material. It is crucial to pick these parts carefully since the characteristics of the matrix and the reinforcing material establish the upper restriction on the MMC properties.

2. Material Selectin and Experimental Setup

2.1 Aluminum properties

Experiments were carried out using aluminum of the IE–07 grade, which is characterized by a high level of purity suitable for commercial use. This aluminum was acquired from the Vizag steel mill in Andhra Pradesh. The resultsof the composition analysis as well as those of the other tests, including those assessing hardness, density, and tensile strength, are shown in Tables 1 and 2, respectively.

Table 1: Chemical analysis of aluminum

Sr. No.	Si	Fe	Ti	V	Cu	Mn	Al
1	0.07	0.15	0.0021	0.006	0.0012	0.0045	99.58

Table 2: Density, Hardness & Tensile Strength of Aluminum

Density	2.7 gm/cc
Hardness	40.8 VHN
Tensile strength	67 MPa

2.2 Red mud properties:

The red mud that was used for this investigation was acquired from the aluminum factory in Vizag, which is located in the state of Andhra Pradesh. Dust was produced by the manual preparation. For the purpose of determining the particle size of the dust, a sieve was used. This study revealed that the usual size of the dust was150 microns. This information was gleaned from the results of the inquiry. The dust that was obtained from the red mud was used for both the XRD and the chemical analysis. The findings of a number of different chemical investigations are shown in Table 3, which provides evidence that a number of elements do in fact exist.

Table 3: Chemical (dry) analysis of red mud

Constituents	% (wt)	Constituents	% (wt)
Al_2O_3	13.0	Fe_2O_3	55.6
TiO_2	4.7	SiO_2	7.62
Na_2O	5.25	CaO	2.35
P_2O_5	0.89	V_2O_5	0.41
Ga_2O_3	0.088	Mn	0.98
Zn	0.015	Mg	0.065
Organic C	0.96	L.O.I	Balance

2.3 Disc type tribology machine for wear test set up

The tests have been carried out under the following conditions;

- The specimens selected for analysis have ties to the current collection being utilized for study. The collectand specimen (Pin) are placed at a predetermined track diameter before being read out. This is done to improve the readability of the collect. Every time we repeat this test, we're going to change the track's diameter and choose a fresh track to put each specimen through its paces on. In this experiment, the discwill be moved around at different intervals, but the specimens will remain in the same locations during the investigation.
- A mechanism that employs dead weight as its load source is responsible for applying force to the pin inorder to bring it into contact with the disc.
- The controller has the capability of reading out the amount of frictional force that is created at the contact.
- You may adjust the number of revolutions per minute (rpm) of the motor as well as the speed of the discby using the controller.
- A total of 27 distinct sets of test pieces were analyzed in order to determine the properties of a particularkind of composite.

- We gave every set of exams a thorough workout for a combined total of six hours' worth of time. After each cycle of one hour had passed, the test pieces were removed from the apparatus and put through a series of stringent weighing procedures in order to determine the percentage of their initial weight that had been lost.

