OPTIMIZATION ON THE EFFECT OF HEAT TREATMENT PARAMETER OF THE WEAR BEHAVIOUR OF HYBRID ALUMINIUM COMPOSITES USING NEURAL NETWORKS

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ABSTRACT

Among the engineering practiced material, the utilization of aluminum based material is rapidly increasing in all domains especially in aerospace and automobile industries due to excellent physical properties such as low density, low weight and low production cost. But it has a limitation of low wear resistance and poor coefficient of friction and low seizure limit to overcome the problem and to improve the wear behavior of aluminum, reinforcement of hybrid composite elements such as silicon carbide and graphite are added. The aluminum hybrid reinforced composite was produced using stir casting process. Heat-treated samples are processed using a pin-on-disc apparatus for accurate wear testing. Experiments were conducted by applying design of experiments (DOE) technique. The experimental values were used for formulation of a mathematical model. The wear surfaces of composite specimens were analyzed using scanning electron microscope (SEM).The objective of this research is to investigate and optimize the influence of most predominant heat treatment parameter of Al 6061 hybrid composites and to obtain the optimal value and interaction effect for the response factor such as aging time, aging temperature, solutionizing time, solutionizing temperature thereby reducing volume. An attempt is made to improve the performance of reduced abrasion, adhesion and delamination on the surface of composite. The research is further justified with optimal value on decreased volume loss by neural networks using Matlab.

Keywords: Wear, Aluminum alloys, hybrid composites, Neural networks Reinforcement, Heat treatment parameters.

1. INTRODUCTION

In Modern days technology is growing at very rapid rate and it requires high materials with effective properties and efficient performance which conventional monolithic materials are could not provide. Engineering materials generally have limitations in achieving optimum levels of strength, stiffness, density, toughness and wear resistance. (Shyirash s Shinde et al 2015).

To overcome these shortcomings, aluminum metal matrix composites (AMMCs) are gaining importance due to their high specific strength, high stiffness, low density and good wear resistance and they have the potential and caliber to replace their monolithic counterparts primarily in automotive, aerospace and energy applications (vinoth kumar et al 2013). Composite materials are formed by combining two or more materials on a macroscopic scale such that they have better engineering properties than the conventional materials. The most important property of these materials are relatively light in weight and having low production cost which make them attractive for different applications from technological point of view (daljeet singh et al 2012)

In (AMMCs) one of the constituent is aluminum, which forms percolating network and is termed as matrix phase. The other constituent is embedded in this aluminum and serves as reinforcement, which is usually non-metallic and commonly ceramic such as Sic, Al2O3 etc.Strengthening of aluminum alloys with a dispersion of fine ceramic particulates significantly increased their potential for wear resistant applications .(arunachalam et al 2015).

The International Alloy Designation System is the most widely accepted naming scheme for wrought alloys. Each alloy is given a four-digit number, where the first digit indicates the major alloying elements.6000 series is alloyed with magnesium and silicon, are easy to machine, and can be precipitation hardened(Hitesh bansal *et al.*, 2006).

Heat treatment gives better result of friction and wear properties of composites. At extreme heat treatment process, metal matrix microstructure was fine and resistance to delamination of composite enhanced. Heat treatment cycle processed by solutionizing and aging steps. During wear testing of heat-treated composite, it was reported that the wear rate of aged specimens of the as-cast composite was higher than that of non-aged specimen's _ 100°C. However, non-aged specimens wear mechanism compared with aged specimens _ 100°C(Kim, 2003).

Majority of the research work, the effect of heat treatment on the friction and wear properties of hybrid composites has not been extensively investigated. Mathematical models to predict the influence of heat treatment on wear rate of composite were developed by few investigators (Mahadevan *et al.*, 2006).

Wear test was performed as a function of sliding distance, applied load, sliding velocity with the help of Pin-On-Disc wear test machine. The worn surfaces were analyzed using scanning electron microscope. The mechanical properties such as hardness have been investigated. (nigam and dilip *et al.*, 2006).

