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Comparison of the Wear Behavior and Hardness of Vinylester Resin Reinforced by Glass Fiber and Nano ZrO_2 and Fe_3O_4

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ABSTRACT

The current trend in scientific researches is to improve the performance of mechanical and physical properties of polymeric compounds, one of these methods is to add nanoparticles to polymeric composites. In this work, the wear behaviour (pin to disc) of nanocomposites composed of vinyl ester reinforced glass fibers and nanoparticles was evaluated under three different factors, such as specimen content, load applied, and distance sliding using a sliding time constant, as well as studying the hardness shore for these nanocomposites. The (hand-lay) method was used for the purpose of preparing the nanocomposites from vinyl ester filled with 10% vf. glass fiber and (0.5%, 1%, 1.5%, and 2% vf. of nano-Fe_3O_4 and ZrO_2). The results are tabulated and analysed using Taguchi experiments (L9) (Minitab 18) for the purpose of determining which of the factors under consideration had the greatest influence on the wear behaviour. From the results, it was found that the specimens (vinyl ester-10% vf. glass fibers-2% ZrO_2) and (vinyl ester-10% vf. glass fibers-2% Fe_3O_4) give the best wear resistance 0.003×10^{-5}, 0.012×10^{-5} mm^3/Nm respectively under the factors (load 20 N, sliding distance 45 cm). It was found that the specimen content is the most important factor influencing the wear behaviour, followed by the factors of the applied load and then the sliding distance. The addition of nanoparticles (0.5-2% vf. ZrO_2, Fe_3O_4) to the vinyl ester resin improved the hardness values. Furthermore, the findings show that the addition of nanoparticles (ZrO_2, Fe_3O_4) had a positive effect on the (wear and hardness) tests, implying that the nanoparticles improved the bonding between the base material and reinforcing material.

1. INTRODUCTION

Nanocomposites have been extensively used in different technical disciplines as well as several industrial fields, such as military, automotive, and space. Polymer filled with nanoparticles has piqued interest due to their unique features and potential in a variety of industries [1]. The chemistry of matrix polymer, the nature and homogeneity of nanomaterials in matrices, and the technique in which they are set up for achieving desirable mechanical qualities and physical features all influence the properties of polymer nanocomposites [2]. Polymer-filled glass fibers are widely used in marine, transportation, and aerospace applications because fiberglass has many properties (low cost, corrosion resistance, and improved structural performance) [3].

Epoxy resins and unsaturated monocarboxylic acids were used to produce vinyl ester resins. Most unsaturated polyester resins lack mechanical strength and chemical resilience when compared with vinyl ester resins [4]. Vinyl ester resin is thought to be an intermediate between unsaturated polyester resin and epoxy resin [5].

Nano zirconia is an engineering ceramic oxide that has a lustrous greyish-white color. The main sources of zirconium are zirconate ($ZrSiO_4$) and baddeleyite (ZrO_2), most of the material used is chemically extracted from two minerals. Zirconia has many properties such as high fracture hardness, high tensile strength, high bending strength, impact resistance, high wear resistance, and has a low modulus of elasticity [6]. Iron oxides are chemical compounds composed of iron and oxygen. The nano iron oxide is usually present in diameters of 1 to 100 nanometres, there are two main forms are (Fe_3O_4) and (γ-Fe_2O_3) [7]. Natural and synthesized magnetite nanocrystals exhibit metallic luster and opaque jet black color. The iron nano oxide can be used in many fields such as engineering, environmental treatment and biomedical [8]. There are several comprehensive studies of the wear behaviour and hardness of polymers filled with nanoparticles. The wear, flexural, and impact tests have been studied for four specimens (Epoxy-0.5, 1%, 5%, and 10% wt. nano ZrO_2 particles). The findings revealed that specimens (Epoxy-0.5% wt. nano ZrO_2 particles) have the best wear and impact resistance, while specimens (Epoxy-5% wt. nano ZrO_2 particles) have the best flexural properties [9]. The wear and SEM tests investigated specimens (EP--3% glass fiber, 0.5%, 1%, and 1.5% wt. MWCNT) at different factors. When comparing the results of the wear tests of all specimens, it was found that the specimens (EP--3% glass fiber-1.5% wt. MWCNT) gave the best wear resistance at all variables (1.5% wt. MWCNT, 10 N normal load, 1m/s sliding velocity, 600 cm sliding distance) [10]. The tensile, compressive, impact, hardness, and wear tests have been described for composites that were prepared from (epoxy-3% wt. basalt fiber-2%, 4%, 6% wt. TiC). The results showed that the specimens (epoxy-3% wt. basalt fiber-2% wt. TiC) gave the best tensile, compressive, and wear resistance. The specimens (epoxy-3% wt. basalt fiber-4% wt.TiC) gave the best (impact strength), while the samples (epoxy-3% wt. basalt fiber-6% wt.TiC) gave the best (hardness) [11].

The wear behavior of specimens made up of (UP. - Zn $(NO_3)_2$ particles) was studied using the orthogonal L9 Taguchi method at the factors (3%, 5%, 7%, 9%, 11% wt. Zn $(NO_3)_2$, 7, 12, 17 sec sliding time, 10, 15, 20 N load applied). The results revealed that the polyester resin by 11%wt. Zn $(NO_3)_2$ gives better wear resistance [12]. The main objective of this work adds the nano ZrO_2 and Fe_3O_4 to vinyl ester resin-filled by 10% vf. glass fiber. The hardness and wear behavior are investigated for these nanocomposites at different factors: specimen content (0.5% - 2% vf.), the load applied (5, 10, 15 N), and sliding distance (25, 35, 45 cm). The results were analyzed using Taguchi's experiments (L9). The addition of nanomaterials improved the bonding between the base material and the reinforcing materials to take advantage of these nanocomposites in industrial applications.

