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Research Article

Synthesized Nanoaluminum Oxide with Al2024 to Investigate Wear Behavior by Grey Relational Approach and ANN

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Aluminum metal matrix composites (AMCs) have been employed in automobile manufacturing to reduce weight. Also this research concentrates on the tribological performances on the processed AMCs by the stir casting liquefying method. The aluminum alloy Al2024 was employed to nanoparticles of aluminum oxide for the preparation of AMCs with constant processing condition of stirring speed to produce the homogeneous dispersion. The processed composites were further investigated to identify the wear characteristics. Therefore, the dry sliding condition was achieved on the processed composites. The input parameters of dry sliding conditions are sliding distance, functional load, and sliding velocity, and the output characteristics are wear rate and coefficient of friction (COF). Those input parameters are framed by the Taguchi L9 array and parameters were further employed to optimize with grey relational analysis. From the L9 parameters, the better wear rate and COF were accumulated in the following parameter: 2,100 mm of sliding distance, 25 N of functional load, and 2.5 m/s of sliding velocity, respectively. Then the wear rates and COF values are subjected to produce the predicted responses with supporting of artificial neural network. Most of the predicted values are much higher than the actual wear response vales. The wear resistance of all the samples composed better performances with dispersion of nanoaluminum oxide particles on the Al2024 alloy.

1. Introduction

The metal matrix composites are improving the tribological behaviors in the applications of various engineering fields [1]. Especially, the automotive, aerospace, and ship industries are highly satisfied with metal matrix composites due to the low weight in frames without conciliation of weight properties and better wear characteristics [2]. Recently, the processed aluminum metal matrix composites (AMCs) have fulfilled the necessity of the world marketplace for lightweight structures [3]. It is revealed that the processed AMCs contain maximum life period for the mechanical components with high satisfaction of superior mechanical attributes and electrical and thermal conductivity for electrical components, which is fully replaceable for traditional components [4]. Similarly, the wear and corrosion properties are also highly utilized with AMCs [5] with suitable nanoreinforcement particles. The matrix composites are typically produced through the stir

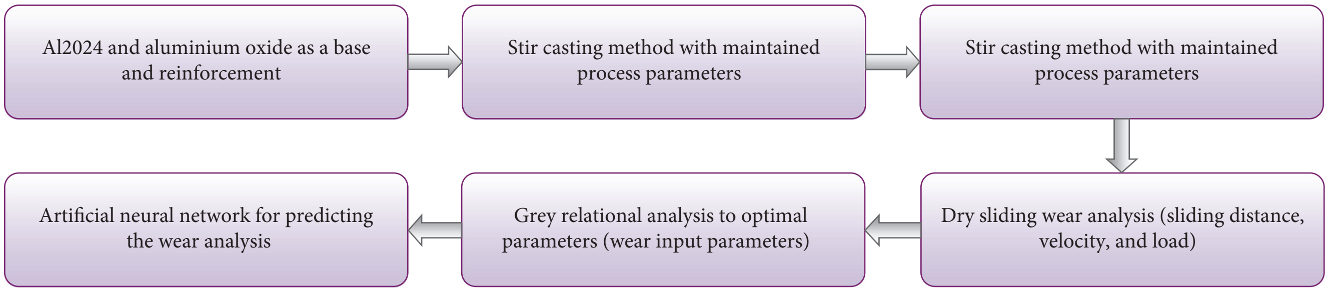

Figure 1: Summary of present studies' layout.

casting method, which involves melting the materials, as solid-state processing is expensive. This approach is considered a more effective and cost-efficient means of manufacturing matrix composites [6]. The stir casting technique was fabricating the composites with rapid method to generate the AMCs and melting was greatly achieved with the optimized processing conditions [7].

To enhance the mechanical properties with failed wear resistances, aluminum was mingled with highly issued materials with hard and brittle nature. Therefore, suitable reinforcement is major a significant reason to improve the AMCs' characteristics to form the multifunctional materials [8]. In this research, the authors severely focused to identify the base matrix for achieving the mechanical characteristics by maximum potency. Aluminum–copper alloy had a better option to compose the AMCs because it possesses medium strength and great capability of heat treatment and also is a notable consideration in the aerospace industries. Based on the brittle nature of reinforcements like boron carbide, silicon carbide, silicon nitride, etc. Aluminum oxide was better a combination of aluminum–copper alloys to create the superior properties of metal matrix composites [9]. This kind of materials were highly utilized in the applications like tube, crane, mold, boat materials and also feasible for the machinabilities and weldability [10]. Gupta et al. [11] developed the metal matrix composites between the LM27 alloy and ceramic particles. Then the composites were employed to achieve the dry sliding characteristics with various processing conditions. Due to the presence of ceramic particles mechanical attributes were greatly achieved with increasing wear performances. Gupta et al. [12] investigated the metal matrix composites on the aluminum silicon alloy with boron carbide particles. During the wear analysis, increase of boron carbide improves the intermetallic phases with grain refinement structures. Due to low density and high hardness, boron carbide creates better wear characteristics.