2. EXPERIMENTAL RESULT

2.1**Selection of materials with appropriate mixture of reinforced metal matrix composite**

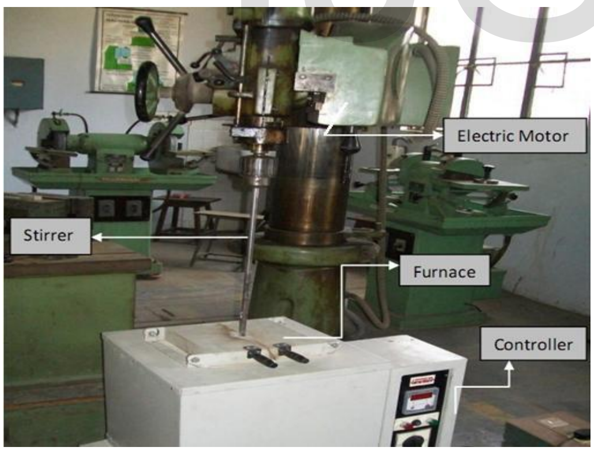
Since the material Al 6061 possess High strength, Ease of fabrication low cost, and good chemical stability and Density and distribution the material Al-6061 is selected and it is reinforced with 10 weight per cent sic and 2 weight per cent graphite particulates with a average size 75 microns measured using spectrometer. Chemical composition of al6061 alloy contributes 97.57% of aluminum and other materials with their proportions as mentioned in table1

2.2 **COMPOSITE FABRICATION**

Reinforced metal matrix composites are fabricated by Stir casting since production of wide range of shape, larger size up to 500 kg, no damage to reinforcement and easy availability

2.2.1 **Stir casting** Stir casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring.

In preparing metal matrix composites by the stir casting method there are several factors that need considerable attention, including



Process parameters considered for stir casting process
Stirring speed -300-600 rpm
Blade angle -45
Inert gas -nitrogen
Stirring temperature- 400 k
Number of blade-4
Preheat temperature- 1073 k
Reinforcement temperature- 673 k
Blade diameter- 20mm
Powder feed rate-uniform
Addition of mg- 1%
Stirring tim-45 minutes

- The difficulty in achieving a uniform distribution of the reinforcement material.
- Wettability between the two main substances.
- Porosity in the cast metal matrix composites.
- Chemical reactions between the reinforcement material and the matrix alloy.

Initially the method of stir casting starts with empty crucible in the furnace. The melting process was carried out in a graphite crucible and graphite mixer was employed for effective mixing .Aluminum alloys are cleaned to remove dust particles, weighed and charged in the crucible for melting .the superheated metal was heated at 1063k where the reinforcement materials are heated at 673 k for about 45 minutes to remove the moisture content in the alloys and reinforcement materials. The addition of magnesium powder helps to increase wet ability .At this heater temperature stirring is started and continued for five minutes. Stirring rpm is gradually increased from 0 to300 RPM with the help of speed controller. Preheated reinforcements are added during five minutes of stirring. the melt with reinforced particulates of silicon carbide and graphite is poured into a preheated cylindrical cast iron mould. At room temperature the mould was allowed to cool And the cast composites were removed from the mould.

2.2.3**Wear testing of heat treated samples using pin on disc apparatus**

Wear test is conducted by pin on disc apparatus(Heat-treated test specimens in the form of pins,)diameter of 10 mm and height of 25mm.the specimens are tested with a help of disc made of EN-32 steel which is rotatory in motion.

At a condition of room temperature, relative humidity of 30 percent, applied load of 10 N and a disc velocity of 1 m/s test were conducted. At every run the specimens in the form of disc are cleaned for ease of accuracy. Electronic weighing machine were employed to measure initial weights of specimens with an accuracy of 0.0001 g. At a sliding distance of 1250 m, the specimen was removed, cleaned with acetone and weighed to determine the weight loss .Each test was repeated three times and the results were averaged. Measurement of weight loss of the pin was used to evaluate the volume loss. *(Velmurugan et al 2011)*

Tab 1.chemical composition of Al 6061 as shown

Element	Si	Fe	Mn	Mg	Cu	Zn	Ti	Cr	Al
Wt.%	0.76	0.14	0.29	0.84	0.33	0.004	0.02	0.006	97.61

