THE EXPERIMENTAL STUDY AND MATHEMATICAL MODEL OF THE EFFECT OF ALUMINA PARTICLES REINFORCEMENT ON MECHANICAL PROPERTIES OF EPOXY

Dr. Ibtihal A. Mahmood [1] Jabbar H. mohmmed [2] Sarmad I. Ibrahim[3] Muslim M. Ali[4]

ABSTRACT

This article describes some mechanical properties of alumina-filled epoxy composites. In this work, the epoxy matrix was reinforced with increasing amount of alumina particles in the range of 0-40% by weight with different particle size (d≤8, 18≤d≤25, 33≤d≤45, 50≤d≤62)µm. From the flexural test results, it was observed that the flexural modulus increases with increasing α-alumina content from 10 to 40 wt%. At the same time, the results indicated that there are no much effect on the flexural modulus with change the particle size in the range of (d≤8, 18≤d≤25)µm. The highest value of flexural modulus was recorded with 40 wt% of α-alumina content and (d≤8)µm particle size. It was also found that the 40 wt% alumina content and (d≤8)µm particle size recorded the highest value of fracture toughne ss (Gc), fracture toughness (Kc), hardness (HB), and wear resistance which were improved by (253%, 282%, 230%, and 82%), respectively. Also, in this work a mathematical modeling is implemented and regression equations are obtained by using (SPSS) software to predict the properties of alumina filled epoxy composites. Comparing the predicted and measured values gives high prediction accuracy. The accuracy of prediction has been (90.13%, 85.95%, 90.28%, 89.76%, and 84.36%) for flexural modulus, toughness, fracture toughness, hardness, and wear rate respectively.

Keywords: alumina filled composites, epoxy resin, flexural modulus, SPSS software.

دراسة عملية وموديل رياضي لتأثير التقوية بدقائق الالومينا على الخواص الميكانيكية للايبوكسي

د. ابتهال عبد الرزاق محمود جبار حسين محمد سرمد عماد ابراهيم مسلم محسن علي

الخلاصة

يصف هذا ألبحث بعض الخواص الميكانيكية لمتراكبات الايبوكسي المقواة بدقائق الالومينا. حيث تم في هذا البحث اضافة دقائق الالومينا لتقوية راتنجات الايبوكسي بنسب وزنية مختلفة (40-0)% مع احجام حبيبية مختلفة (d≤8, 18≤d≤25, 33≤d≤45, 50≤d≤62) مايكرومتر. بينت نتائج اختبار الانحناء زيادة قيمة معامل الانحناء بزيادة نسبة الالومينا. وفي نفس الوقت بينت النتائج عدم وجود تأثير كبير لتغيير الحجوم الحبيبية في حدود(d≤8, 18≤d≤25)مايكرومترعلى قيمة معامل الانحناء. أعلى قيمة

لمعامل الانحناء تم الحصول عليها عند اضافة الالومينا بنسبة 40 % من الوزن بحجم حبيبي (d≤8) مايكرومتر. من ناحية اخرى فقد وجد ايضا أن اعلى القيم للمتانة ، متانة الكسر، الصلادة، ومقاومة البلى والتي تحسنت بمقدار(253%، 282%، 230%، و 82%) على التوالي قد سجلت ايضا عند اضافة الالومينا بنسبة 40 % وحجم حبيبي (d≤8) مايكرومتر. تم ايضا في هذا البحث استخدام موديل رياضي وتم الحصول على معادلات الانحدار باستخدام برنامج (SPSS) لغرض التنبؤ بخواص متراكبات الايبوكسي المقواة بالالومينا. بينت النتائج من خلال المقارنة بين القيم المتنبئة والحقيقية إن هذا البرنامج يعطي دقة تنبؤ عالية . فقد كانتدقة التنبؤ بمقدار (90.13%, 85.95%, 90.28%, 89.76%, 84.36%) لمعامل الانحناء، المتانة،ومتانة الكسر، الصلادة، ومعدل البلى على التوالي.