Gladston et al. [13] prepared the metal matrix composites by the stir casting process with aluminum 6XXX series using rice husk reinforcements. During the wear performances with dry sliding conditions, wear surfaces were highly modified with the presence of suitable reinforcements on the aluminum alloy which creates low-damaged surfaces on the wear samples. Jha et al. [14] conducted the wear analysis on the processed metal matrix composites of alumina with silicon carbide contents. The dry sliding parameters are highly influenced by wear performances. Saessi et al. [15] investigated the tribology characteristics of the processed AMCs of Al5083 and boron carbide particles. When compared the wear rate, it was higher for milled Al5083 than the processed AMCs Al5083 with B4C. In this research, the aluminum alloy Al2024 was used as a base matrix of stir casting process and nanoaluminum oxides as strengthening particles for achieving the metal matrix composites. Then the composites are employed to dry sliding wear behavior to identify the wear characteristics. Figure 1 shows the study plan of current investigations.

2. Materials and Methods

In this present study, Al2024, a parent material for the stir casting process and the strengthening reinforcing particles, is aluminum oxide having the size of 20 nm. The parent material contains possible tailored processes with heat treatment in elevated temperatures without compromising the strength. In this process, the 9 wt% of aluminum oxide was mixed with Al2024 remaining weight percentages. The chemical composition of Al2024 is 0.1 Cr, 0.25 Zn, 0.5 Si, 0.6 Mn, 1.5 Mg, 4.4 Cu, and remaining the 98% of aluminum, respectively. The density of aluminum oxide is 2.71 g/cc. The metal matrix composites have high stiffness and greater strength when the aluminum alloy is blended with appropriately selected reinforcements of aluminum oxide. Basically, aluminum has hard and brittle behavior and is contained in the ductile base reinforcements [16].

In this investigation, the stir casting was utilized to compose the metal matrix composites and therefore the base matrix was preheated at a higher than the melting temperature. Similarly, the preheated strengthened nano-Al_2O_3 particles also preheated and then blended together in the crucible furnace with help of spinning stirrer at 420 rpm to produce the proper dispersion that occurred among the base and its reinforcements. During the process, hexachloro ethane was mixed into the matrixes to reduce the pores which formed in the gas and, similarly, the 2.0% of Mg was also added to the liquefied metal to attain fine wettability. After melting the metal, it was poured into a cast iron mold that measured 16 mm in diameter and 100 mm in length. The molten metal was allowed to sit for 2 min before the casted samples were removed from the mold.

The taken out composites samples were subjected to investigate the wear analysis to identify the performances of metal matrix composites samples with supporting nanoparticles. In this study, pin on disc wear test was conducted

Table 1: Wear input parameters with L9 Taguchi array.

Runs	Sliding distance (mm)	Functional load (N)	Sliding velocity (m/s)
1	1,700	15	2
2	1,700	25	2.5
3	1,700	35	3
4	1,900	15	2.5
5	1,900	25	3
6	1,900	35	2
7	2,100	15	3
8	2,100	25	2.5
9	2,100	35	2

Table 2: Wear analysis on processed metal matrix nanocomposites with input parameters.