2.3 Conducting experiments by using Design of Experiments

A number of experiments required, mainly depends on design of experiment. Thus, it is important to have a well-designed scheme of the experiment, so that number of experiments required can be minimized .A prior knowledge and understanding of the process and the process variables under investigation are necessary for achieving a more realistic model. The range and level of variables that were used in this experimental design were decided on the basis of literature reports as represented in table 2

In the present work, the response factors (volume loss) vary as a function of solutionizing time, solutionizing temperature, aging time and aging temperature. The factors and its level used for the present investigation are listed in Table 2

The coded values for intermediate values of a variable were calculated using equation (1):

$$X_i = 2[2X-(X_{max} + X_{min})]/(X_{max} - X_{min})$$

2.4 Development of mathematical model using RSM

Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for analyzing problems in which several independent variables influence a dependent variable or response, and the goal is to optimize this response.

For the present work, RSM has been applied for developing the mathematical models in the form of multiple regression equations for the wear characteristic produced by stir casting. In applying the response surface methodology, the dependent variable is viewed as a surface to which a mathematical model is fitted with a factorial design with 31 points as discussed in table 3

SECOND ORDER RESPONSE SURFACE MODEL IS EXPRESSED AS

$$\mathbf{Y=\alpha+\alpha_1A+\alpha_2B+\alpha_3C+\alpha_4D+\alpha_{11}A+\alpha_{22}B^2+\alpha_{33}C^2+\alpha_{44}D^2+\alpha_{12}AB+\alpha_{13}AC+\alpha_{14}AD+\alpha_{23}BC+\alpha_{24}BD+\alpha_{34}CD}$$

α free term of the regression equation

$\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are the linear terms α

$\alpha_{11}, \alpha_{22}, \alpha_{33}, \alpha_{44}$ are the quadric terms

$\alpha_{12}, \alpha_{13}, \alpha_{14}, \alpha_{23}, \alpha_{24}, \alpha_{34}$ are the interaction of regression terms the values of α are shown in table 4 The values of the regression coefficients of the polynomial are showed in the tabulation *(Velmurugan et al 2011)*

Where *Xi is* the required coded value of a variable *X*,
X is any value of the variable from *Xmin* to *Xmax*,
X min is the lower limit of the variable and
X max is the upper limit of the variable.

Table 2 shows factor and its level for DOE

factors	**unit**	**notation**	**-2**	**-1**	**0**	**1**	**2**
Solutionzing time	hours	A	1	2	3	4	5
Solutionzing temperature	ºc	B	200	250	300	650	400
Aging time	hours	C	5	6	7	8	9
Aging temperature	ºc	D	120	155	190	225	260

Table 3. Shows variables and its points for DOE

total variables used	Factorial design 2^k	Factorial point	Axial point	Center point	Total design of experiment point
4	2^k	16	8	7	31

Table 4 shows coefficient and its values for RSM model

SI.NO	CO EFFICIENCT	VALUE
1	α	28.3286
2	α_1	-1.5808
3	,α_2	-0.7942
4	α_3	0.5000
5	α_4	-1.3250
6	α_{11}	2.3916
7	α_{22}	3.4691
8	α_{33}	2.3675
9	α_{44}	1.5041
10	α_{12}	-0.7338
11	α_{13}	-0.1112
12	14	-0.1550
13	α_{23}	-0.1738
14	α_{24}	0.1624
15	α_{34}	-0.0075

Table 5 shows coefficient of the polynomials

Volumeloss(Y)=28.3286-(1.5808×A)-(0.7942×B)+(0.500×C)(1.3250×D)+(2.3916×A2)+(3.4691×B+(2.3754×C2)+(1.504×D2)-(0.7338×A×B)-(0.112×A×C)-(1.550×A×D)-(0.1738×B×C)+(0.1675×B×D)(0.0075×C×D)

Optimization using neural networks

Software employed mat lab 2014 a

Neural network is one among the non traditional approaches for optimization. To obtain global minima and effective values for the wear behavior of hybrid aluminum composites neural networks are used. The objective of this optimization function is to obtain minimum volume loss in the wear behavior such as adhesive abrasion and delamination re to reduced and increase the performance of specimen. The effect of heat treatment parameters arte optimized and best fit for the hybrid composites are obtained using neural networks