1. INTRODUCTION

Epoxy resin is widely used as a substrate material in electronic packaging industry. As one of the most widely used thermosetting resin, epoxy resin possess special chemical characteristics such as little or no by-products or volatiles formation upon curing, low shrinkage, can be cured over a wide range of curing temperatures and control-able degree of cross-linking [Zhang 2003]. However, these materials exhibit low impact strength, poor resistance to crack growth and small elongation at break, i.e. they are inherently brittle.

In the last few decades, a great deal of effort was devoted to the improvement of the fracture resistance and the ductility of brittle polymers such as epoxy and unsaturated polyester resins. Approaches to improve the toughness of epoxy resins include mainly the incorporation of solid particles [Fellahi et.al. 2001] and copolymers [Pearson et.al. 1991], glass-fiber [Bennet et.al 1998], silica powder, and aramid fiber [Alvarez et.al. 2003] depending on the application of the products. In the other hand, for predictive purposes there are many researchers used the statistical package to develop the mathematical models and optimize the properties of composite. Jayabal et.al 2011 studied the Influence of fiber parameters on tensile, flexural, and impact properties of nonwoven coir–polyester composites and the mathematical models were developed for these properties. Empirical models for estimating properties of developed composite material from agro waste were investigated by Osarenmwinda et.al 2010.

The properties of composites depend on shape, particle size, content, and surface area of fillers, as well as the type of polymer matrix [Tanimoto et.al. 2006].

the selected filler in this work was α-alumina. This ceramic filler was incorporated into the epoxy resin to improve the mechanical properties. In order to maximize the reinforcement effect of α-alumina, it is important to ensure that the particles are homogeneously dispersed in epoxy matrix. Thus, in this study the effects of particle size and content of filler on some mechanical properties (flexural modulus, toughness, fracture toughness, hardness, and wear resistance) properties of epoxy composite have studied to obtain the optimum level of alumina content and particle size. Mathematical model of the effects of particle size and weight fraction of alumina on properties of the epoxy composite have been also reported in this paper.

2. EXPERIMENTAL

2.1 Materials

Epoxy resin (CY 233 supplied by CIBA-GEIGY Co., Ltd.) and curing agent (Epoxy Hardener Crystal Clear HY 965) were used in this experiment. This resin has epoxies equivalent density approximately of 1.1-1.2 g/cm^3. The α-alumina has a density of 3.97 g/cm^3 with different particle size ranging of ($d \leq 8$, $18 \leq d \leq 25$, $33 \leq d \leq 45$, $50 \leq d \leq 62$)μm were used as filler in this work.

2.2 Mold preparation

A standard steel sample for each type of tests was manufactured for the purpose of making the final mold. The molds were manufactured from the white cement material. Manufacturing mold process can be summarized in the following steps:

- Forming a rectangular frame of wood for each mold and then put them on glass bases.
- Poured the mixture of white cement into the wooden structures.
- Put the standard steel samples in own mold and kept for one hour.
- Take out the standard samples from molds. The cement material will take the form of standard samples.
- Take out the molds from the wooden frames.

2.3 Sample preparation

Hand-lay up method was used for specimens preparation. Prior to mixing, the α-alumina powder was dried in an oven at 110C for 1 hour. The mixture of α-alumina and epoxy was then mixed in a container with continuous stirring for homogenization. Hardener (1:3 ratio from epoxy resin) was added at 8 minutes of stirring and the mixture was further stirred for another 15 minutes. Then, The mixture was quickly poured into mold covered with Vaseline film to avoid the adherence between epoxy and wall of mold. The mixture was kept in mold at room temperature for 12 hr. in this work, the alumina particles were added epoxy resin in different weight fraction (0,10,20,30,40)% and particle size ($d \leq 8$, $18 \leq d \leq 25$, $33 \leq d \leq 45$, $50 \leq d \leq 62$)μm to study their effect on resultant composite properties.