Composites samples	Sliding distance (mm)	Functional load (N)	Sliding velocity (m/s)	Wear rate (mm^3/min)	COF
1	1,700	15	2	0.00493	0.289
2	1,700	25	2.5	0.00351	0.268
3	1,700	35	3	0.00487	0.335
4	1,900	15	2.5	0.00298	0.385
5	1,900	25	3	0.00451	0.346
6	1,900	35	2	0.00217	0.454
7	2,100	15	3	0.00210	0.549
8	2,100	25	2.5	0.00175	0.245
9	2,100	35	2	0.00198	0.331

COF, coefficient of friction.

for all the composites specimens. The required wear sample sizes are 30 and 10 mm in length and diameter, respectively. The polished samples were employed with acetone medium after the metallographic analysis with balancing of the machine with 0.0001 g. In the progressing of pin on disc wear test, the EN 32 die steel disc plate was utilized to carry out the applied load on the sample pin with pressure by the balance of the pin. The load cell with the LVDT probe was maintained to determine the wear rate by the creating signals. The input parameters of wear analysis are sliding distance, applied load, and sliding velocity with the ranges (1,700–2,100 m), (15–35 N), and (2–3 m/s), respectively. Before that the parameters were framed by the Taguchi L9 method for easy identification of each level. The composites specimens were prepared for all the nine specimens as per indicated weight proportions like 9 wt% of nano-Al_2O_3 with Al2024 alloy. The wear analysis input parameters are listed in Table 1 as per the Taguchi method [17].

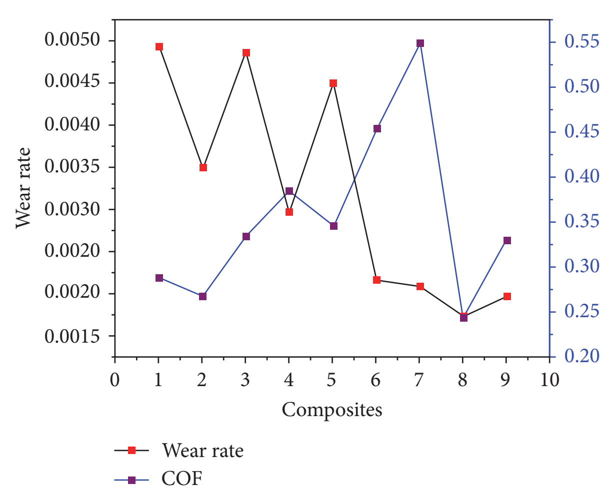

Figure 2: Wear rate and COF on the processed composites samples.

3. Results and Discussion

The procedures of wear analysis are detailed in the previous sections. As per the conditions, all nine samples were subjected to compose the wear rate and coefficient of friction (COF) with their input parameters. In this investigation, the influence of input parameters like sliding distance, functional load, and sliding velocity on the dry sliding wear performances of maintained matrix composites Al2024 and 9 wt% of Al_2O_3 with nanoparticles were conferred. The output responses like wear rate and COF were tabulated with Taguchi L9 and is shown in Table 2. As shown in Table 2, the wear analyses of processed composite samples were clearly posted. Therefore, the sample number 8 with the parameters 2,100 mm, 25 N, and 2 m/s of sliding distance, functional load, and sliding velocity composes the better wear rate and COF. It is due to the increase of sliding distance and sliding velocity decreases the heat generation with the presence of aluminum oxide in the high-level fraction. It was a major reason to reduce the wear rate and COF. The Figure 2 exhibits