2. EXPERMENTAL WORK

2.1 Materials and tests

The vinyl ester resin and hardener, which have a density of 1.32 g/cm^3, a tensile strength of 73-81 Mpa, and a tensile modulus of 2.10-3.45 Gpa, were supplied by the United Arab Emirates. The glass fiber (woven type), which has a density of 2.58 g/cm^3, a tensile strength of 3.44 GPa, a Youngs modulus of 72.5 GPa, and a compressive strength of 1080 MPa, was supplied by Tenax Company, England. Nano ZrO_2 and Fe_3O_4 particles, which were supplied by Skyspring Nanomaterials, Inc., USA. A formalized.

Figure 1 (a-b) shows the AFM of (Nano ZrO_2 and Fe_3O_4), where it was shown from test that the average volume of the nano particles (ZrO_2) was (38 nm) while the average volume of the nano particles (Fe_3O_4) was (46 nm).

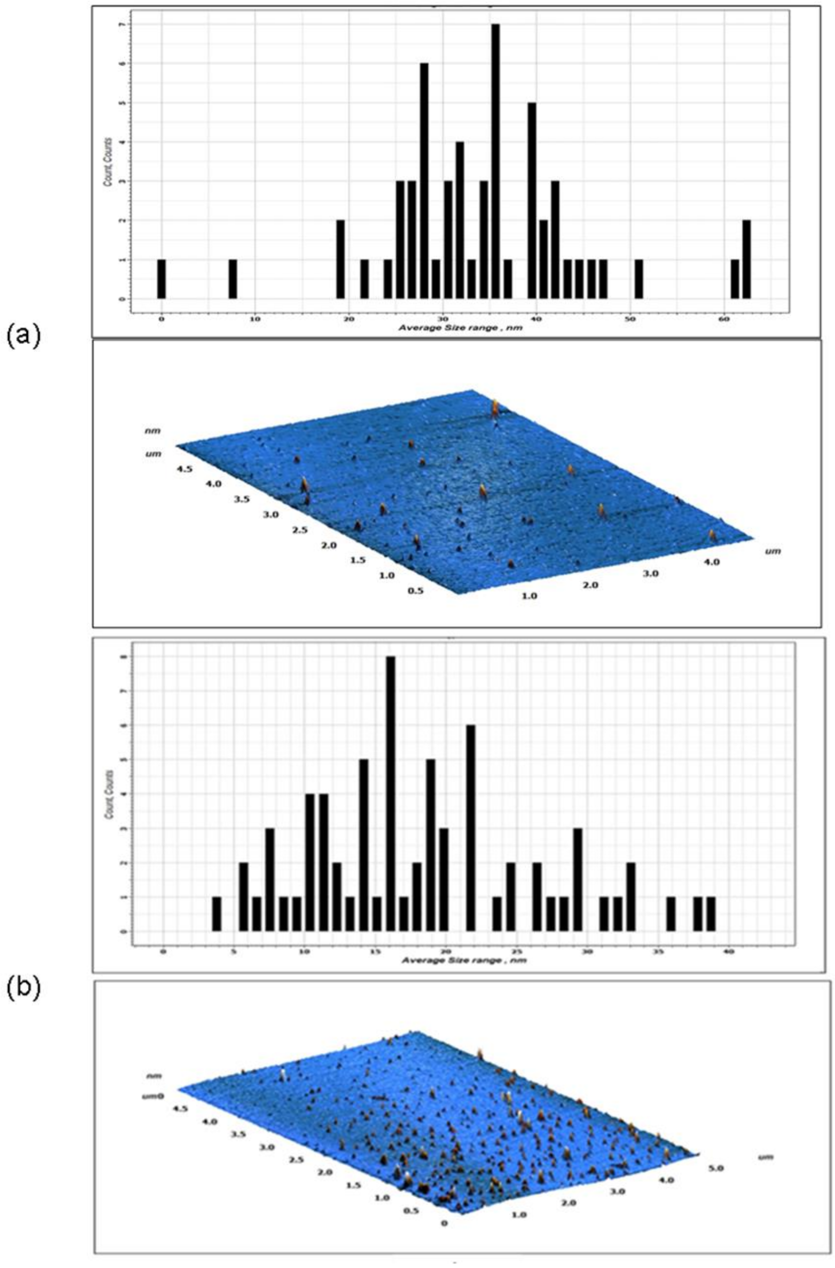


Figure 1. AFM of the nano ZrO_2 (a), and (b) AFM of the nano Fe_3O_4

Table 1. L9 orthogonal array experimental design

No. expt.	(A) Specimens	(B) Load (N)	(C) Distance sliding
1	1	10	25
2	1	15	35
3	1	20	45
4	2	10	35
5	2	15	45
6	2	20	25
7	3	10	45
8	3	15	25
9	3	20	35

The molds are prepared from aluminum at dimensions ($30 \times 30 \times 0.4$ cm^3) for the purpose of fabricating specimens of the nanocomposites using the manual casting method. In this work, a glass fiber (woven) is laid with a constant content of 10% volume fraction. Nano filler ZrO_2 and Fe_3O_4 are mixed with vinylester resin and then a solidifier is added to the mixture and mechanically accelerated in a mixer. This mixture was mechanically agitated for half an hour to ensure the appropriate dispersion of nanofillers.

The mixture is slowly poured into the prepared molds and left for 24 hours at room temperature and then the composite samples are extracted from the mold. Samples are processed in an oven at 60°C for a period of 60 minutes. This step is critical for getting the best bonding between polymer chains, as well as reducing tensions created during the preparation and completion solidification of the specimens [13]. For each test, specimens were cut using a (CNC) machine (computer numerical control) in accordance with ASTM standards.