2.4 Tests

2.4.1 Flexural Testing

Flexural tests under three-point bend configuration were performed according to ASTM D790. The span to depth ratio of Test samples was 32:1. all the tests were performed at room temperature. The values of flexural modulus were calculated based on Equation:

$$E = \frac{mL^3}{4DB^3} \quad \ldots\ldots 1$$

E : modulus of elasticity (MPa).

L : support span (mm).

D : width of sample (mm).

B : depth of sample (mm).

m : slope of the tangent to the initial straight line portion of the load-deflection curve (N/mm) of deflection.

2.4.2 Impact Testing

Charpy impact test was performed by using a pendulum machine H.20 (Tensometer Ltd., Croydon) with a weighing capacity varying from 0.14 to 9.07 N. specimens were notched by using Notch machine (Ceast type) . the notch depth was equal for all specimens with (1.5mm). For each weight fraction, 3 specimens of 55mm×10mm×10mm (length×width×thickness) with different particle size were produced and tested according to (ISO-179) standard. All tests were performed at room temperature. The energy absorbed at fracture (U_c) can be obtained from impact tests, from which, the value of toughness (G_c) were calculated based on equation:

$$G_c = \frac{U_c}{BD\Phi} \quad \ldots \ldots \ldots 2$$

Where:

B : depth of sample (mm).

D : width of sample (mm).

Φ: geometry function.

When the ratio between length of sample exposed to impact to cross section of sample equal to 4, the geometry function (Φ) can be calculated from the following equation:

$$\Phi = 0.135\left(\frac{a}{D}\right)^{-0.77} \quad \ldots \ldots \ldots 3$$

Where

$\frac{a}{D}$: Ratio of notch depth to cross section of sample.

In addition to, the values of fracture toughness K_c can be calculated from the following equation:

$$K_c = (EG_c)^{1/2} \quad \ldots \ldots \ldots 4$$

2.4.3 Hardness Test

Hardness has been performed by using Brinell hardness test instrument. During this test, a hard, spherical indenter is forced in to the surface of the sample to be tested.

The diameter of the hardened steel indenter is (5.00mm). In this test load (1500) N was applied on surface of sample and the maintained constant for a specified time (15 sec.). The diameter of the resulting indentation is measured with a special low-power micro scope, utilizing a scale

that is etched on the eye piece. The measured diameter is then converted to the appropriate HB number using a chart or the following Equation:

$$HB = \frac{2P}{\pi D(D-(D^2-d^2)^{0.5})} \quad \ldots\ldots 5$$

HB= Brinell

P = applied load (Kg)

D = Ball diameter (mm)

d =Indention diameter on the sample surface (mm)

2.4.4 Wear Test

Wear tests were performed in accord with the ASTM G99 for wear testing with a pin-disk apparatus. The wear rate of the materials were determine at a load of 10N, rotating speed of 2cm/sec, sliding distance of 50m using a pin-on-disk tribometer. The wear rate expressed in (mg/cm) is calculated as follows:

$$W.R = \frac{\Delta w}{S} \quad \ldots\ldots 6$$

Where: $W.R$: wear rate, Δw : weight loss in (mg), S : sliding distance in (m).

All of the tests were conducted at ambient atmospheric condition at room temperature (25)˚C. Lubrication are not applied to avoid the complication of terbo-chemical effects.

3. MATHEMATICAL MODELING

A statistical model for the prediction of the mechanical properties of the resultant composite was created by regression function in SPSS software from training data set. The definition of the variation factors (independent variables) and their values are given in Table 1, while the dependent variables (response functions) were the composite properties (flexural modulus (E), toughness (G_c), or fracture toughness (K_c), Hardness (HB), and Wear rate (WR)). All original 17 samples within experimental data within experimental data shown in Table 2 were randomly divided into two data sets; the training data set and the testing data set. The training data set contained 9 samples which were used to build a prediction model as shown in Table 3 and the testing data set contained 8 samples which were used to test the flexibility and the validity of the prediction model as shown in Table 4.