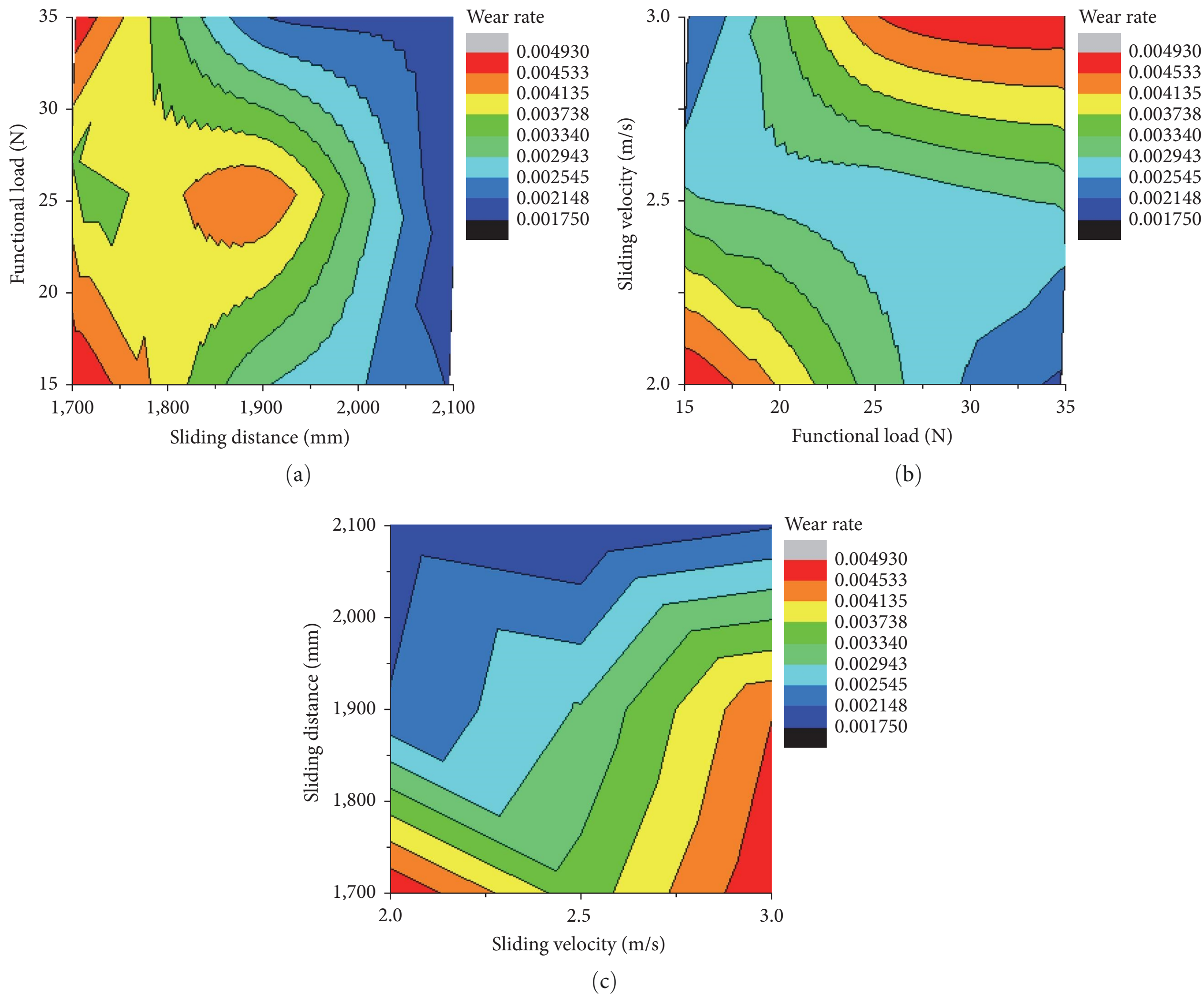

Figure 3: (a) Wear performances between sliding distance and functional load. (b) Wear performances between functional load and sliding velocity. (c) Wear performances between sliding velocity and sliding distances.

the wear rate and COF on the processed composites samples. Some optimization was needed to analyze the input parameters for identifying the best parameters. So with that concern, the grey relational analysis is utilized to find the optimal solution with input parameters.

3.1. Interaction Effects of Input Parameters and Wear Rate. The interaction plot between the input parameters and the wear rate was explained with contour analysis in Figure 3(a)–3(c). As shown in Figure 3(a), sliding distances and functional load of dry sliding wear behavior performances are correlated with wear resistance output [18]. It is revealed that the wear rate was developed by the increasing of sliding distance from 1,900 mm to 2,100 mm and functional load increasing from 15 to 20 N, respectively. Increasing the sliding distance improves the wear rates due to heat generation were attained not maximum during the wear process by the presence of nanoparticle aluminum oxides in the high level [19]. As shown in Figure 3(b), functional load and sliding velocity of dry sliding performances are interrelated with wear resistances; increasing the functional load and sliding velocity decreases the wear rate accurately and the friction heat was not highly initiated. Figure 3(c) shows the correlation between the sliding velocity and sliding distance on the wear rates, respectively [20]; low-level sliding velocity and increasing sliding distances improve the wear rates. The decreasing wear rate values are fully related to addition of nanoalumina particles on the aluminum alloy Al2024 that was dispersed homogenously during the stir casting process [21]. At the same time, the maintained weight proportions were mixed properly in all the composites mainly to improve the wear properties.