2.2 Test devices

For the purpose of investigating the wear behaviour of all nanocomposite specimens, a pin-on-disk test according to (ASTM: G99) was used [14]. The disc used in this test was alloy steel with (165 mm) diameter, (8 mm) thickness, and hardness of 62 HRC. The specimen, which had a 2 cm wide, 3 cm length, and 0.4 cm thickness, was placed on the specimen holder normal to the steel disk. In the (pin-on-disk) test, three experiments were performed for each sample under three conditions (specimens' content vf., load N, distance sliding cm) with the time sliding constant. An electronic scale is used to calculate the weight of the sample before and after each test, and then calculate the wear rate depending on Eq. (1) [15]. The hardness test was carried out for all specimens according to ASTM D 2240 [16]. Then readings were taken for each specimen and the average readings were calculated.

$$\mathrm{W.s} = \frac{\Delta \mathrm{m}}{\rho.\mathrm{Fn.L}} \quad (1)$$

where:

W.s: Wear rate (mm^3/Nm)
Δm: Difference weight
ρ: density of specimens
Fn: load applied
L: distance sliding

2.3 Taguchi method: Design of experiments

The L9 orthogonal array table with 3 rows was adopted according to the Taguchi quality design principle [17], and as shown in Table 1. MINITAB (18) was used to generate all designs, graphs, and analyses in this study. The input parameters chosen were: content of specimens (vf.), load (N), and sliding distance (cm). This method employs two key tools:1) the S/N ratio to assess quality, and (2) orthogonal arrays to accommodate several elements impacting tribological performance at the same time. The S/N ratios were calculated based on the type of input variables, and a lower value of S/N indicates a better resistance to wear behavior.

3. RESULTS AND DISCUSSION

3.1 Wear behavior

The program (MINITAB 18) was used to evaluate the statistical significance of the parameters (content of the specimens, load, and sliding distance) on the wear behaviour of the two groups of specimens: the first group specimens (vinyl ester-10% glass fiber-nano ZrO_2), and the second group specimens (vinylester-10 vf. % Glass fiber-nano Fe_3O_4). Table 2-5 shows the wear rate results and S/N for all nanocomposites specimens under the influence of parameters. Experiments have shown that a larger (S/N) ratio always has better wear resistance. The specimens (vinylester-10% vf. glass fiber-2% vf. Nano ZrO_2) had a higher (S/N) ratio (50.4576 dB) for the specimen group reinforced with nano (ZrO_2), while the specimens (vinylester-10% vf. glass fiber-2% vf. Nano Fe_3O_4) had S/N higher (S/N) ratio (38.4164 dB) for the sample group reinforced with nano (Fe_3O_4). The influence of the control parameters on wear behaviour is graphically depicted in Figures 2-5. The graphs show how the (S/N) ratio changed as the setting of the control factor was adjusted from one level to another. Response histograms with the highest S/N values had the best wear rate. From Figures 2 and 3 plots, it is clear that the factor combination of A3, A6, B2, and C2 gives the minimum wear rate. Thus, the minimum wear rates for the nanocomposites are obtained when the content of specimens (A) is at the highest level, while the load (B) and the sliding distance (D) are at middle levels. From Figures 4 and 5 plots, it is clear that the factor combination of A7, A10, B2, B3, and C2 gives the minimum wear rate. Thus, minimum wear rates for the nanocomposites are obtained when the content of specimens (A) is at the highest level, while the load (B) and the sliding distance (C) are at middle levels. It is self-evident that the fillers of the specimens have a direct impact on wear behaviour more than the load applied and distance sliding.

Figure 6 depicts the results of wear rate after adding 10% vf. glass fiber to vinylester. Figure 7 (a and b) depicts the results of wear after adding (0.5- 2% vf. nano ZrO_2, nano Fe_3O_4) to vinylester filled with 10% vf. glass fiber. Experimental results show that the wear resistance improved significantly with the addition of (10% vf.) glass fibers and nanoparticles compared with the wear resistance of vinyl ester resin without any reinforcement.

The specimens (vinylester - 10% vf. glass fiber- 2% vf. nano ZrO_2), (vinyl ester -10% vf. glass fiber- 2% vf. nano Fe_3O_4) (0.003×10-5 mm^3/Nm), (0.012×10-5 mm^3/Nm) respectively, exhibited the highest wear resistance. This behavior can be attributed to the presence of such hard nanoparticles acting as effective barriers to prevent large-scale matrix fragmentation [18]. From results note that the specimens filled by (nano ZrO_2) give better wear resistance compared to the specimens filled by (nano Fe_3O_4) because the nanoparticles with less size have high surface energy that helped in strengthening the bonding between the nanoparticles and the resin and thus contributed to increasing the mechanical strength and increasing the wear resistance [19].

Table 2. Results of wear rate and S/N ratio for specimens (Pure Vinylester, Vinylester- 10%vf. Glass fiber, Vinylester- 10%vf. Glass fiber- 0.5% vf. Nano ZrO_2)

No. expat.	Specimens (VF.) (A)	Load (N) (B)	distance sliding (cm) (C)	Wear Rate (mm^3/Nm) $\times 10^{-5}$	S/N (db)
1	Pure Vinylester	10	25	0.542	5.3200
2	Pure Vinylester	15	35	0.660	3.6091
3	Pure Vinylester	20	45	0.720	2.8534
4	Vinylester- 10%vf. Glass fiber	10	35	0.215	13.3512
5	Vinylester- 10%vf. Glass fiber	15	45	0.169	15.4423
6	Vinylester- 10%vf. Glass fiber	20	25	0.280	11.0568
7	Vinylester- 10%vf. Glass fiber- 0.5% vf. Nano ZrO_2	10	45	0.066	23.6091
8	Vinylester- 10%vf. Glass fiber- 0.5% vf. Nano ZrO_2	15	25	0.060	24.4370
9	Vinylester- 10%vf. Glass fiber- 0.5% vf. Nano ZrO_2	20	35	0.052	25.8000