Figure 1: Disc type wear testing machine

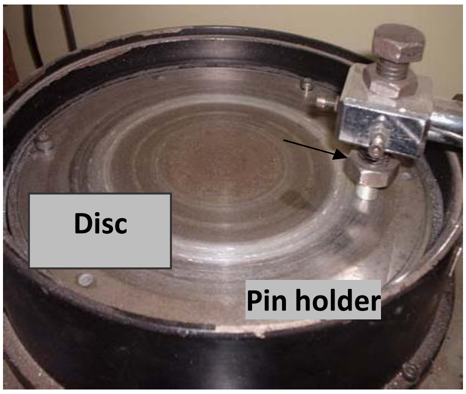


Figure 2: Disc and pin holder

Figure 3: Applying dead weight to study wear rate

2.4 Tensile and impact test

In order to conduct the tensile tests, a circular cross-section specimen with a specific gauge length of 60 mm, a grab distance of 100 mm, and an 8 mm gauge diameter was used. In addition to that, the distance between the hands was evaluated in millimeters. Tensile tests were carried out using INSTRON 1195 tensile testing equipmentwith a capacity of 100 kN. The crosshead speed was held constant at 5 mm/min, and the full scale load range was20 kN. This resulted in an initial sample rate of 9.103 points per second. The dimensions of the specimen that wasused for the impact test were 10 millimeters by 10 millimeters by 50 millimeters, and the size of the rectangular notch was 2 millimeters. The tests were carried out using impact testing equipment of the Charpy kind, and the temperature at which they were carried out was room temperature. Out in the field, the trials were carried out using a striking velocity of 5.6 meters per second and an initial hammer energy of 30 kilograms per meter. Thereis a summary of the outcomes of the impact tests that were carried out on a variety of test specimens.

3. Results and Discussion

Red mud particles have been successfully incorporated into aluminum matrix composites in a very equal distribution. In an aluminum matrix, red mud particles are dispersed to increase the material's hardness and the composite's wear properties. As a consequence of the larger interfacial area between the red mud particles and thealuminum matrix, the strength is noticeably improved. At higher weights and quicker speeds, the specific wear rate decreases as red dirt content rises. As particle volume content increases, the wear coefficient tends to decrease. Additionally, it implies that red mud inclusion aids in making the aluminum-red mud composite fade more slowly.The composite's resistance to wear is increased by the addition of red dirt particles. Despite the fact that there is no filler volume friction, the composite has the highest wear resistance. The results of the tensile test are shown in the table below.

Table 4: Mechanical properties of specimens

Specimen	Yield Stress (MPa)	Ultimate Stress (MPa)	Modulus of Elasticity (GPa)	Percentage Elongation	Impact Strength (Kg.m/cm^2)	Hardness (VHN)
Pure Al	24.5	65	71	29	6.5	41.21
90% Al + 10% RM	23.47	7.86	35.86	9.85	8.59	53.25
85% Al + 15% RM	31.77	7.68	44.53	12.01	9.26	54.2
80% Al + 20% RM	25.83	6.83	44.1	13.99	9.98	56.71
70% Al + 30% RM	31.96	6.5	59.61	15.01	11.22	53.24

Table 5: Wear result of Al at 10N, V=1.885 m/sec, RPM = 200 and ρ = 2.62 x 10^3 Kg/m^3

m1 (gm)	m2 (gm)	Δm (gm)	t (sec)	Ff (kg^f)	μ	R.D × 10^3 (m)	Wr ×10^{-6} (N/m)	Wv × 10^{-12} (m^3/sec)	Ws × 10^{-13} (m^3/N-m)
8.25	7.18	0.02	3600	0.36	0.31	5.12	0.12568	8.2156	6.548
8.25	7.98	0.21	7200	0.39	0.35	10.12	0.15067	7.2548	6.2548
8.25	8.25	0.36	10800	0.31	0.36	14.23	0.16125	7.5465	6.8791
8.25	8.025	0.30	14400	0.28	0.29	19.62	0.13265	7.8954	6.5487
8.25	8.36	0.42	18000	0.25	0.37	23.62	0.17845	7.225	5.784
8.25	8.35	0.41	21600	0.35	0.51	28.46	0.15684	7.125	5.556

Table 6: Wear result of Al with 10% RD at 10N, V=1.257 m/sec, RPM = 200 and ρ = 2.62 x 10^3 Kg/m^3

m1 (gm)	m2 (gm)	Δm (gm)	t (sec)	Ff (kg^f)	μ	R.D × 10^3 (m)	Wr × 10^{-6} (N/m)	Wv × 10^{-12} (m^3/sec)	Ws × 10^{-13} (m^3/N-m)
8.40	8.25	0.01	3600	0.29	0.28	4.89	0.0549	5.124	4.012
8.40	8.445	0.025	7200	0.45	0.21	10.012	0.06548	4.568	4.012
8.40	8.15	0.12	10800	0.41	0.36	14.02	0.0745	5.213	4.215
8.40	8.46	0.26	14400	0.32	0.24	19.21	0.07145	5.2365	4.23
8.40	8.49	0.29	18000	0.32	0.55	23.25	0.0854	5.1236	3.658
8.40	8.76	0.21	21600	0.34	0.33	26.21	0.0859	3.998	4.001

