Proceedings of the International Symposium of Mechanism and Machine Science, 2017
AzCIFToMM ±Azerbaijan Technical University
11-14 September 2017, Baku, Azerbaijan

The tribological wear behavior of carbon fabric-reinforced epoxy composites

Yusuf ùDKLQ[1*], Erdi Erdil[2], +DNDQ[3] ùDKLQ

[1]Department of Manufacturing Engineering, Gazi University, Besevler-06500, Ankara, Turkey,
E-mail: ysahin@gazi.edu.tr,

[2]Department of Mechanical Engineering, Gazi University, Besevler-06500, Ankara, Turkey,
E-mail: erdiergul@gmail.com,

[3]Institute of Natural Science and Technology RI *D]L 8QLYHUVLW\, %HúHYOHU-06500, Ankara, Türkiye,
E-mail: hakansahin85@hotmail.com

Abstract

The tribological behavior of carbon fabric-reinforced epoxy composite (CFRC) and its nano-based composites including Al2O3 and PTFE powders produced by molding technique was investigated using a pin-on-disc configuration. Response surface methodology of Box-Behnken was utilized to model the effects of various variables such as applied load, rotational speed and material types on the weight loss under dry sliding conditions The second order mathematical regression model was developed. Moreover, ANOVA indicated that the load was higher significant than the others at 95% confidence level. The percentage contributions of the linear were about 82 % (load (39.41%, speed 25.22%, and materials type 17.13%)), but square effect and two-way interactions were about 11.5% and 1.43% on the weight loss, respectively. The error obtained was about 5% while the pure error was about 1.41.

Keywords: epoxy, carbon fabric, composite, load, speed, wear

1. Introduction

Polymer based materials reinforced with various fibers or particles have gained considerable attentions in many industrial fields such as aircraft, space and automotive and marine applications because of their high specific/strength and easy of processing and thermal stability [1,2]. Among the reinforcements, carbon is the best choice for using such applications. The drawback of the carbon fibres in polymeric resins, however, is higher cost and their high brittleness. Thus, it is imperative to modify carbon fibers or to select the carbon fabrics. To improve the better mechanical and tribological properties and load carrying capacity, carbon fabrics were used owing to the orderly aligned structure. The mechanical properties of polymer based composites are greatly LQÀXHQFHG E\ PDQ\ IDffect of ¿ber VXFK DV WKH H ORDGLQJ ¿EHU OHQJWKQ WL E¿UHH U W VSDWULEUH FRQW property, fiber diameter, applied processing, fiber/matrix interface and orientation of fibers [3-11].

In recent years, much research has been devoted to exploring the potential advantage of polymeric matrix for composite applications using nanoscale inorganic compounds such as TiO2, ZnO, SiO2, Al2O3, Si3N4 etc. as the fillers of fabric composites to improve the tribological properties [12±17] due to their specific properties such as high surface activity and energy and small size effect of the nano-particulates. For instance, Deng et al. [12] studied the self-lubrication of Al2O3/TiC/CaF2 ceramic composites in sliding wear tests. The tribo-formation on the wearing surfaces resulted in lower wear because of acting as a lubricating additive between the sliding surfaces. Hyung et al. [13] investigated the effect of solid lubricants like graphite, Sb2S3, MoS2 for brake pad materials. The results indicated that amounts of solid lubricants in the friction materials affected the friction stability, fade resistance and wear of gray iron discs and pad friction materials. Tateoki et al. [14] demonstrated the tribological behavior of Mo5Si3 particle reinforced Si3N4 matrix composites. The friction and wear of an unoxidized Mo5Si3-Si3N4 composite, oxidized Mo5Si3-Si3N4 composites and Si3N4 were investigated under dry sliding. Basavarajappa et al. [15] revealed that the incorporation of graphite particles in the aluminum matrix as a secondary reinforcement increased the wear resistance of the hybrid metal matrix composites. The smearing of the graphite and formation of protecting layer between the pin and the counter face enable in reducing the wear volume loss [16]. Chauhan et al. [17] concluded that the coefficient of friction and wear rate of carbon and glass fabric increased with increase in load/sliding velocity and depended on type of fabric reinforcement and temperature at the interphase. The excellent tribological characteristics were obtained with carbon fiber in vinyl ester