Table 3. Results of wear rate and S/N ratio for specimens (Vinylester- 10%vf. Glass fiber- 1%, 1.5%, 2% vf. Nano ZrO_2)

No. expat.	Specimens (VF.) (A)	Load (N) (B)	distance sliding (cm) (C)	Wear Rate (mm^3/Nm) $\times 10^{-5}$	S/N (db)
1	Vinylester- 10%vf. Glass fiber- 1% vf. Nano ZrO_2	10	25	0.042	27.5350
2	Vinylester- 10%vf. Glass fiber- 1% vf. Nano ZrO_2	15	35	0.047	26.5580
3	Vinylester- 10%vf. Glass fiber- 1% vf. Nano ZrO_2	20	45	0.052	25.6799
4	Vinylester- 10%vf. Glass fiber- 1.5% vf. Nano ZrO_2	10	35	0.027	31.3727
5	Vinylester- 10%vf. Glass fiber- 1.5% vf. Nano ZrO_2	15	45	0.010	40.0000
6	Vinylester- 10%vf. Glass fiber- 1.5% vf. Nano ZrO_2	20	25	0.038	32.4043
7	Vinylester- 10%vf. Glass fiber- 2% vf. Nano ZrO_2	10	45	0.007	43.0980
8	Vinylester- 10%vf. Glass fiber- 2% vf. Nano ZrO_2	15	25	0.010	40.1203
9	Vinylester- 10%vf. Glass fiber- 2% vf. Nano ZrO_2	20	35	0.003	50.4576

Table 4. Results of wear rate and S/N ratio for specimens (Pure Vinylester, Vinylester- 10%vf. Glass fiber, Vinylester- 10%vf. Glass fiber- 0.5% vf. Nano Fe_3O_4)

No. expt.	Specimens (VF.) (A)	Load (N) (B)	distance sliding (cm) (C)	Wear Rate (mm^3/Nm) $\times 10^{-5}$	S/N (db)
1	Pure Vinylester	10	25	0.542	5.3200
2	Pure Vinylester	15	35	0.660	3.6091
3	Pure Vinylester	20	45	0.720	2.8534
4	Vinylester- 10%vf. Glass fiber	10	35	0.215	13.3512
5	Vinylester- 10%vf. Glass fiber	15	45	0.169	15.4423
6	Vinylester- 10%vf. Glass fiber	20	25	0.280	11.0568
7	Vinylester- 10%vf. Glass fiber- 0.5.% vf. Nano Fe_3O_4	10	25	0.093	20.6303
8	Vinylester- 10%vf. Glass fiber- 0.5.% vf. Nano Fe_3O_4	15	35	0.085	21.4116
9	Vinylester- 10%vf. Glass fiber- 0.5.% vf. Nano Fe_3O_4	20	45	0.078	22.1581

Table 5. Results of wear rate and S/N ratio for specimens (Vinylester- 10%vf. Glass fiber- 1%, 1.5%, 2% vf. Nano Fe_3O_4

No. expat.	Specimens (VF.) (A)	Load (N) (B)	distance sliding (cm) (C)	Wear Rate (mm^3/Nm) $\times 10^{-5}$	S/N (db)
1	Vinylester- 10%vf. Glass fiber- 1% vf. Nano Fe_3O_4	10	35	0.060	24.4370
2	Vinylester- 10%vf. Glass fiber- 1% vf. Nano Fe_3O_4	15	45	0.068	23.3498
3	Vinylester- 10%vf. Glass fiber- 1% vf. Nano Fe_3O_4	20	25	0.073	22.7335
4	Vinylester- 10%vf. Glass fiber- 1.5% vf. Nano Fe_3O_4	10	45	0.047	26.5580
5	Vinylester- 10%vf. Glass fiber- 1.5% vf. Nano Fe_3O_4	15	25	0.040	27.9588
6	Vinylester- 10%vf. Glass fiber- 1.5% vf. Nano Fe_3O_4	20	35	0.050	26.0206
7	Vinylester- 10%vf. Glass fiber- 2% vf. Nano Fe_3O_4	10	25	0.018	34.8945
8	Vinylester- 10%vf. Glass fiber- 2% vf. Nano Fe_3O_4	15	35	0.029	30.7520
9	Vinylester- 10%vf. Glass fiber- 2% vf. Nano Fe_3O_4	20	45	0.012	38.4164

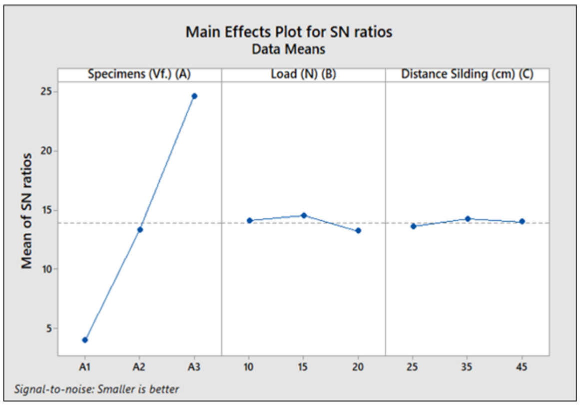


Figure 2. Main effect plot (S/N ratio) for specimens (Pure Vinylester, Vinylester- 10%vf. Glass fiber, Vinylester- 10%vf. Glass fiber- 0.5% vf. Nano ZrO_2)