3.2. Interaction Effects of Input Parameters and COF. The interaction plot between the input parameters and the COF has been explained with contour analysis in Figure 4(a)–4(c). As shown in Figure 4(a), sliding distances and functional load of dry sliding wear behavior characteristics are interconnected with COF output [22]. It is revealed that the COF was developed by increasing of the sliding distance from 1,900 to 2,100 mm and functional load increased from 15 to 25 N, respectively. Increasing the sliding distance decreases the

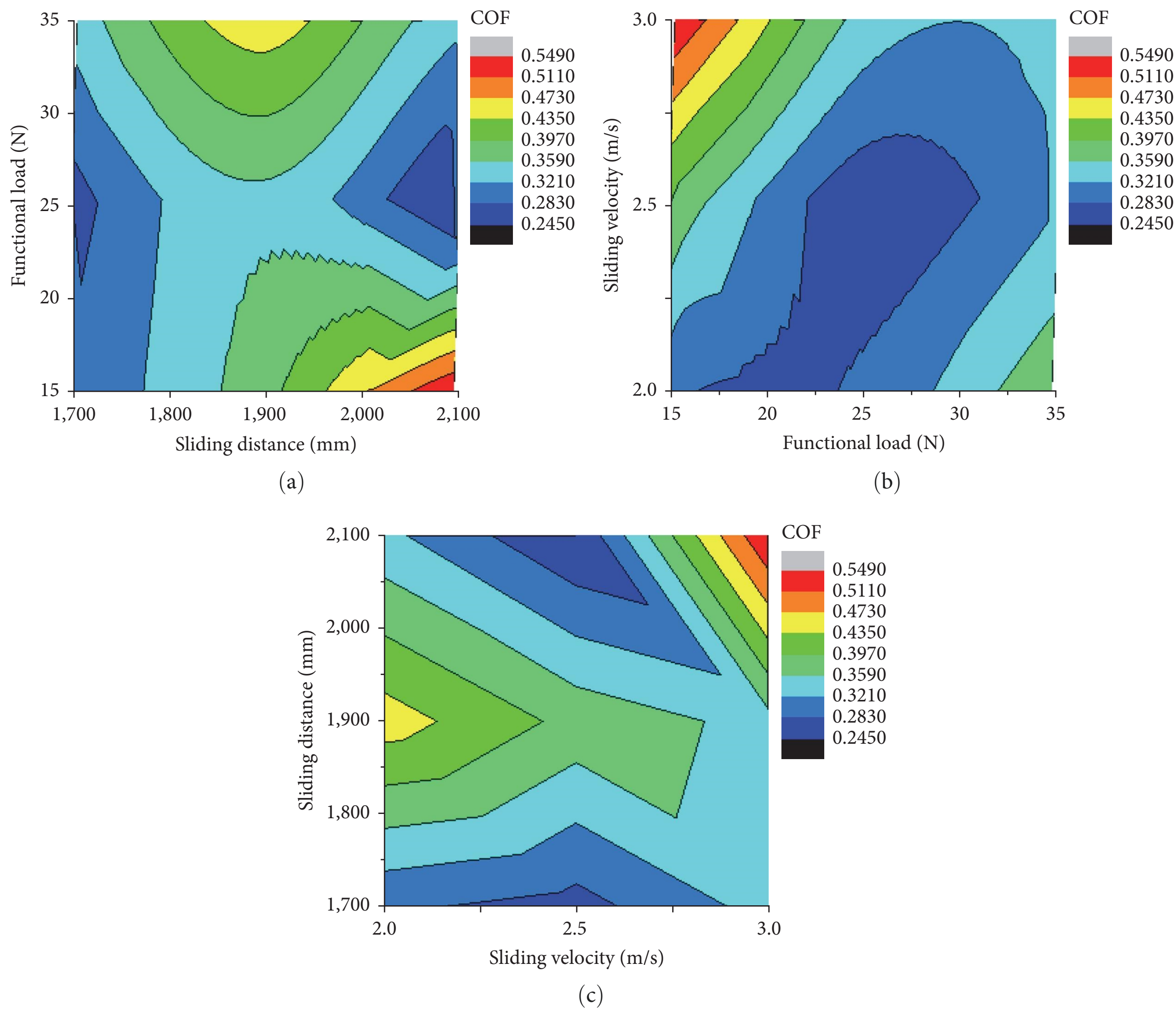

Figure 4: (a) COF between sliding distance and functional load. (b) COF between functional load and sliding velocities. (c) COF between sliding velocity and sliding distances.

friction values due to heat generation attained not highly by the existence of nanostrengthening particle aluminum oxides in the elevated level [23]. As shown in Figure 4(b), functional load and sliding velocity of dry sliding attributes are organized with COF; increasing the functional load from 15 to 25 N and sliding velocity from 2 to 3 m/s decreases the friction values perfectly and the friction heat was not highly initiated due to the presence of alumina particles [24]. Figure 4(c) shows the relationship between the sliding velocity and sliding distance on the COF, respectively [25]. As shown in Figure 4, level sliding velocity from 2 to 2.5 m/s and increasing of sliding distances from 1,900 to 2,100 mm improves the COF. The decreasing COF values are fully related with adding up substances of nanoalumina particles on the aluminum alloy Al2024 that was dispersed homogenously during the stir casting process. At the same time, the maintained weight proportions were mixed properly in all the composites mainly to improve the COF [26].