Wang et al.[18] studied the friction and wear behaviour of basalt fabric composites filled with graphite and nano-SiO_2. The results showed that graphite was more beneficial than that of nano-SiO_2 due to formation of tranfer film. Suresha et al.[19] reported that coefficient friction and wear rate increased with increase in load/sliding speed for carbon and glass fabric reinforced vinyl ester composites. The best tribological properties were obtained with carbon fibre due to thin film formation on the counterface [20]. The influence of graphite fillers on two body abrasive wear behaviour of carbon fabric reinforced composites, and wear performance of carbon-epoxy (C-E) composites indicated that the graphite fillers resulted in enhancement of wear behaviour significantly [21]. Better abrasion wear resistance was observed in B-E composite compared to G-E composite because the more damage occurred to glass fiber compared to basalt fiber [22, 23]. ùDKLQ LQYHVWLJDWHG WKH ZH and its composites including glass-filled composites and carbon-filled composites by Taguchi technique [24]. The wear rate decreased with increasing grit size, load, sliding distance, whereas, slightly with compressive strength. The dry wears of PTFE-based composites were investigated under different conditions. Taguchi L27 method was used to identify the effect of process parameters on the wear. ANOVA exhibited that the sliding distance was the most significant factor affecting the wear behavior of polymer composites [25]. Tribological behavior of unidirectional carbon fiber-reinforced epoxy composites containing 42wt.% (CU42) and 52wt.% (CU52) carbon fibers fabricated by molding technique was investigated on a pin-on-flat plate configuration [26]. The experimental results indicated the carbon fiber improved the tribological properties of thermoset epoxy by reducing wear rate, but increased the coefficient of friction (COF). The wear rate decreased with decreasing load while COF increased with decreasing load. Moreover, COF of composites of CU42 tested at 90 N load was measured to be in the range 0.35 and 0.13 for static and dynamic component, respectively. The last work by Sahin and Patrick [27] on the tribological behavior of carbon fabric-reinforced epoxy composites was shown that the wear rate considerably decreased by a factor of 8 when the reinforcing carbon fabrics were introduced into the epoxy matrix. The wear rate the composites increased with an increase in normal load. Moreover, COF for epoxy/steel and composite/steel tribo-pairs decreased with increasing load. Royal and Yadav [28] studied the wear rate and COF for graphite flake (GF)-filled polytetrafluoroethylene (PTFE) composites. The wear rates of 5 and 10 wt. % GF composites were reduced by more than 22 and 245 times, respectively. However, with increasing sliding distance up to 8 km, the wear rate of pure PTFE decreased by 1.4 times while it decreased up to three times for the composites.

The literature review above have indicated that number of studies are carried out on the effect of fillers on the wear behaviour of polymer based composites [12-21]. However, there are only few studies performed on the abrasive wear or statistical method on the fabric-reinforced composites [22-25]. The objectives of this work, thus, were to investigate the effects of load, speed and materials type on the tribological behavior of carbon fabric-reinforced epoxy composite (CFRC) and its nano-based composites using response surface methodology

2. Experimental

2.1. Materials

Neat epoxy and carbon fabric reinforced epoxy composites were manufactured in laboratory by molding technique. The resin used in this work is commercial SR 8500 epoxy resin and hardener was SD 860x supplied by MCtechnic Ltd., Netherland. The filler materials used in this study was carbon fabrics supplied by MCtechnic Ltd. Carbon plain weave fabric with a fiber diameter of 7 µm and specific weight of 200 g/m^2 was used as a strengthener. The manufacturing process involved mixing of the epoxy resin with the hardener at a fixed ratio of 100:28.

For the manufacturing the nanocomposites, the fillers material used are Al_2O_3 and PTFE, respectively. Al_2O_3-Alpha, 99.5% pure (grit size is about 40-60 nm) was provided from MKnano, Canada. The specific gravity is about 3.3 g/cm^3. PTFE (grit size is about 20 nm) was provided from Beijing Starget New Materials Limited in Zhejiang, China. PTFE powder-JX-16 type, 12-20 nm in size with 99.98% purity and white colour. Its specific gravity is about 2.16 g/cm^3. Three different types of specimens were prepared for this study. These three different types of specimens such as CF60 fabric reinforced epoxy composite without nano particles, CF60+2.5wt.% nano Al_2O_3 epoxy composites and CF60+2.5wt.% nano PTFE reinforced epoxy composites were prepared, respectively. Nano particles/fillers were evenly dispersed in the epoxy resin by mechanical stirring for a period over 30 min.