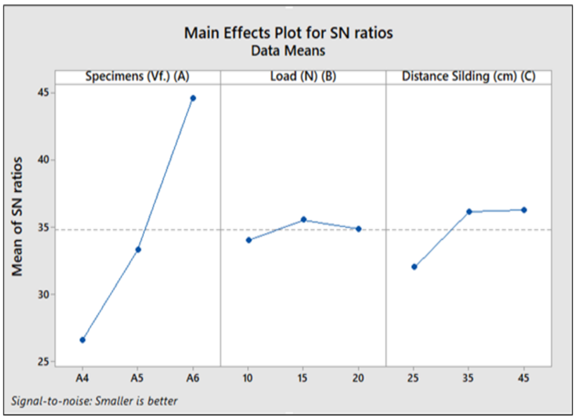


Figure 3. Main effect plot (S/N ratio) for specimens ((Vinylester- 10%vf. Glass fiber- 1%, 1.5%, 2% vf. Nano ZrO_2)

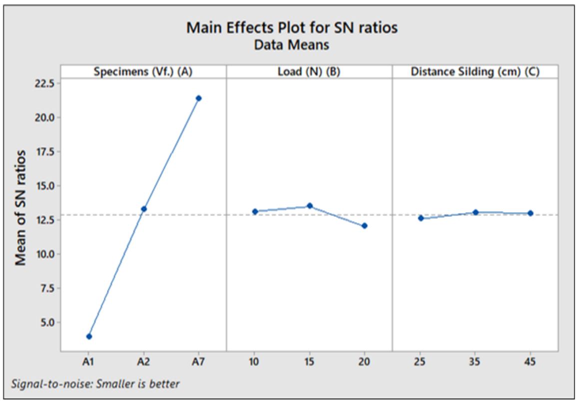


Figure 4. Main effect plot (S/N ratio) for specimens (Pure Vinylester, Vinylester- 10%vf. Glass fiber, Vinylester- 10%vf. Glass fiber- 0.5% vf. Nano Fe_3O_4)

Figure 8 shows the relationship between the wear rate for the specimens (pure vinyl ester, vinylester-10% vf. glass fibers) and the applied load (10, 15, 20 N). Figure 9 (a and b) shows the results of the wear rate after adding (10% vf. fiberglass, 0.5-2% vf. nano ZrO2, nano Fe3O4) to vinyl ester resin under the effect loads (10, 15, 20 N). It is clear from all the experiments (Taguchi) that the wear rate increased with the increase of the applied load from (10 to 20 N). The specimens (vinyl ester- 10%vf. glass fiber-2% vf. nano ZrO_2) and (vinyl ester- 10%vf. glass fiber-2% vf. nano Fe_3O_4) give the best wear resistance at load (20N).

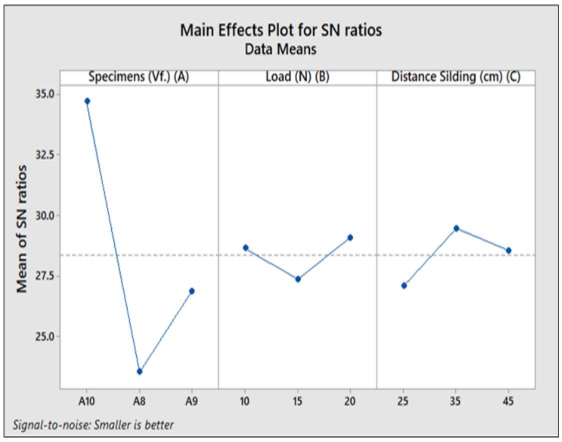


Figure 5. Main effect plot (S/N ratio) for specimens (Vinylester- 10%vf. Glass fiber- 1%, 1.5%, 2% vf. Nano Fe_3O_4)

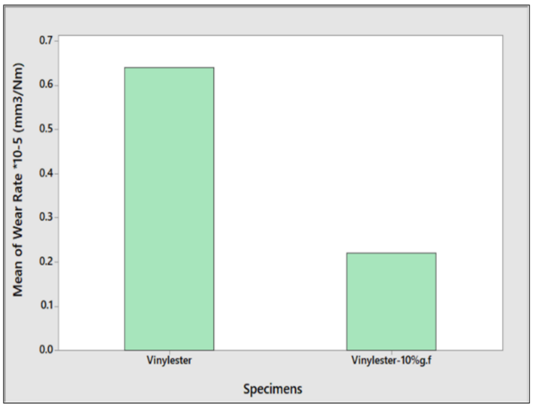


Figure 6. Mean wear rate of specimens (vinyl ester, vinylester-10%vf. glass fiber)

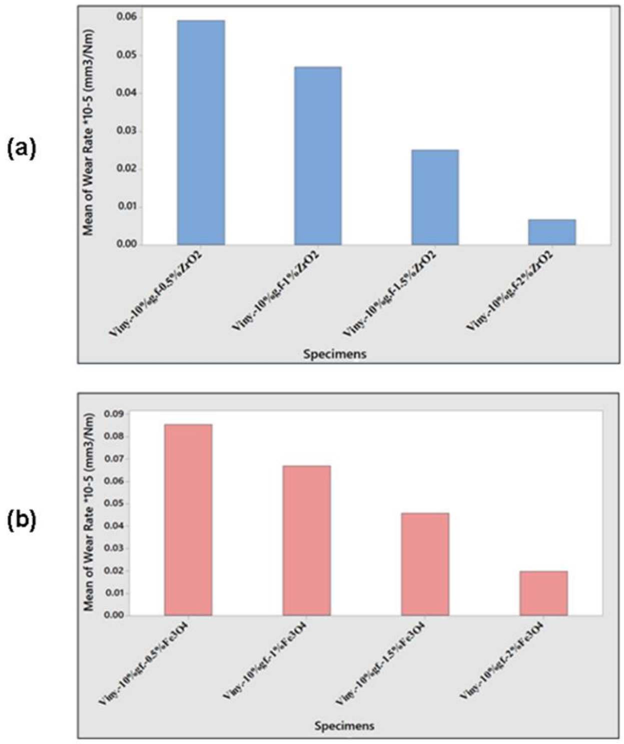


Figure 7. Mean wear rate of specimens filled with nano ZrO_2 (a), and (b) Mean wear rate of specimens filled with nano Fe_3O_4