4. RESULT AND DISCUSSION

4.1 Experimental Work

4.1.1 Flexural Modulus

Flexural modulus is the ratio of stress to strain within the elastic limit (when measured in flexural mode) and this property was used to indicate the bending stiffness of the material. The

results indicate the addition of α-alumina particles has larger effect on the flexural modulus of the composites than particle size as shown in Fig 1. The obtained results show that an increase in flexural modulus is realized in all the weight fraction of alumina particle addition, and there is no significant difference in results when change the particle size in range (8-25) μm. It is widely accepted that the addition of the rigid filler will increase the modulus of the composites materials following the Rule of Mixtures [Matthews et.al. 1994]. The optimum value of flexural modulus of the composites was brought at 40wt% of α-alumina content with particle size ($d \leq 8$) μm which is improved by 74% comparing with the neat epoxy. The increasing in flexural modulus is mainly attributed to the inherent stiffness of α-alumina particles and the restriction of chain mobility this can be explained by plastic deformation mechanism. Ability of the material to plasticity deformed is largely determined by the mobility of the molecular chain (molecular motion) to take place under applied load. The presence of rigid particles such as α-alumina in this case has restricted the mobility of the molecular chain to pass each other and orientation which consequently resulted in increase in rigidity (stiffness).

4.1.2 Impact test results

The toughness (G_c) and fracture toughness (K_c) values can be obtained from impact test results by using the equations (2, 3).

Figures 2 and 3 show the toughness material (G_c) and fracture toughness (K_c) as a function of alumina content with different particle size. It is clear from these figures that G_c and K_c values increase with increasing the alumina content. This improvement is explained by the fact that the addition of alumina particles to epoxy reduce the strain rates, and absorb a part of fracture energy. Also, these particles serve as barrier which impedes progress the cracks, and redistribution the applied fracture stress.

The same trend was observed with decrease the particle size of added alumina. This is because of the larger particle size reduce the barriers against the crack propagation and increase the stress concentration, as well as reduce the particle witting with the matrix (epoxy resin). Thus, reducing the particle size will enhance the toughness and fracture toughness of composite.

4.1.3 Hardness

The hardness of any material is a measure of its resistance to indentation by an external force. The hardness of composite material is closely related to the properties of its components, and it can be controlled by tailoring the chemical composition, weight fraction, and particle size.

Figure 4 shows the effects of weight fraction of reinforcement on the hardness values of epoxy matrix with different particle size of alumina addition. It is clear from figures that the alumina addition increases the hardness value. This improving in hardness of the coating is due to incorporating a greater percentage of a hard component (alumina) into epoxy matrix. It is also obvious from figures, when the weight fraction of alumina is kept constant; hardness of epoxy composite is enhanced greatly by decreasing the particle size of alumina added.

4.1.4 Wear Rate

The results of wear rate of composite varied from 17.34×10^{-4} mg/m (for neat epoxy) to 1.53×10^{-4} mg/m (for reinforced epoxy).

The results present in Fig 5 indicate that the wear rate of epoxy composite improves with increasing the weight fraction of alumina particles as well as with decreasing the particle size.

The presence of a certain amount of dispersed hard particles of alumina throughout the epoxy matrix results in high improvement of wear rate. This improvement attributed to that alumina particle will absorb a portion of applied stress and heat generated by friction as a result slip between the surface of samples and the surface of the rotating disk. Thus, the applied stress and heat generated will be distributed on each matrix and reinforcing particles, and this will improve the ability of the epoxy resin to resist the wear.

Also, the same trend was observed with decrease the particle size. This is because of the increasing in particle size increase the interface surface and this leads to impede the process of transfer of stresses and heat of the matrix to the reinforcing particles, and increases the concentration of stress, heat, and this will increase the wear rate with increasing the particle size.

The results of this study suggest that there is an inverse relationship between the hardness and wear rate. The harder materials revealed more wear resistance as shown in Fig 6. Although similar results have been reported by Borgioli et al. 2005, several studies have found no correlation between hardness and wear due to the complexity of wear process [Seghi et.al. 1991, Yap et.al 1997, Mandikos et.al. 2001, Mair et.al. 1996].