The epoxy resin was mixed thoroughly with weight fractions of nano Al_2O_3 powders (2.5 wt.%) and nano PTFE particles (2.5 wt.%), respectively. The production process involved the mixing of the epoxy resin with a hardener at a fixed ratio to ensure complete mixing. Then the catalyzed resin mixtures were spatulated on a composite panel of a 100 x 100 mm^2 with a thickness of 4.0 mm. Alternate layers of the resin and reinforcement were finally put on the steel molding at 28 plies were stacked to achieve required final thicknesses and weight fractions (60 wt.%, referred to as C60) as a reference material. Particularly, they were peUIRUPHG XVLQJ prismatic samples for each composite type and its matrix.

Finally, post curing was done at 45 °C for 24 hours. The specimens required for abrasive wear study (5x5x4 mm^3) were cut from the laminated composites by using a water jet machining.

2.2. Experimental design

The response surface methodology (RSM) design of experiment approach eliminates the need for repeated experiments and thus saves time, material, and cost. This approach identifies not only the significant control factors, but also their interactions influencing the wear rate predominantly. This experiment specifies three principle wear testing conditions including the applied load (L), rotational speed (S) and type of materials (M) of the tested materials as the process parameters. Codes and levels of control parameters and their levels were shown in Table 1. This table showed that the experimental plan had three levels. A standard RSM plan with notation L15 was chosen, as shown in Table 1.

An orthogonal array and ANOVA were applied to investigate the influence of process parameters on the wear behavior of composites.

Table 1. Control parameters and their levels.

Sym.	Controlling parameters	Level 1	Level 2	Level 3
L	Applied load, N	5 (-1)	10 (0)	15 (+1)
S	Speed, rpm	80 (-1)	140 (0)	200 (+1)
M	Material types, HRB	C60 (-1)	C60+ Al2O3 (0)	C60+PTFE (+1)

2.3. Wear tests

The experimental apparatus was a pin-on-disc type of wear-testing machine. A pin specimen waV ¿[HG WR rotational stage or to a pin specimen holder by setting screws. The pin was then mounted in a steel holder the wear machine so that it was held firmly perpendicular to that of the flat surface. The normal load was applied through a spring and lever system. Carbon fiber-reinforced composite (CFRC) was slid in a circular rotational motion against cold rolled steel of AISI 4140 grinded to perpendicular to the sliding direction. The steel counter face was fixed to the base mm with an average surface roughness of 0.350 µm perpendicular to the sliding direction. Silicon carbide (SiC) abrasive papers of grit 500 were fixed on the steel counter face for the abrasive wear testing process. The specimens were loaded under 5 N, 10 N and 15 N under three different sliding speeds of 80 rpm, 140 rpm and 200 rpm against the SiC emery papers. The total sliding distance was about 125 m. For each percentage of fiber volume fractions, three types of test specimens were prepared. The wear pin was cleaned in acetone prior to and after the wear tests, and then weighed on a microbalance with 0.1 mg sensitiveness. The weight loss was calculated from the mass loss method.

3. Results and discussion

3.1. Analysis of weight loss

The experimental data was analyzed using the software MINITAB 16. The experimental lay out and results of the abrasive wear of epoxy composites under different conditions were shown in Table 2. The tests relevant to this table were carried out at a fixed speed, but indicated parameters of loads. The weight loss of composites and its matrix experiments were plotted as a function of the control factors in Fig.3. The mean response referred to the average values of the performance characteristics at different levels. Among the control factors, the factor L (load) showed the highest effect on the weight loss because the penetration ability of SiC abrasives on the counter face disc increased with increasing the strength of laminate structure of the composites (Fig. 3a), followed by the factor S (speed) and the factor M (type of material), respectively (Fig. 3b,c).

It was revealed that the mean weight loss obtained was at the lower values for all cases. In other words, linear decreases were observed with load and sliding speed, but decreased remarkably for both nano addition effect. However, it is noted that the sensitivity of the load was slightly higher than that of the sliding speed (Fig. 3b). They were clearly related to the Archard's equation because it had proven very useful in describing the abrasive wear, which were in good agreement with this work [24].