Table 7: Wear result of Al with 15% RD at 10N, V=1.257 m/sec, RPM = 200 and ρ = 2.62 x 10^3 Kg/m^3

m1 (gm)	**m2 (gm)**	**Δm (gm)**	**t (sec)**	**Ff (kg^f)**	**μ**	**R.D × 10^3 (m)**	**Wr ×10^{-6} (N/m)**	**Wv × 10^{-12} (m^3/sec)**	**Ws × 10^{-13} (m^3/N-m)**
7.88	7.52	0.02	3600	0.51	0.52	3.98	0.0712	4.3568	2.458
7.88	7.53	0.071	7200	0.61	0.61	9.52	0.0743	4.5684	3.1458
7.88	7.52	0.15	10800	0.57	0.63	14.12	0.0768	4.6524	3.6587
7.88	7.61	0.16	14400	0.57	0.61	19.52	0.0758	4.1225	3.4514
7.88	7.96	0.2	18000	0.59	0.62	23.74	0.0852	4.9845	3.8457
7.88	7.62	0.25	21600	0.62	0.64	28.46	0.0841	4.1542	3.2354

Table 8: Wear result of Al with 20% RD at 10N, V=1.257 m/sec, RPM = 200 and ρ = 2.62 x 10^3 Kg/m^3

m1 (gm)	**m2 (gm)**	**Δm (gm)**	**t (sec)**	**Ff (kg^f)**	**μ**	**R.D × 10^3 (m)**	**Wr × 10^{-6} (N/m)**	**Wv × 10^{-12} (m^3/sec)**	**Ws × 10^{-13} (m^3/N-m)**
8.47	8.54	0.03	3600	0.41	0.40	5.68	0.0965	5.21	3.485
8.47	8.45	0.09	7200	0.44	0.38	10.25	0.0964	5.21	3.492
8.47	8.78	0.21	10800	0.24	0.35	14.521	0.0968	6.11	3.427
8.47	8.45	0.18	14400	0.22	0.30	19.625	0.0945	4.2236	3.896
8.47	8.75	0.22	18000	0.42	0.42	23.254	0.0742	4.7251	3.522
8.47	8.46	0.23	21600	0.41	0.43	28.457	0.0742	4.6254	3.894

Table 9: Wear result of Al with 30% RD at 10N, V=1.257 m/sec, RPM = 200 and ρ = 2.62 x 10^3 Kg/m^3

m1 (gm)	**m2 (gm)**	**Δm (gm)**	**t (sec)**	**Ff (kg^f)**	**μ**	**R.D × 10^3 (m)**	**Wr × 10^{-6} (N/m)**	**Wv × 10^{-12} (m^3/sec)**	**Ws × 10^{-13} (m^3/N-m)**
8.45	8.52	0.06	3600	0.38	0.39	5.53	0.1224	6.112	5.213
8.45	8.47	0.08	7200	0.34	0.38	10.12	0.0846	4.112	3.855
8.45	8.56	0.15	10800	0.33	0.36	14.52	0.0897	4.215	3.289
8.45	8.68	0.17	14400	0.29	0.29	19.52	0.0775	3.854	3.456
8.45	8.52	0.19	18000	0.41	0.41	23.64	0.069	3.546	2.758
8.45	8.46	0.18	21600	0.42	0.44	28.21	0.0752	4.221	2.681

Figure 5 depicts the change in wear rate that occurs with sliding distance for three different weights (10N, 20N, and 30N) when the sliding speed is set to 200 rpm. The findings show that the wear rate of the composite is decreased when red dirt particles are included in its composition. In addition, the drop in wear rate that occurs asa direct result of an increase in sliding distance is followed by an almost complete maintenance of that level throughout the test. It has not been included here since the pattern for 300 and 400 rpm is the same as the one for200 rpm and is thus the same. Figure 5 shows the link that may be drawn between a certain wear rate and the fillervolume fraction, often known as "red mud." The graph indicates without a shadow of a doubt that as the filler volume percent increases, the wear rate decreases, then climbs, until it achieves a minimum value somewhere between 10 and 20%. There is a perfect filler volume fraction that, therefore, provides the composite with the highest possible wear resistance.