5. RESULTS AND DISCUSSION OF MATHEMATICAL MODEL

After processing of experimental results, mathematical models (regression equation) for coating properties were obtained:-

$$E = 1.41 + 0.111X_1 - 0.004X_2 \quad \ldots\ldots 7$$

$$G_c = 1.001 + 0.073X_1 - 0.017X_2 \quad \ldots\ldots 8$$

$$K_c = 1.197 + 0.091X_1 - 0.015X_2 \quad \ldots\ldots 9$$

$$HB = 16.264 + 0.64X_1 - 0.222X_2 \quad \ldots\ldots 10$$

$$W.R = 14.205 - 0.325X_1 - 0.093X_2 + 0.005X_1X_2 \quad \ldots\ldots 11$$

Where:

E : Flexural modulus, G_c : toughness, K_c : fracture toughness, HB : Brinell hardness,

$W.R$: wear rate.

The values of the multiple correlation coefficient R, that tell us how strongly the multiple independent variables are related to the dependent variable, were (0.996, 0.95, 0.988, 0.958, 0.915) for (7, 8, 9, 10 & 11) respectively.

The result of average percentage deviation (Φ) shows that the training data set (m=9) were (3.75% , 9.98%, 6.03%, 10.53%, and 13.84%) for (flexural modulus, toughness, fracture toughness, hardness, and wear rate) respectively and the testing data set (m=8) were (9.87% , 14.05%, 9.72%, 10.24%, and 15.63%) for (flexural modulus, toughness, fracture toughness, hardness, and wear rate) respectively .

This means that the statistical model could predict the epoxy composite properties with about (96.24%, 90.02%, 93.97%, 89.47%, and 86.16%) accuracy of the training data set and approximately (90.13%, 85.95%, 90.28%, 89.76%, and 84.36%) accuracy of the testing data set for properties (flexural modulus, toughness, fracture toughness, hardness, and wear rate) respectively.

Figures (7, 8, 9, 10, and 11) show the comparison between the predicted values and measured values of 17 original data for mechanical properties respectively by using (SPSS) software.

It is clear from these figures that the predicted values are in a close match with the measured values for all properties.

6. CONCLUSIONS

Based on the above discussion of results it can be concluded that:

- The addition of alumina improved the studied mechanical properties of the epoxy resin in all cases;
- Decrease of particle size of alumina added improves the mechanical properties (flexural modulus, hardness, adherence strength, acid resistance, and thermal stability) of the epoxy resin which were improved by (292%, 253%, 282%, 230%, and 82%), respectively.
- The multiple regression models could predict the properties of epoxy composite with higher accuracy for different alumina addition, and particle size.

Table 1: Definition and values of independent variables used in regression equation

Designations of independent variable	Name of variable	Value
x_1	alumina addition (%wt)	0,10, 20, 30, 40
x_2	Particle size (μm)	d≤8, 18≤d≤25, 33≤d≤45, 50≤d≤62