However, it was contradictory to the some other tests carried out on the composites showed that the abrading distance was more effective on the wear of other parameters [16, 30]. Besides, the effect of load on the wear rate of Zinc based Al_2O_3 composite was more severe than that of abrasive sizes [29]. Recent work by [27] indicated that the sliding speed was not an effective on the wear of the polyamide samples due to the self-lubricated ability, but the abrasive size and sliding distance had great effects on the weight losses for Kestoil samples and Kestamid samples, respectively.

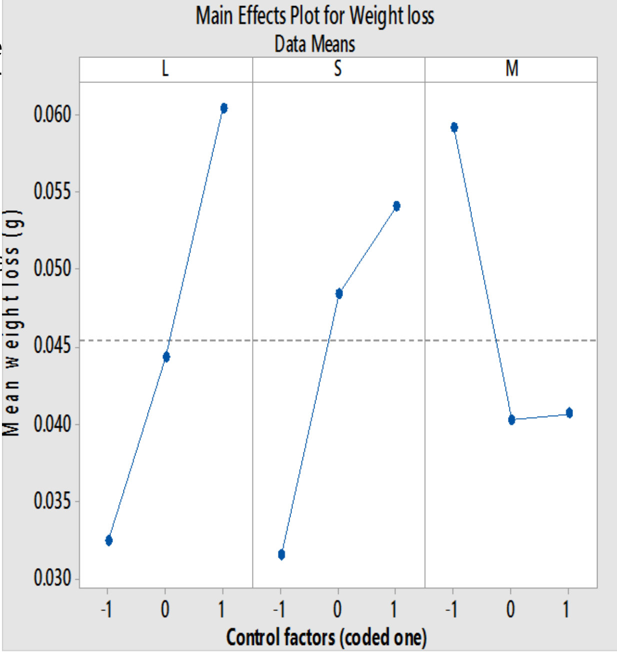


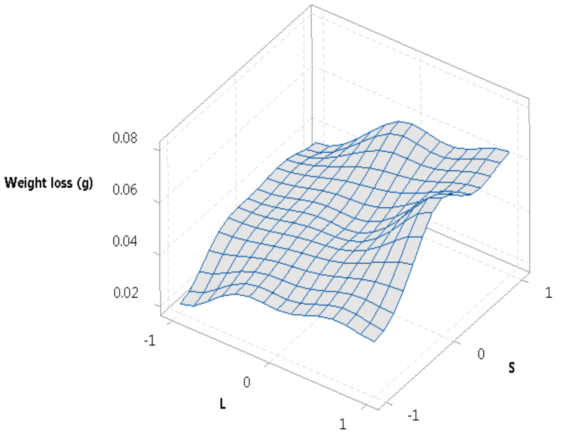
Fig. 3. Weight loss as a function of control factors for carbon fiber-reinforced epoxy composites, tested against the SiC abrasive emery paper

Fig.4 shows the surface plots of the combined effects of the independent variables on the weight loss of the carbon epoxy composites and including nano additions to the carbon epoxy based composites. Fig.4 (a) indicates the WL vs. L&S Fig.4 (b) exhibits the WL vs. L&M, but Fig.4 (c) revealed the WL vs. M&S. These figure also indicated the load and speed were more effective on the wear behavior of the composites. There appeared a little variation with changing material from Al2O3 to PTFE in terms of the weight loss (Fig.4 (c)).

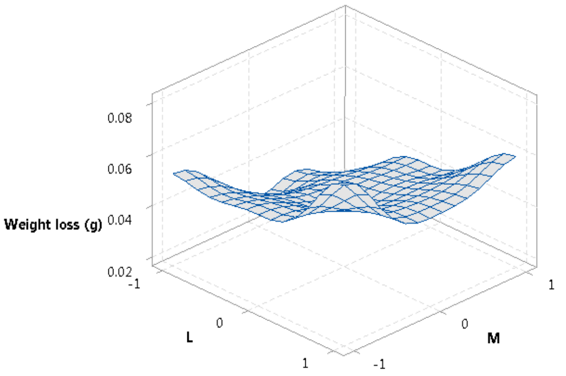
Moreover, contour plots of the combined effects of the independent variables on the abrasive wear of the tested samples are shown in Fig. 5 (a, b and c) respectively. Fig. 5 (d) shows the WL vs. L&S while Fig.5 (e) indicates the WL vs. M&L, and Fig.5(f) exhibits the WL vs. S&M, respectively. These graphs also visualize the response surface of the tested samples, which are allowed to establish the response values and desirable wear testing conditions Similar findings were observed for the UHMWPE composites using RSM and emprical models were also constructed to indicate the connection between the main control factors like filler loading, load and speed and wear rate and COF responses [31]. Their results revealed that the filler loading, applied load and sliding speed had a significant effect on the wear rate and COF.