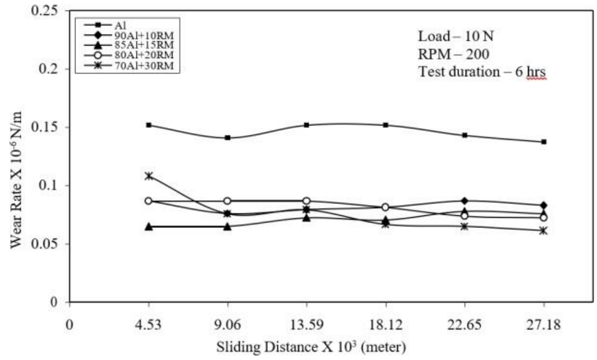
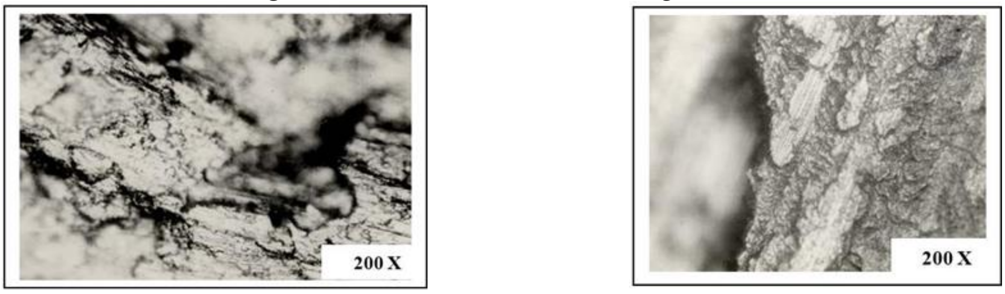
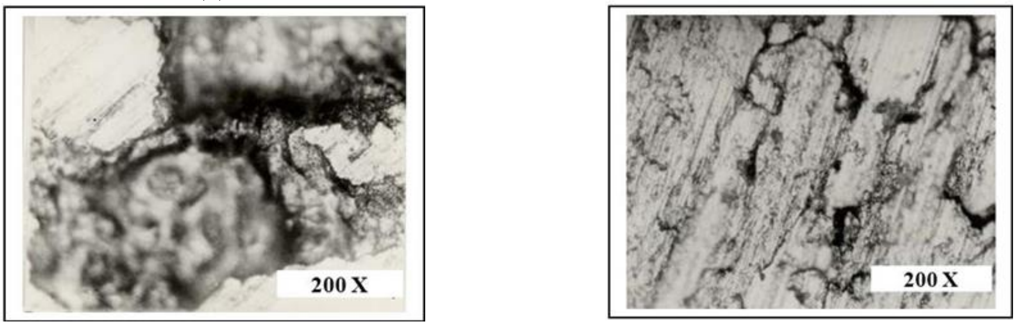


Figure 4: Variation of wear rate with sliding distance



(a) (b)



(b) (d)

Figure 5: Micrographs showing wear surface of samples at 200 rpm (a) 10% mud at 10 KN (b) 15% mud at 10KN (c) 20% mud at 10 KN (d) 30% mud at 10 KN