Step by step optimization procedure

1. **Open neural network tool** command window dialog box by feeding nn tool graphical user interface

2. **Feed input and output** in the workspace and import them in their respective arena. Where input is the combination of factor and its level (-2,-1, 0, 1, 2) Output is the experimental value of heat treatment composites

3. **Create a network** the following parameter are consider to create a network

Network type: feed forward BACKPROP

Training function: TRAINLM

Adaption learning function: LEARNGDM

Performance function: MSE

NUMBER OF LAYERS: 2

NUMBER OF NEURONS: 1000

TRANSFER FUNTION: PURELIN

Thus network is created with specified inputs and outputs are formed as shown in diagram 2

4. **Train function** Train the function for the respective inputs and outputs with the following parameters

Epochs-1000 Data division random -(dividerand)
Time- infinite Training- **levenberg marquard**
Goal- 0 Performance- **mean square error**
Minimum grade -1e-07 Calculations - **matlab**
Max fail -1000 .The accuracy of the result depends upon proper training

5. **Plot the graph for simulating the network**

The accuracy of the system can be evaluated with the graph of regression, performance and training function as shown in figure 3, 4, 5. The linearity function with proportional values plotted in the graph gives us the best optimal result The change in linearity the accuracy of the result gets diversified .Adaption of network is done when the linearity gets diversified beyond the certain limit and reinitializing weights for input parameters are set. The optimal values of the heat treatment parameters are displayed at data manager dialog box and corresponding errors values are also noted for optimality diversification

Fig 2 **creation of a network**

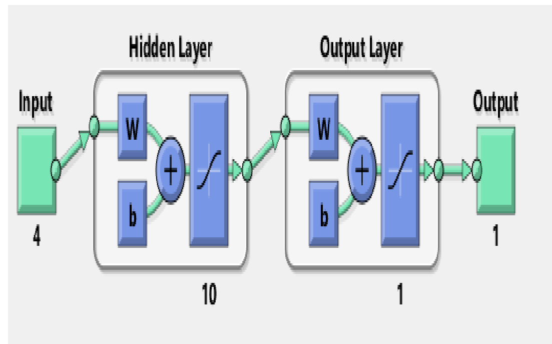


Fig 3 training plot with best linearity and validation

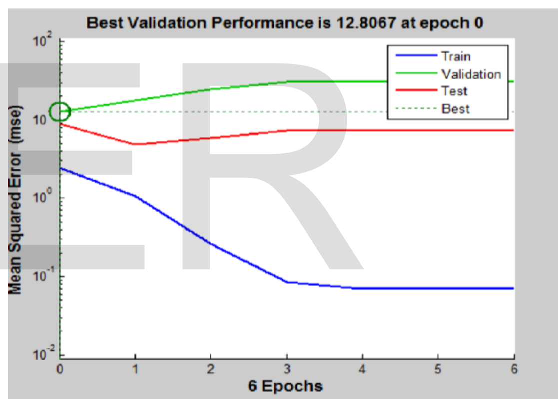
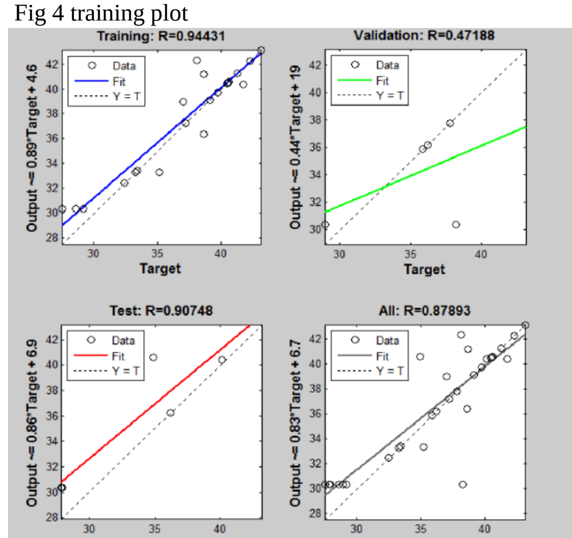
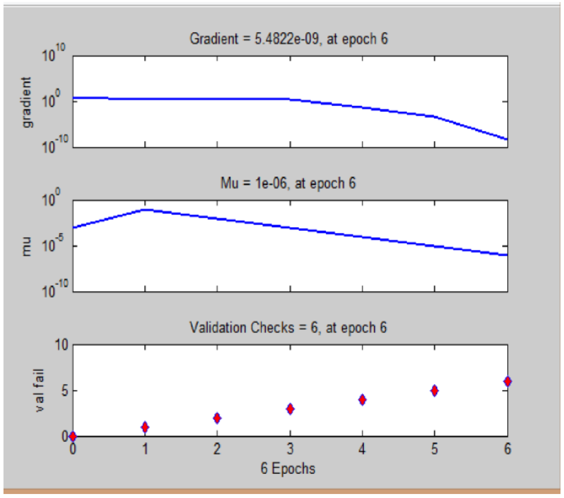