Table 2. Abrasive wear results of FRPCs

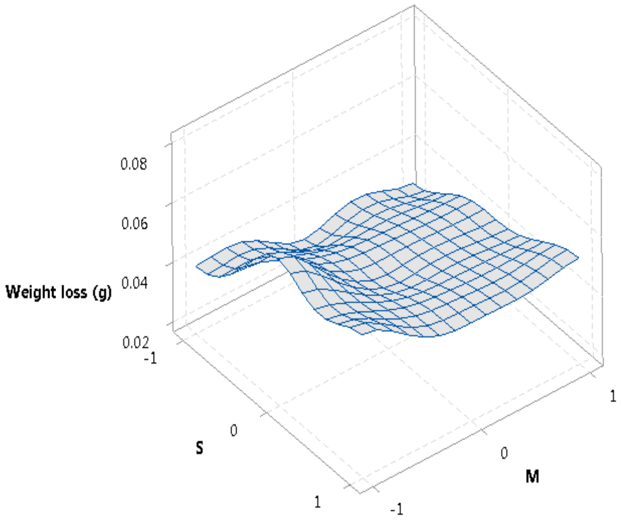
Exp. Run	Applied load (N)	Rotational speed (rev/min)	Material types (HRB)	Weight loss (g)
1	-1	1	0	0.0351
2	1	-1	0	0.0380
3	-1	-1	0	0.0202
4	-1	0	-1	0.0524
5	0	0	0	0.0368
6	1	0	-1	0.0799
7	0	-1	-1	0.0393
8	0	1	-1	0.0648
9	-1	0	1	0.0220
10	0	1	1	0.0522
11	1	0	1	0.0597
12	0	-1	1	0.0288
13	1	1	0	0.0639
14	0	0	0	0.0473
15	0	0	0	0.0409



(a)

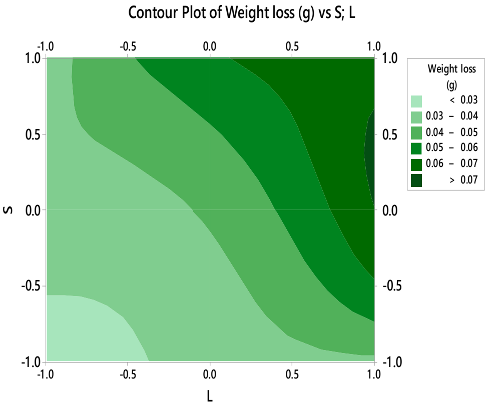


(b)

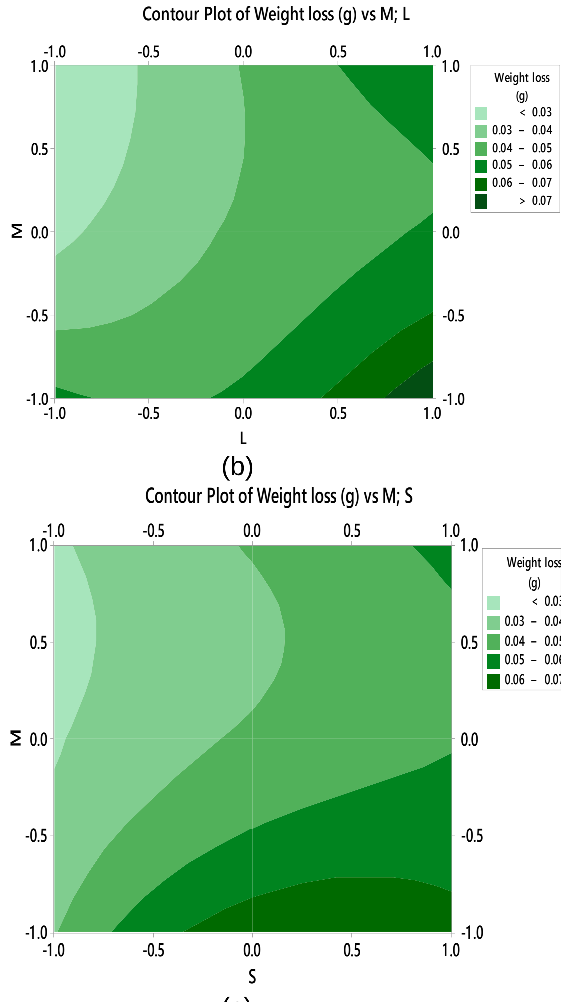


(c)