Following the wear test, an optical microscope is used to look at the damaged surface of a few selected or typical specimens. Figures 5 and 6 depict the surface morphology of an aluminum-red mud composite that was tested under two different load and speed conditions (a–c). When the sample is examined at low speeds, such as 300 rpm, it appears that cavities have formed in the composite matrix and have aligned parallel to the direction of sliding in Fig. 5(a, b, and c). Some particles have also been cut off while sliding. The worn surface changes as sliding velocity rises, as shown in Fig. 3.25(b) at 400 rpm. There are fewer cavitations now than there were before. In certain places, the substructures are sometimes parallel to the sliding direction. In other locations, smaller particles have protruded from the composite matrix. At the same sliding speed of 400 rpm and with a rising appliedstress, i.e., from 20 N to 30 N, cracks have formed and are propagating in different directions for the same composite. These could have helped break up tough particles like red dirt. The outcomes for a composite consisting of red mud and 15% aluminum tested at sliding velocities of 300 and 400 rpm, respectively, are shown in Figures3.26(a) and (b). The figures show that as the sliding velocity increased, grooves formed [Fig. 5(b)]. Slower speeds,on the other hand, may reveal wave-like patterns (Fig. 3.5(a), b, c, d)).

The structures of the worn surfaces are significantly influenced by the slider speed and the conditions of the applied force [194]. Surface structures of the samples are shown in Figures 5 (Al+20% RM) (a–d). By comparingthese data, it can be observed that when the sample is rubbed against a steel wheel at a low sliding speed and lowapplied force, the aluminum matrix seems to be spread along the direction of sliding, which suggests that hard particles may have chipped off. The size of the aluminum granules similarly rises from 10 N to 30 N of applied force. Furthermore, there are more cavitations now. The tough particles seem to contain some holes (i.e., red mudparticulates). The worn surfaces for the same composite attained a higher sliding velocity (400 rpm) for two different applied loads, i.e., 10 N and 20 N, as illustrated in Figs. 5, respectively. The worn surfaces are substantially smoother than those at slower sliding speeds, as seen in Figures 5 (a) and (b). It should be noted thatfractures happen in a straight line with the sliding direction. Hard particles (like red mud) fracture, fragment, andmigrate along the crack lines as the applied tension decreases or increases. With an increase in applied stress, thenumber of cavitations seems to be low, but deep cracks and grooves are still clearly visible [Fig. 5 (d)].

4. Prediction of Wear by Using Neural Networks

Fifty-nine separate data sets were used in the training and assessment of two neural networks, with the initial process data serving as the primary source of information. The first neural network was used for samples that werecooled by air and water, while the second neural network was used for samples that were cooled by water at 15 and 50 degrees Celsius, respectively. Both of these temperatures were employed for the cooling process. These two temperatures were used together to cool the samples. Inputs such as the normal load, sliding distance, and heat treatment temperatures were included in each of the data sets that were compiled. After that, the neural network that was used for prediction began producing output values such as the wear rate, the volumetric wear rate, and the specific wear rate. The training parameters that were used for networks I and II, respectively, are shown in tables 10 and 11, respectively, and are broken down into further depth. Figure 7 depicts the anticipatedvalues of wear rate, volumetric wear rate, and specific wear rate under typical load conditions. These values are provided for a range of temperatures at which heat treatment was performed (a–d). The findings of the neural network are shown by the dotted line, while the outcomes of the experiment are indicated by the solid line. The expected values, as can be seen from these statistics, coincide with the values discovered via testing, with the mean relative error ranging anywhere from 4% to 0.46% of the total. Moreover, the expected values are consistent with the values discovered through testing.

A neural network was constructed with the intention of forecasting the volumetric, specific, and wear rates of the particle-reinforced aluminum matrix composite based on a certain volume percent of red mud particles. The neural network was used to accomplish this. You may locate this piece of work in Chapter 5. The findings of this experiment show that ANN is able to provide reliable forecasts about the wear parameters of aluminum red mudcomposite. It is feasible to arrive at the conclusion that ANN is a valuable analytical instrument that, if applied inthe appropriate manner, has the potential to be exploited in the field of tribology. This conclusion is reachable because it is possible to derive the following conclusion: A neural network that has been appropriately trained may create more useful data from an experimental data base that is on the smaller side, and it may also be utilizedto determine the outcomes of significant and large-scale operational circumstances.