Fig 4 training plot



with best fit

Fig 5 performance plot with best validation



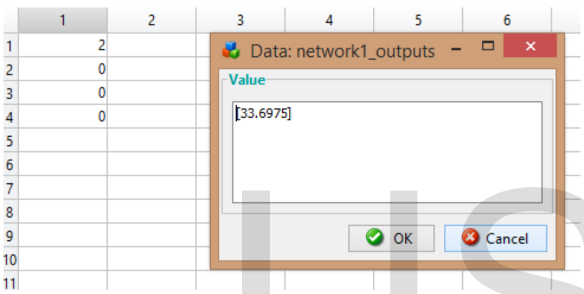


Fig 6 data network sample output with optimized value for a factor (2, 0, 0, 0)

PARAMETERS CONSIDERED FOR TRAINING

Backtracking search - Linear search routine that begins with a step multiplier of 1 and then backtracks until an acceptable reduction in the Performance is obtained

Epoch - The presentation of the set of training (input and/or target) vectors to a network and the calculation of new weights and biases.

Levenberg-Marquardt - An algorithm that trains a neural network 10 to 100faster than the usual gradient descent back propagation method

Mean square error function - The performance function that calculates the average squared error between the networks outputs and the target outputs

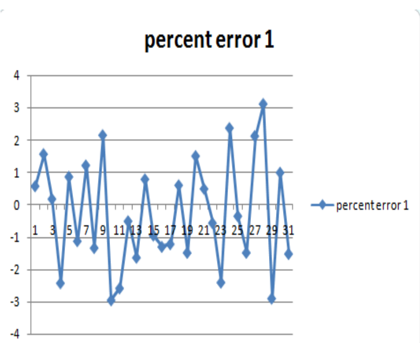
Training - A procedure whereby a network is adjusted to do a particular job.

Global minimum - The lowest value of a function over the entire range of its input parameters. Gradient descent methods adjust weights and biases in order to find the global minimum of error for a network.

Local minimum - The minimum of a function over a limited range of input values. A local minimum may not be the global minimum

Conformity tests

The reliability of the predicted values is calculated using Conformity tests using a formula *%Error= actual value-predicted value/predicted value**100 and values are plotted in a systematic view

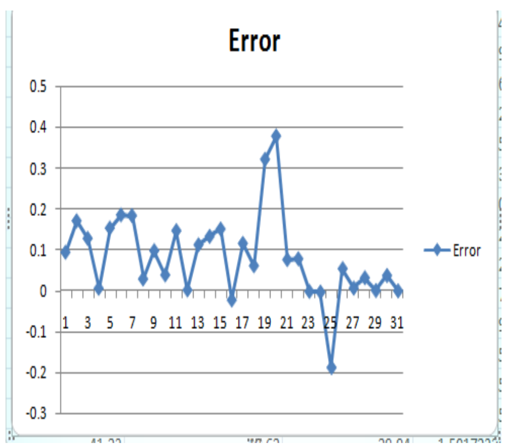


Graph 1 shows the percent error between predicted and experimental values

The reliability of the optimized values is calculated using Conformity tests using a formula