Fig. 4. Surface plots of the combined effects of the independent variables on the weight loss of the epoxy composites(a) WL vs.L&S, (b) WL vs.L&M, (c) WL vs. M&S



(a)



(b)

(c)

Fig. 5. Contour plots of the combined effects of the independent variables (a) WL vs. L&S, (b) WL vs. M&L, (c) WL vs. S&

3.2. ANOVA

The ANOVA was used to investigate which design parameters significantly affect the quality characteristic for the weight loss of the composites. The ANOVA results for the abrasive dry sliding wear behavior of polymer composites under different conditions were listed in Table 3. This analysis was performed for the 5% significance level, that is, for the 95% confidence level.

This table showed the analysis of variance for the tested samples. It could be resulted that the probability value (P-value) for the weight loss was 0.002, 0.004 and 0.009 for L, S and M, respectively. The L parameter had a significant effect because the probability value of L parameter was lower than 0.05, but other two parameters had also significant influence on the response.

Table 3 Analysis of variance for the weight loss

Sour.	DF	Adj.SS	Adj.MS	F-value	Contr. P(%)	P-Value
Model	9	0.00376	0.00042	10.34	94.9	0.010
Linear	3	0.00324	0.00108	26.79	81.9	0.002
L	1	0.00156	0.00156	38.68	39.4	0.002
S	1	0.00100	0.0010	24.90	25.2	0.004
M	1	0.00067	0.00067	16.81	17.1	0.009
Square	3	0.00045	0.00015	3.76	11.5	0.094
L*L	1	0.00002	0.00002	0.54	0.55	0.496
S*S	1	0.00008	0.00008	2.10	2.14	0.207
M*M	1	0.00032	0.00032	8.08	8.25	0.036
2-Way Int.	3	0.00005	0.00002	0.47	1.43	0.714
L*S	1	0.00003	0.00003	0.75	0.75	0.426
L*M	1	0.00002	0.00002	0.64	0.65	0.459
S*M	1	0.000001	0.000001	0.03	0.25	0.875
Error	5	0.00020	0.00004	5.0		
Lack of Fit	3	0.00014	0.00004	1.74	3.68	0.386
Pure Error	2	0.000056	0.000028	1.41		
Total	14	0.003963				

DF = degrees of freedom, Seq SS = sequential sum of squares, Adj SS = adjusted sum of squares, Adj MS = adjusted mean squares.

Moreover, analysis of variance shown in this table that the linear effect (L,S,M) revealed the most significant (0.0032), followed by quadratic M*M (0.00045) and lastly two-way interactions of L*S (0.000057), respectively. Furthermore, the lack of fit values was about 0.00014, which was significant because it was lower than that of 0.05.

3.3. Multiple linear regression model

Regression technique was used to study the weight loss of the composites. The regression equation for the weight loss of epoxy and its composites when tested against the SiC paper can be expressed as follows

To establish the correlation between the material properties and wear process parameters like load, speed and hardness, multiple linear regression model with uncoded units was obtained using statistical

VRIWZDUH ³0LQLWDE´ The second order model equation for the weight loss prediction is given by

$$\text{Weight loss, WL (g)} = 0.04167 \pm 0.01398L + 0.01121S - 0.00921M + 0.00243L*L - 0.00480S*S + 0.00940M*M + 0.00275L*S + 0.00255L*M - 0.00052S*M \qquad (1)$$

where WL is the mean weight loss. Eq. (1) indicated that the weight loss increased the load and a speed, but decreased with changing material when testing against SiC abrasive papers. The model had an adjusted R^2 value of 94.9%. In other words, WL: weight loss of the samples (mg × m-1), L: load (N) and S: rotational speed (rpm) and M: Materials type of the tested samples. By substituting the recorded values of the variable for Eq. (1), WL of epoxy matrix composites was calculated (Fig. 13). It could noted from this equation that the coefficients of load (L), speed (S) were positive, but material type (M) was negative. It was exhibited that load was the main factor to the weight loss, followed by speed while material type was less effective than the other factors. The higher value of regression coefficients would be directly translated into higher effect of the variables to the response.