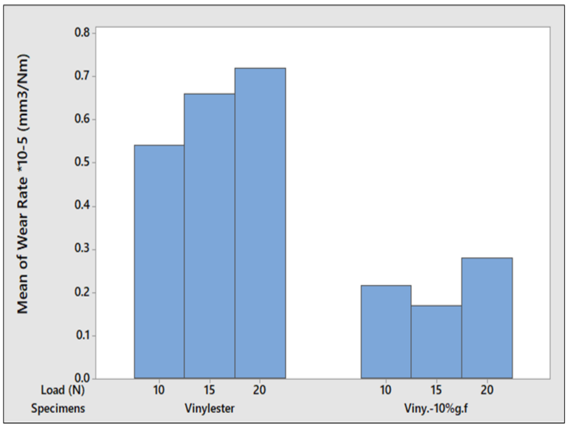


Figure 8. Mean wear rate of specimens (vinyl ester, vinylester-10%vf. glass fiber) under effect applied load

(a)

(b)

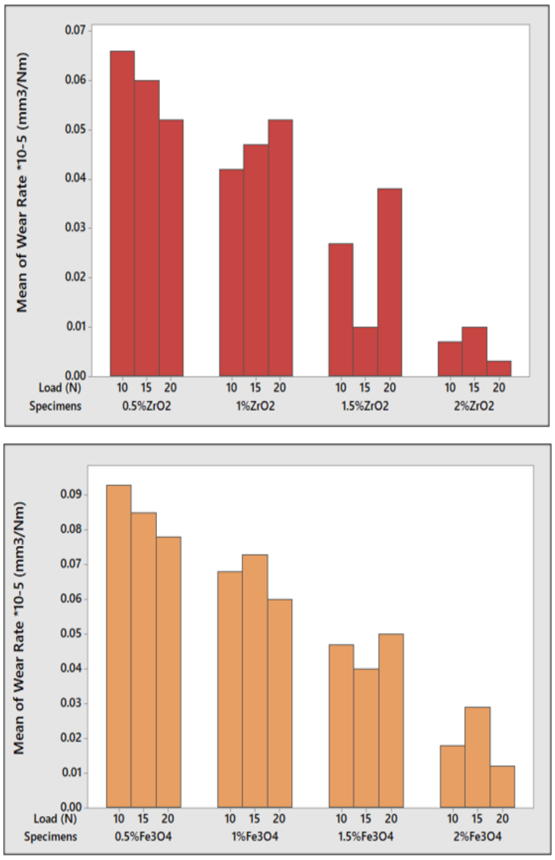


Figure 9. (a) Mean wear rate of specimens filled nano ZrO_2 under effect load. (b) Mean wear rate of specimens filled nano Fe_3O_4 under effect load

The increase in the load causes the thermal softening of the nanocomposites, thus weakening the matrix material and increasing the wear rate [20]. However, when the matrix material is displaced, the nanoparticles added to the resin and fibers act to withstand the applied load thus attempting to reduce the rate of wear [21].

Figure 10 shows the wear rate results after adding 10% vf. glass fiber to vinyl and resin its relation to sliding distance. Figure 11 (a and b) shows the results of wear rate after adding (10% vf. fiberglass, 0.5-2% vf. nano ZrO_2, nano Fe_3O_4) to vinyl ester and its relationship to sliding distance. The best wear resistance for the specimens of the first group was present at (vinylester- 10%vf. glass fiber-2% vf. nano ZrO_2) at (35 cm sliding distance), and the best wear resistance for the specimens of the second group was present at (vinylester-10%vf. glass fiber-2% vf. nano Fe_3O_4) at (45 cm sliding distance). The shape, size, hardness, and volume fraction of nanoparticles play an important and effective role in reducing the wea rate [22].

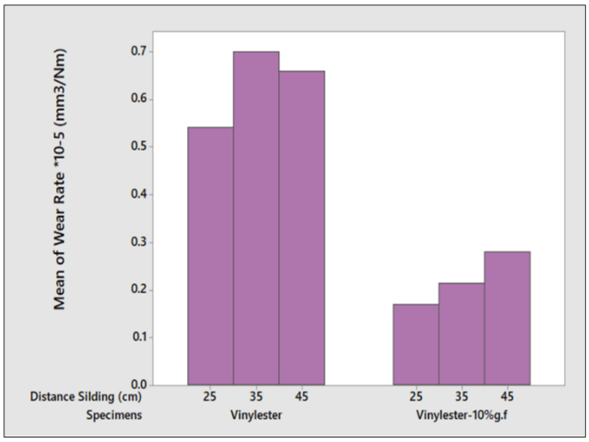


Figure 10. Effect distance sliding on wear behavior for specimens (vinylester, vinylester-10%vf. glass fiber)

(a)

(b)