Error= actual value- optimized value/ optimized value

The values of percent error and error of predicted and optimized values are mentioned in tabulation 7



Graph 2 shows the error between optimized and experimental values

Result and discussions

Wear test- design matrix with optimized values

A	B	C	D	E	F	G	H	I	J	K
run ord	standard or	solutioning ti	solutioning tempera	aging tin	aging temperatu	experimental value	predicted volume lo	optimized result	percent erro	Error
1	15	-1	-1	-1	-1	40.49	40.26	37	0.571286637	0.094324324
2	19	1	-1	-1	-1	39.7	39.09	33.91	1.560501407	0.170746093
3	25	-1	1	-1	-1	40.1	40.03	35.55	0.174868848	0.127988748
4	6	1	1	-1	-1	35.87	36.76	35.64	-2.4211099	0.006453423
5	12	-1	-1	1	-1	42.25	41.89	36.64	0.85939365	0.153111354
6	18	1	-1	1	-1	40.43	40.89	34.11	-1.12496943	0.185282908
7	22	-1	1	1	-1	41.73	41.23	35.26	1.212709192	0.183494044
8	26	1	1	1	-1	36.21	36.7	35.18	-1.33514986	0.029277999
9	27	-1	-1	-1	1	38.12	37.32	34.71	2.143622722	0.098242581
10	28	1	-1	-1	1	34.92	35.98	33.61	-2.94608116	0.038976495
11	30	-1	1	-1	1	37.76	38.76	32.93	-2.57997936	0.146674765
12	10	1	1	-1	1	33.27	33.44	33.193	-0.50837321	0.002319766
13	1	-1	-1	1	1	39.13	39.78	35.18	-1.63398693	0.112279704
14	31	1	-1	1	1	37.21	36.92	32.84	0.785482124	0.133069428
15	23	-1	1	1	1	38.65	39.02	33.58	-0.94823168	0.150982728
16	2	1	1	1	1	33.42	33.86	34.17	-1.2994684	-0.021949078
17	24	-2	0	0	0	40.56	41.06	36.35	-1.21773015	0.115818432
18	13	2	0	0	0	35.19	34.98	33.15	0.600343053	0.061538462
19	5	0	-2	0	0	43.14	43.79	32.67	-1.48435716	0.320477502
20	21	0	2	0	0	41.23	40.62	29.94	1.501723289	0.377087508
21	16	0	0	-2	0	37.01	36.83	34.38	0.488732012	0.076497964
22	11	0	0	2	0	38.61	38.83	35.8	-0.56657224	0.07849162
23	4	0	0	0	-2	36.2	37.09	36.24	-2.39956862	-0.001103753
24	3	0	0	0	2	32.45	31.7	32.54	2.365930599	-0.002765827
25	14	0	0	0	0	28.23	28.33	34.7	-0.3529827	-0.186455331
26	9	0	0	0	0	27.91	28.33	26.47	-1.48252736	0.054401209
27	20	0	0	0	0	28.93	28.33	28.73	2.117896223	0.006961364
28	17	0	0	0	0	29.21	28.33	28.3	3.106247794	0.032155477
29	29	0	0	0	0	27.51	28.33	27.48	-2.89445817	0.001091703
30	8	0	0	0	0	28.61	28.33	27.57	0.988351571	0.037722162
31	7	0	0	0	0	27.9	28.33	27.89	-1.51782563	0.000358551

Tabulation 7 shows the design matrix for wear test

Mathematical models are calculated using RSM, and the regression coefficients were calculated using Minitab r14.