From the results, the increasing content of alumina oxide contains nanoparticles that improve the mechanical properties during the wear analysis performances. The stir casting process produces the metal matrix composite specimens under constantly maintained stirring parameters which was the significant reason to enhance the wear performances. The process parameters were validated by the responsible technique; therefore, this study suggests the grey analysis to optimize the parameters.

3.3. Grey Technique on the Wear Analysis. In this research, the validation is a very significant process to optimize the parameters. The wear analysis is fully independent of input parameters and multioutput responses. The multiobjective technique is a suitable method for mingling the two responses into a single response. Therefore, the grey method is one of the prominent techniques among the other multiobjective functions. Table 3 shows the wear analysis with grey relation technique. Initially, the grey method fully analyze the initial output responses by the entry-level process. Here, larger the better and smaller the better options were available to measure the ranges in the compact situations. In terms of wear condition, the general rule is "the smaller, the better," as all output responses are aimed at minimizing wear and achieving

Table 3: Wear analysis with grey relation technique.

Composites samples	Data with standardized		Grey COF		Grey grade	Position
	Wear rate	COF	Wear rate	COF		
1	−1.000	−0.145	0.333	0.776	0.55442	6
2	−0.553	−0.076	0.475	0.869	0.67160	3
3	−0.981	−0.296	0.338	0.628	0.48284	9
4	−0.387	−0.461	0.564	0.521	0.54219	7
5	−0.868	−0.332	0.366	0.601	0.48315	8
6	−0.132	−0.688	0.791	0.421	0.60605	4
7	−0.110	−1.000	0.820	0.333	0.57646	5
8	0.000	0.000	1.000	1.000	1.00000	1
9	−0.072	−0.283	0.874	0.639	0.75614	2

COF, coefficient of friction.

Table 4: Contrast between actual and predicted values of wear analysis.

Composites samples	Sliding distance (mm)	Functional load (N)	Sliding velocity (m/s)	Wear rate (mm^3/min)	ANN wear rate	COF	ANN COF
1	1,700	15	2	0.00493	0.00512	0.289	0.279
2	1,700	25	2.5	0.00351	0.00359	0.268	0.259
3	1,700	35	3	0.00487	0.00498	0.335	0.341
4	1,900	15	2.5	0.00298	0.00325	0.385	0.395
5	1,900	25	3	0.00451	0.00435	0.346	0.352
6	1,900	35	2	0.00217	0.00200	0.454	0.465
7	2,100	15	3	0.00210	0.00211	0.549	0.552
8	2,100	25	2.5	0.00175	0.00169	0.245	0.252
9	2,100	35	2	0.00198	0.00191	0.331	0.339

ANN, artificial neural network; COF, coefficient of friction.

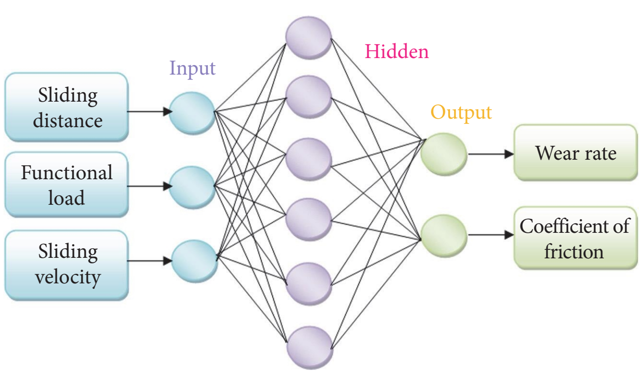

Figure 5: Network modeling for wear analysis.

optimal conditions. During grey analysis, initial data are standardized; COF and grade ranges were processed to compose the rank positions.