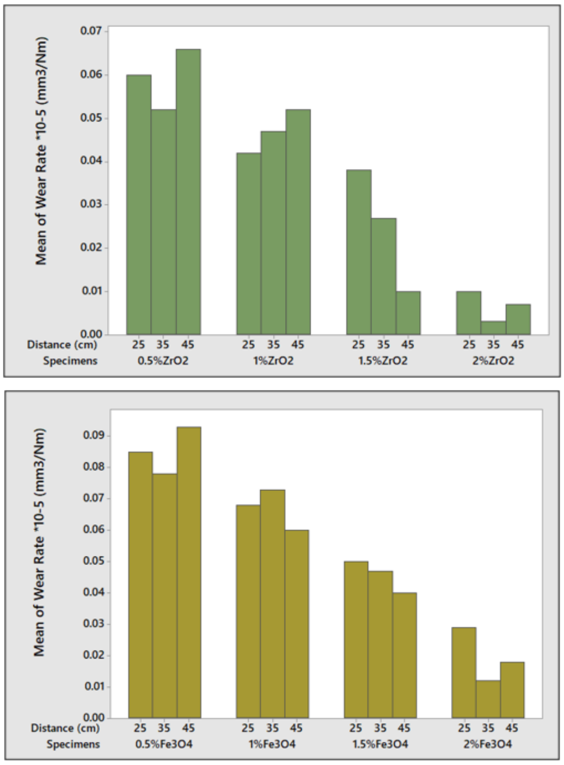


Figure 11. Effect distance sliding for specimens filled nano ZrO_2 (a), and (b) Effect Effect distance sliding for specimens filled nano Fe_3O_4

Figure 12 (a and b) shows the interaction effects for all control parameters and for all specimens. It is well known that interactions do not occur when the lines on the interaction diagrams are parallel and strong interactions between parameters occur when there are lines intersecting [23, 24]. It is clear from the above Figure that there is an interaction between the control parameters. In order to justify the insignificant factor and insignificant interaction, a further statistical analysis (ANOVA) was carried out.

(a)

(b)

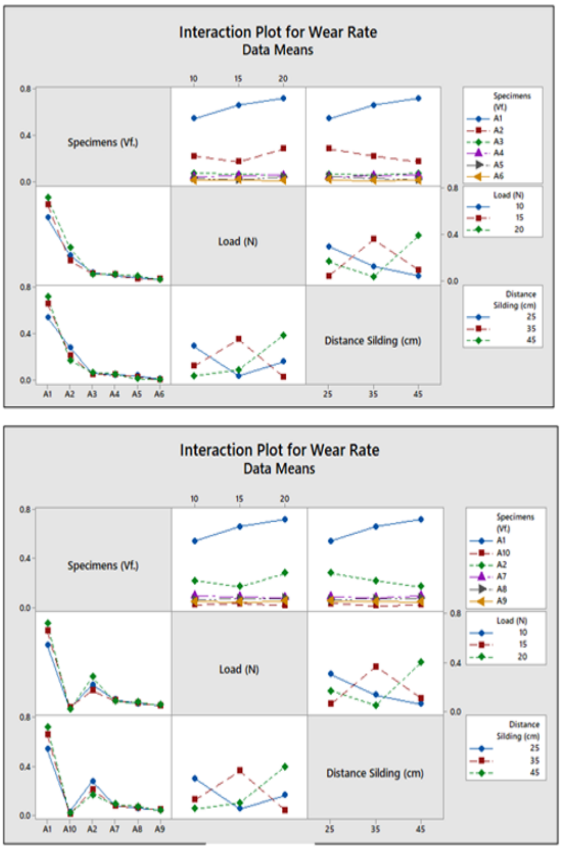


Figure 12. Interaction plot for wear rate for specimens filled nano ZrO_2 (a), and (b) Interaction plot for wear rate for specimens filled nano Fe_3O_4

3.2 Factor effect analysis using ANOVA

ANOVA results for all specimens are shown in Tables 6 and 7 in order to validate the results obtained using the Taguchi technique. This study was carried out with a 5% degree of confidence in its findings, when the P-values are less than 5%, the major effects are more significant [25]. According to Table 6, the volume fraction of nano ZrO_2 nanoparticles (P = 0.001) has a greater effect on the wear behavior, while the applied load (P = 0.03) has a smaller effect on the wear behavior.

From Table 7, observe that the volume fraction of nano Fe_3O_4 nanoparticles (P = 0.003) has a greater effect on wear behavior, while the load applied (P = 0.04) has less on wear behavior. It is clear from the results of the table that the sliding distance factor has the least effect on the wear behavior. The present analysis indicates that wear test variables and their interactions have both statistical and physical significance in the wear behavior of the nanocomposites (vinylester- 10%vf. Glass fiber- Nano ZrO_2, nano Fe_3O_4). From ANOVA results can be noted the filler content of specimens (A) followed the load (B) more effect on wear behavior, while the distance sliding (C) had less effect on wear behavior of specimens filled with nano ZrO_2, and Fe_3O_4.

3.3 Hardness (Shore D)

The standard deviation and average hardness of the all specimens (vinylester- 10%vf. glass fiber- 0.5%, 1%, 1.5%, 2% vf. nano ZrO_2, Fe_3O_4) is displayed in Table 8 and Figure 13 (a and b).

The results show the adding 10% vf. fiber glass to vinyl ester resin leads to improved average hardness values compared with the mean values of pure specimens. It was also evident from the results that adding nanoparticles (2% vf. ZrO_2 and Fe_3O_4) to vinyl ester resin reinforced with 10% vf. fiberglass average hardness values have been significantly improved.

Table 6. ANOVA table for specimens filled nano ZrO_2

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Specimens (Vf.)	5	0.897523	0.179505	82.35	0.001
Load (N)	2	0.005527	0.002763	1.27	0.033
Distance Silding (cm)	2	0.000229	0.000115	0.05	0.549

Table 7. ANOVA table for specimens filled nano Fe_3O_4

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Specimens (Vf.)	5	0.838216	0.167643	75.67	0.003
Load (N)	2	0.004926	0.002463	1.11	0.047
Distance Silding (cm)	2	0.000374	0.000187	0.08	0.620