The coefficients given in table (iv) were used to obtain the full input model. The model developed for the response Variable in coded form is given in equation as mentioned in tabulation 5 as predicted values and calculated using RSM in MINITAB .Experiments were conducted at different conditions varying the inputs (-2, -1, 0, 1, 2) at pin on disc apparatus and corresponding outputs are coded as experimental values. It show minimization volume loss on the effects of different Heat-treatment parameters at following conditions with increase in the duration of solutionzing time, increase in solutionizing temperature, and increase in aging Temperature and at longer aging periods. Optimized values are obtained through neural networks as explained with step by step procedure above in optimization tools and data network sample output with optimized value for a factor (2, 0, 0, 0)

Microstructural studies by scanning electron microscope

Aluminium6061 hybrid heat-treated composite with silicon carbide and graphite reinforced specimens were shown in Figure 5(a-d).abrasion, delamination and adhesion are the characteristics showed in SEM examination.

from Figure5(a) that, the number of grooves, mostly parallel to the sliding direction, were formed on the wear pins. Grooving and scratch marks on the wear surface of the pin shows the abrasion wear of composite. At the lower aging duration Scratching and grooving more, as shown in Figure 5(a and b)shows the characteristics of abrasion in form of Grooves were less adverse for higher aging duration Figure 5(c)tells about heat treatment composite at 7 hours and little delamination on the surface of composites were found

Figure 5(d) tells about delamination

Delamination is a fatigue-related wear mechanism, in which repeated sliding induces sub-surface cracks that gradually grow and eventually shear to the surface, forming long thin wear sheets. The observation of Delamination is to be extensive for an aging duration of 8 hours. Because delamination involves subsurface deformation, crack nucleation and crack propagation, an increase in aging duration _ 6 hours will hasten these processes and produce greater volume loss of the composite specimen. In the present tests, volume loss for the hybrid composites was higher for all aging duration of 8 hours. They reported that over-aging of aluminum composite specimen causes more wear and less strength.

SCATTERDIAGRAM

Scatter diagram showing deviation in optimized values with experimental values represented by blue lines on the diagram shows that global minima is obtained and best fit for the function is initialized through neural networks.

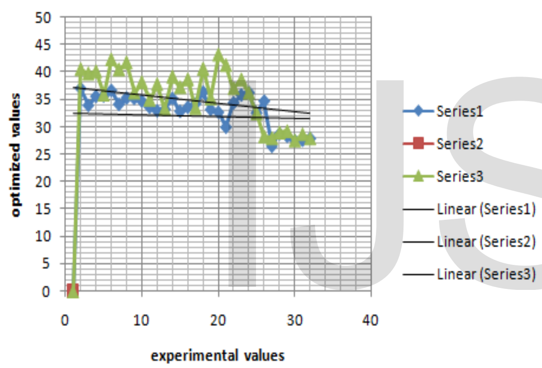
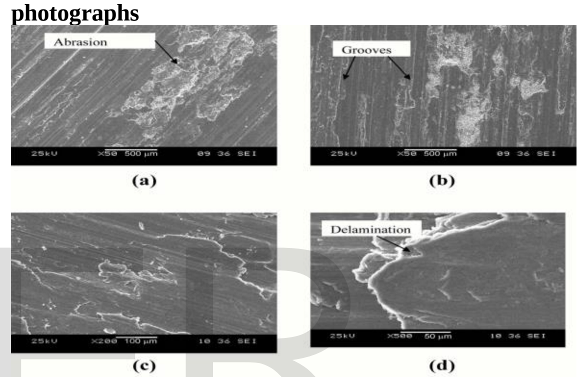


Fig 7.The wear surface of heat-treated composites-SEM photographs



Notes: (a) Wear surface of heat-treated composite specimen aged at 5 hours; (b) wear surface of heat-treated composite specimen aged at 6 hours; (c) wear surface of heat-treated composite specimen aged at 7 hours; (d) wear surface of heat-treated composite specimen aged at 8 hours

Conclusion

- The experimental data shows that the heat treatment parameters are greatly enhanced by hybrid aluminum reinforced composites Mathematical models were created using RSM to calculate aging time, aging temperature, solutionzing time and solutionzing temperature. the developed models is evaluated experimentally and posses low values of error
- From the result and scatter diagram , we can conclude minimization of volume loss on the effects of Heat-treatment parameters at conditions with increase in the duration of solutionzing time, increase in solutionizing temperature, and increase in aging Temperature and at longer aging periods.
- Optimized tools neural networks dynamic feedback system with graphical tool interface, can employed to evaluate closely approximate unknown functions and to obtain result at any desired level of accuracy and to improve performance

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