Table 10: Training parameters used in Prediction Neural Network – I

Training input parameters	Values
Error tolerance	0.01
Learning parameter	0.01
Momentum coefficient	0.001
Noise factor	0.001
Cycles	500000
Slope parameter of sigmoid function	0.6
Hidden layer	2
Number of inputs	3
Number of hidden layer neurons	12
Number of output	3

Table 11: Training parameters used in Prediction Neural Network – II

Training input parameters	Values
Error tolerance	0.01
Learning parameter	0.01
Momentum coefficient	0.001
Noise factor	0.001
Cycles	200000
Slope parameter of sigmoid function	0.6
Hidden layer	2
Number of inputs	3
Number of hidden layer neurons	12
Number of output	3

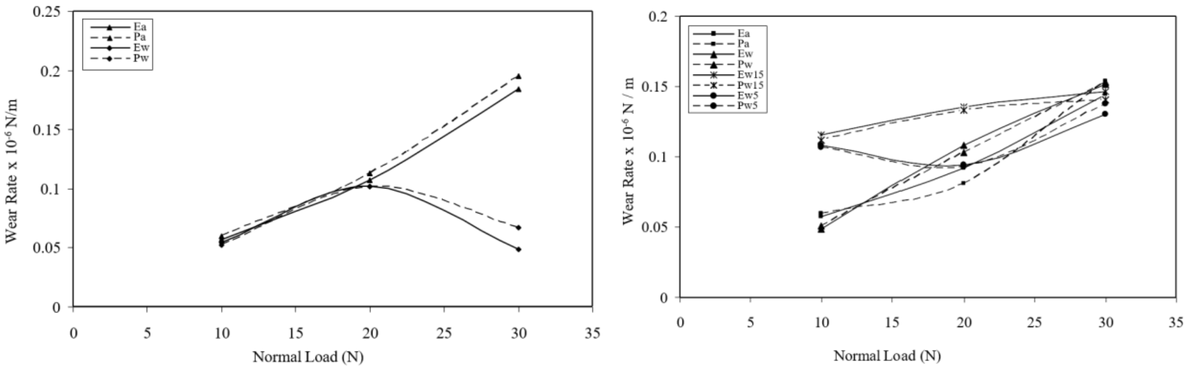


Figure 6: Comparison between experimental and predicted values ofwear rate with different load

5. Conclusion

- In the creation of a Metal-Matrix Composite (MMC) component that will be employed in a wear-prone environment, the waste product of an alumina mill known as "red mud" has the potential to be used successfully as a reinforcing material. It might be used efficiently in place of more conventional materials that include a lot of aluminum, saving around 15% of the matrix material.
- The red mud particles are readily dissolved in the aluminum matrix, increasing both the material's hardness and the composite's resistance to wear. By increasing the interfacial area between the matrix material and the red mud particles as a consequence of this impact, the strength is noticeably increased.
- The specific wear rate of the composite material decreases when more filler volume fraction is added, but it begins to increase again once it reaches a minimum value of between 15 and 20 percent. As a result,there is a filler volume fraction that, when employed to its full potential, gives the composite the most wear resistance.
- Wear is a result of a variety of variables, including load, sliding distance, and sliding velocity. On the other hand, using the wear co-efficient (K), which can be calculated from Archard's law, to describe theeffects of sliding wear is more precise.
- The sliding wear experiment's various variables are connected to one another to varying degrees depending on the wear coefficient, abbreviated as "K." The addition of red mud is beneficial in reducingthe wear of aluminum red mud composites, as it was shown that the wear coefficient tends to decrease with increasing particle volume contact (15–20%).
- The results indicate that quenching the samples in water following heat treatment, as opposed to coolingthem with air, improves their wear resistance. This is because water quenching may reach cooling rates that are substantially higher than those that can be obtained with air cooling, which causes the samples to be put under a lot more strain.

- The results of this study suggest that the oxide phases, including Al_2O_3, Fe_2O_3, TiO_2, and others, mayhave diffused evenly throughout the aluminum matrix, contributing to the composite's improved strengthfollowing heat treatment.

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