Table 8. Standard deviation and average hardness for all specimens

	N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
Pure Vinlyester	5	76.40	.4000	75.406	77.394	76.0	76.8
Vinlyester- 10% g.f	5	77.50	.3000	76.755	78.245	77.2	77.8
Vinlyester- 10% g.f- 0.5%ZrO_2	5	79.30	.4010	78.306	80.294	78.9	79.7
Vinlyester- 10% g.f- 1%ZrO_2	5	82.40	.2000	81.903	82.897	82.2	82.6
Vinlyester- 10% g.f- 1.5%ZrO_2	5	83.33	.2517	82.708	83.958	83.1	83.6
Vinlyester- 10% g.f- 2%ZrO_2	5	84.60	.3025	83.855	85.345	84.3	84.9
Vinlyester- 10% g.f- 0.5% Fe_3O_4	5	78.33	.2517	77.708	78.958	78.1	78.6
Vinlyester- 10% g.f- 1% Fe_3O_4	5	80.60	.3034	79.855	81.345	80.3	80.9
Vinlyester- 10% g.f- 1.5% Fe_3O_4	5	81.36	.4041	80.363	82.371	81.0	81.8
Vinlyester- 10% g.f- 2% Fe_3O_4	5	82.60	.2044	82.103	83.097	82.4	82.8

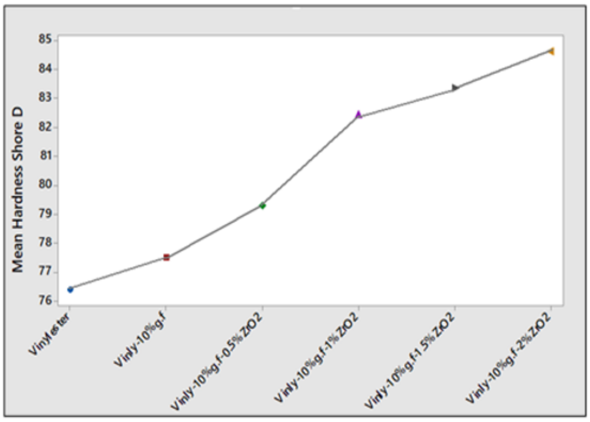
Table 9. ANOVA analysis for specimens (vinylester- 10%vf. Glass fiber- 0.5-2%vf. Nano ZrO_2)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	166.951	5	33.390	332.057	0.03
Within Groups	1.207	12	.101		
Total	168.158	17			

Table 10. ANOVA analysis for specimens (vinylester- 10%vf. Glass fiber- 0.5-2%vf. Nano ZrO_2)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	87.807	5	17.561	173.684	0.04
Within Groups	1.213	12	0.101		
Total	89.020	17			

(a)



(b)

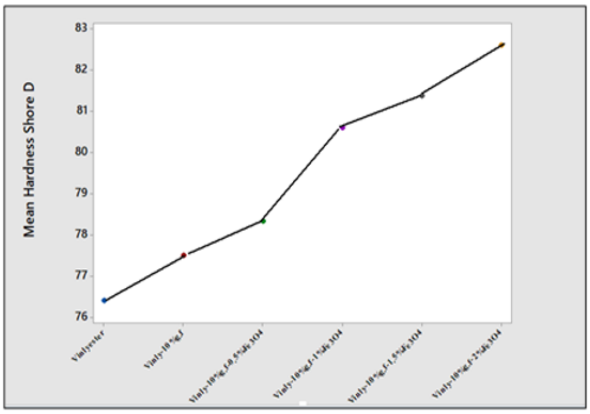


Figure 13. Average hardness for specimens (vinylester- 10%vf. Glass fiber- 0.5-2%vf. Nano ZrO_2) (a), and (b) Average hardness for specimens (vinylester- 10%vf. Glass fiber- 0.5-2%vf. Nano Fe_3O_4)

The reason for the improvement in the hardness values could be explained by the homogeneous dispersion of nanoparticles in the polymer resins and the cross-linking density of the polymer chains which led to the increased hardness, higher hardness of the nanocomposite is frequently associated with increased wear resistance [26]. The results of the average values hardness tests were gathered and analyzed using a one-way analysis of variance (Tukey's posthoc and Scheffe).

Tables 9 and 10 display the results of ANOVA of all specimens. The Sig values of the first group specimens (vinyl ester- 10%vf. glass fiber- 0.5-2%vf. Nano ZrO_2) were ($0.03 \leq 0.05$), and the Sig values for the second group specimens (Vinylester- 10%vf. Glass fiber- 0.5-2%vf. Nano Fe_3O_4) were ($0.04 \leq 0.05$). These values indicate there is a statistically significant difference between the mean hardness at the confidence level of 95.0%. The results show that the presence of glass fibers with nanoparticles (ZrO_2 and Fe_3O_4) with polymer resin has a positive effect on the hardness property.

4. CONCLUSION

The wear behavior of nanocomposites composed of vinyl ester reinforced glass fibres and nanoparticles was evaluated in this work under three different conditions, including specimen content, applied load, and distance sliding using a sliding time constant, as well as the hardness shore for these nanocomposites. The results of the current work reveal the following:

(1) The nanocomposites consisting of (0.5- 2% vf. ZrO_2, Fe_3O_4), polymer (vinyl ester) and glass fibers can be used in many industrial applications because they have good wear resistance.

(2) The specimens (vinyl ester-10% vf. glass fiber-2% ZrO_2) under the influence of the following factors (20 N load applied, 35 cm sliding distance) gave the best wear performance (0.003 x 10^{-5} mm^3/Nm).

(3) The specimens (vinyl ester-10% vf. glass fiber-2% Fe_3O_4) under the effect factors (20 N load applied, 45 cm distance sliding) give the best wear performance (0.012×10^{-5} mm^3/Nm).

(4) The found that the content of specimens (A) is the most important factor affecting the wear behaviour, followed by the factors (B-load applied) and (C-distance sliding).

(5) The increase in the volume fraction of nanoparticles from (0.5% to 2% vf.) in the vinyl ester improved the mean of the hardness tests.

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