4.0 Conclusions

The application of RSM modelling on the abrasive wear of the neat epoxy and carbon fabric reinforced epoxy against the stainless steel was presented and second-order mathematical models were developed using three testing parameters. The following conclusions can be drawn from the present study.

The results showed that the load was found to be a dominant factor on the weight loss, followed by the speed IDFWRU ODVWO\ WKH PDWHULDO¶V W\SH The optimum selected testing process parameters settings were at a load of 5N, spindle speed of 80 rpm, and running the composite of C60+2.5wt.% Al_2O_3-epoxy, which resulted in a minimum weight loss.

Moreover, ANOVA indicated that the load was higher significant but other factors were also significant effects on the weight loss at 95% confidence level. The percentage contributions of the linear ((load (39.41%), speed (25.22%) and material types (17.13%)) square, and two-way interactions were about 82%, 11.5%, and 1.43% on the weight loss, respectively. The error obtained was about 5% while the pure error was about 1.41.

References

[1]. B.R. Raju, B. Suresh and R.P. Swamy, Tribo performance of silicon dioxide filled glass fabric reinforced epoxy composites, ARPN Journal of Eng. Appl. Sci. 7 (4), pp.6604±6608 (2012).

[2]. F.H. Su, Z.Z. Zhang, K.Wang, W. Jiang, X.H. Men, and W.M. Liu, Friction and wear properties of carbon fabric composites filled with nano-Al2O3 and nano-Si3N4, Composites: Part A 37, pp. 1351±1357 (2006).

> @ < `DKLQ, Introduction to Composite Materials, 3rd Press, Seckin Book Store & Distributions, Ankara, Turkey (2015).

[4]. H. Rahmani, S.H.M. Najafi, S. Saffarzadeh-Matin and A. Ashori, Mechanical properties of carbon fiber/epoxy composites: Effects of number of plies, fiber contents, Poly. Eng. Sci. 54 (11), pp. 2676±2681 (2014).

[5]. I.D.G.A.Subagia, Y. Kim, L.D. Tijing, C.S. Kim and H.K., Shon, Effect of stacking sequence on the flexural properties of hybrid composites reinforced with carbon and basalt fibers, Compos. Part B 58, pp.251±256 (2014).

[6]. Y.Zhou, F. Pervin, S.Jeelani and P.K.Mallick, Improvement in mechanical properties of carbon fabric±epoxy composite using carbon nanofibers, J. Mater.Proces.Technol. 198 (1±3), pp.445±453 (2008).

[7]. S.H.Han, H.J. Oh, H.C. Lee and S.S. Su, The effect of post-processing of carbon fibres on the mechanical properties of epoxy composites, Compos. Part B-Eng. 45 (1), pp.172±177 (2012).

[8]. J.R.Tarpani, M.T. Milan, D. Spinelli and W.W.Bose, Mechanical performance of carbon-epoxy laminates Part I: quasi-static and impact bending properties, Mat. Res. 9 (2), São Carlos, pp.115±120 (2006).

[9]. T. D.Jagannatha and G. Harish, Mechanical properties of carbon/glass fiber reinforced epoxy hybrid polymer composites, Int. J. Mech. Eng. & Rob. Res. 4 (2), pp.131±136 (2015).

[10]. U. Dwiedi and N.Chand, Influence of fibre orientation on friction and sliding wear behaviour of jute fibre reinforced polyester composite, Appl. Comp. Mater. 16(2), pp.93±100 (2009).

[11]. M.P.Prasad,, B. Vinod and Dr.L.J. Sudev, Effect of fiber orientations on tribological behaviour of palf reinforced bisphenol-a composite, Int. J. Eng. Res. &General Sci. 2 (4), pp.809±814 (2014).

[12]. J.Deng, L.Liu, X.Yang, J. Liu, J.Sun and J.Zhao, Self lubrication of Al2O3/TiC/CaF2 ceramic composites in sliding wear tests and in machining processes, Mater. Des 28, pp.757±64 (2007).