3.4. Artificial Neural Networks (ANN) for Predicting the Wear Parameters. The forecasting method was highly incorporated with actual values to validate the parameters. Therefore, the ANN approaches the input parameters and output responses. Before the initiation, input parameters such as sliding distance, functional load, and sliding velocity were entered into hidden layers and the then hidden layers transformed the values from input to output layers with predicted values. Normally, the Levenberg–Marquardt method approaches the input layers with help of forward and back propagation algorithms to finalize the model. In this method two input, three hidden, and two outcomes were followed to construct the model. The entire predicted values with related actual ranges are exhibited in Table 4. As shown in Table 4, most of the predicted values are much greater than the actual values. Therefore, this method was suitable to these wear analysis performances. The constructed ANN model has been displayed in Figure 5. Figures 6 and 7 show the correlation of actual and predicted values of wear performances.

The actual and predicted values of wear rate and COF are clearly indicated in Figures 6 and 7, respectively. Moreover, most of the predicted values of wear outputs were achieved very effectively with the support of back propagations algorithm with most of the executions of trial and error methods. The grey analysis was used to support the ANN methods to frame the predicted values.

4. Conclusion

(i) The investigations of metal matrix composites of Al2024 and nanoaluminum oxides were completely produced without any defects by stir casting techniques.

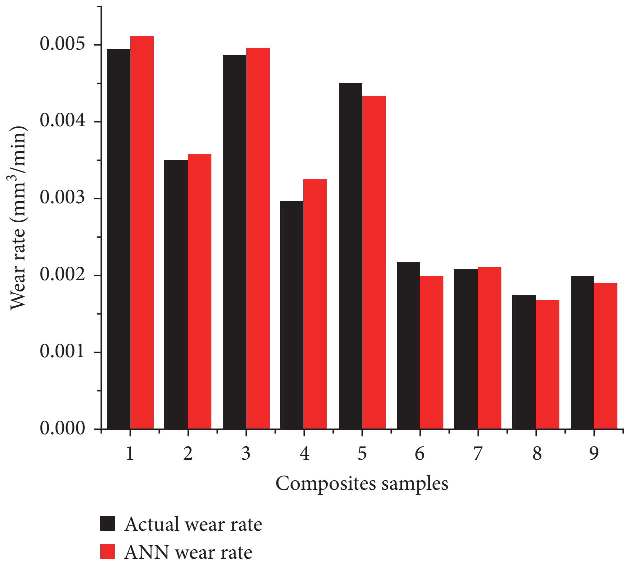

Figure 6: Wear rates of predicted and actual COF.

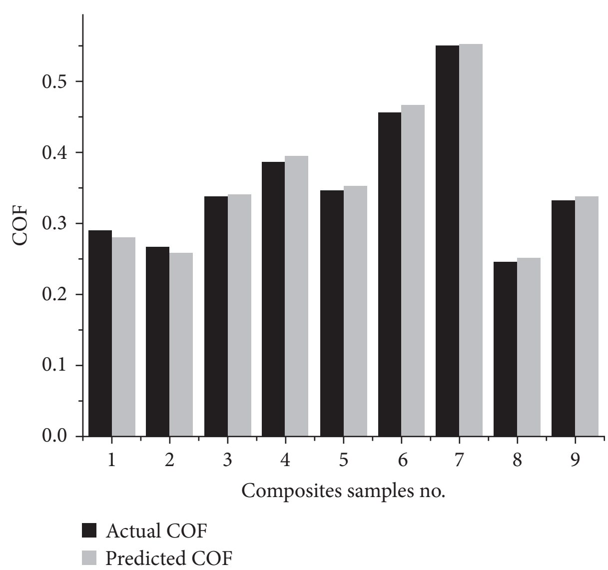

Figure 7: COF of predicted and actual values with ANN.

(ii) The metal matrix nanocomposites were produced using consistent processing parameters, including stirring speed, preheating temperature, and the use of Mg as a wettability agent, in order to ensure high quality.

(iii) Then the samples were successfully employed with dry-sliding behaviors with various input parameters such as sliding distances, functional load, and sliding velocity.

(iv) The output of wear analysis such as wear rates and COF on the processed specimens were conducted by the pin on disc apparatus very effectively.

(v) The enhanced wear rates and COF were attained at the parameters 2,100 mm sliding distance, 25 N functional load, and 2.5 m/s sliding velocity.

(vi) The grey analysis successfully optimized the input parameters of wear analysis. Similarly, the ANN also conducted the modeling validation with the output responses and through this method, values were predicted.

Data Availability

The data used to support the findings of this study are included in the article. Any further data or information are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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