[13]. C.M.Hyung, J.Jeong, K.S.Jin and J.Ho, Tribological properties of solid lubricants (graphite, Sb2S3, MoS2) for automotive brake friction materials, Wear 260, pp.855±60 (2006).

[14]. I.Tateoki and K.Hideki, Tribological behavior of Mo5Si3 particle reinforced Si3N4 matrix composites, Wear 258, pp.877±89 (2005).

[15]. S. Basavarajappa, G. Chandramohan and J. Paulo Davim, Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites, Mater. Des. 2006.

[16]. S.Basavarajappa, A.G.K. Joshi, V. Arun, A.P. Kumar and P.M. Kumar, Three-body abrasive wear behaviour of polymer matrix composites filled with SiC particles, Polymer-Plastics Technology and Engineering, Vol. 49 (1), pp.8±12 (2010).

[17]. S.Chauhan, A. Kumar, A. Patnaik, A. Satapathy and I. Singh, Mechanical and Wear Characterization of GF Reinforced Vinyl Ester Resin Matrix Composites With Different Co-Monomers, J. Reinf. Plast. Comp. 28, pp. 2675-2684 (2008).

[18]. Q.H.Wang, X.R.Zhang and X.Q. Pei, Study on the friction and wear behavior of basalt fabric composites filled with graphite and nano-SiO_2, Mater.Des. 31, pp.1403-1409 (2010).

[19]. B. Suresha, K.S. Kumar, S. Seetharamu and P.S. Kumaran, Friction and wear behaviour of carbon and glass fabric reinforced vinylester composites, Tribol. Int. 43, pp.602-609 (2010).

[20]. B.Suresha, G. Chandramohan, J.N. Prakash, V.Balusamy and K. Sankaranarayanasamy, The role of friction and slide wear characteristics in Glass-epoxy composite system, J. Miner.Maters.Charact. Eng. 5, pp.87-101 (2006).

[21]. B. Suresha, B.N. Ramesh, K.M. Subbaya, B.N.R. Kumar and G. Chandramohan, Influence of graphite filler on two body abrasive wear behaviour of carbon fabric reinforced epoxy composites, Mater.Des. 31, pp.1833-1843 (2010).

[22]. C.A. Chairman and S.P. Kumaresh Babu, Three-body abrasive wear behavior of basalt and glass fabric reinforced epoxy composites, Appl. Mech. Maters 121-126, pp.534-538 (2012).

[23]. N.Anjum, S.L.A. Prasad and B.Suresha, Role of SiO_2 filler on mechanical and dry sliding wear behaviour of Glass-Epoxy composites, Adv. in Tribol. ID 324952, pp.1±10 (2013).

> @ < ùDKLQ Analysis of abrasive wear behavior of PTFE composite using Taguchi¶V WHFKQLTXH, Cogent Eng. 2, 1000510 (2015).

> @ < ùDKLQ DQG +0 Wear characteristics of polymer-based composites, Mech. Compos. Maters. 51, pp.1-12 (2015).

> @ < ùDKLQ DQG ' % 3DWULFN 7

unidirectional carbon fibre-reinforced epoxy composites, The 13th International Conference on *Tribology ROTRIB'16*, September 22-24, pp. (2016), Galati, ROMANIA.

[27]. Y. ùDKLQ and D.B. Patrick, Friction and wear behaviour of carbon fabric-reinforced epoxy composites, JOM, pp.1-5 (2017).

[28]. R.K. Goyal and M. Yadav, Study on Wear and Friction Behavior of Graphite Flake-Filled PTFE Composites, J. Appl. Polym. Sci. pp.3186-3191 (2013).

[29]. O.P.Modi, R.P.Yadav, D.P. Mondal, R.Dasgupta, S. Das and A.H.Yegneswaran, Abrasive wear of Zinc-Al alloy-10% Al2O3 composite through factorial GHVLJQ¶, J.Mater.Sci. 36, pp.1601±1607 (2001).

[30]. H.Unal, U.Sen and A. Mimaroglu, Abrasive wear behaviour of polymeric materials, Mater. Des. 26 (8), pp.705±710 (2005).

> @ % 3 &KDQJ + 0G $NLO 5 %W

Optimization on wear performance of UHMWPE composites using response surface methodolgy, Tribol.Int. 88, pp.252-262 (2015).