Table 2: Original experimental data for properties of Epoxy composite

No	Alumina added (%)	Particle size (μm)	Measured E (GPa)	Predicted E (GPa)	Measured G_c (KJ/m²)	Predicted G_c (KJ/m²)	Measure d K_c (MPa√m)	Predicted K_c (MPa√m)	Measured HB	Predicted HB	Measured WR	Predicted WR
1	.00	.00	1.5	1.40995	1.16	1.00063	1.29	1.19703	13.02	16.26443	17.34	14.20515
2	10.00	d≤8.00	2.3	2.48715	1.5	1.59228	1.91	1.98489	23.11	20.88615	8.11	10.59738
3	20.00	d≤8.00	3.62	3.59764	2.2	2.32119	2.71	2.89265	28.74	27.28601	6.31	7.72995
4	30.00	d≤8.00	4.67	4.70812	2.7	3.0501	3.69	3.8004	32.15	33.68587	5.16	4.86253
5	40.00	d≤8.00	5.88	5.81861	4.1	3.77901	4.93	4.70816	43.05	40.08572	3.1	1.9951
6	10.00	18≤d≤25	2.55	2.42891	1.62	1.35209	2.05	1.77508	21.12	17.77442	8.65	9.96517
7	20.00	18≤d≤25	3.34	3.53939	1.99	2.08099	2.56	2.68284	23.18	24.17428	6.32	7.76113
8	30.00	18≤d≤25	4.88	4.64988	2.44	2.8099	3.34	3.5906	27.48	30.57413	5.71	5.55709
9	40.00	18≤d≤25	5.66	5.76036	3.82	3.53881	4.65	4.49835	35.86	36.97399	4.16	3.35305
10	10.00	33≤d≤45	2.82	2.35818	1.4	1.06042	1.72	1.52032	16.54	13.99588	9.1	9.19749
11	20.00	33≤d≤45	3.28	3.46867	2.1	1.78932	2.31	2.42807	19.33	20.39574	7.95	7.79899
12	30.00	33≤d≤45	4.14	4.57915	2.6	2.51823	3.1	3.33583	24.91	26.7956	6.66	6.40049
13	40.00	33≤d≤45	5.5	5.68964	3.5	3.24714	3.95	4.24359	32.11	33.19546	5.01	5.00199
14	10.00	50≤d≤62	2.51	2.28746	1.2	0.76875	1.44	1.26555	11.49	10.21735	9.44	8.42981
15	20.00	50≤d≤62	2.99	3.39794	1.83	1.49766	1.88	2.17331	14.43	16.61721	8.21	7.83685
16	30.00	50≤d≤62	3.88	4.50843	2.31	2.22656	2.78	3.08106	22.86	23.01706	7.33	7.24389
17	40.00	50≤d≤62	4.93	5.61892	3.12	2.95547	3.71	3.98882	27.16	29.41692	6.02	6.65093

Table 3: Training data for properties of Epoxy

No	Alumina added (%)	Particle size (μm)	Measured E (GPa)	Predicted E (GPa)	Measured G_c (KJ/m²)	Predicted G_c (KJ/m²)	Measure d K_c (MPa√m)	Predicted K_c (MPa√m)	Measured HB	Predicted HB	Measured WR	Predicted WR
1	.00	.00	1.5	1.40995	1.16	1.00063	1.29	1.19703	13.02	16.26443	17.34	14.20515
2	10.00	d≤8.00	2.3	2.48715	1.5	1.59228	1.91	1.98489	23.11	20.88615	8.11	10.59738
3	20.00	d≤8.00	3.62	3.59764	2.2	2.32119	2.71	2.89265	28.74	27.28601	6.31	7.72995
4	30.00	d≤8.00	4.67	4.70812	2.7	3.0501	3.69	3.8004	32.15	33.68587	5.16	4.86253
5	40.00	d≤8.00	5.88	5.81861	4.1	3.77901	4.93	4.70816	43.05	40.08572	3.1	1.9951
6	10.00	18≤d≤25	2.55	2.42891	1.62	1.35209	2.05	1.77508	21.12	17.77442	8.65	9.96517
7	20.00	18≤d≤25	3.34	3.53939	1.99	2.08099	2.56	2.68284	23.18	24.17428	6.32	7.76113
8	30.00	18≤d≤25	4.88	4.64988	2.44	2.8099	3.34	3.5906	27.48	30.57413	5.71	5.55709
9	40.00	18≤d≤25	5.66	5.76036	3.82	3.53881	4.65	4.49835	35.86	36.97399	4.16	3.35305

Table 4: Testing data for properties of Epoxy composite

No	Alumina added (%)	Particle size (μm)	Measured E (GPa)	Predicte d E (GPa)	Measured Gc (KJ/m2)	Predicte d Gc (KJ/m2)	Measure d Kc (MPa√m)	Predicte d Kc (MPa√m)	Measured HB	Predicte d HB	Measured WR	Predicte d WR
1	10.00	33≤d≤45	2.82	2.35818	1.4	1.06042	1.72	1.52032	16.54	13.99588	9.1	9.19749
2	20.00	33≤d≤45	3.28	3.46867	2.1	1.78932	2.31	2.42807	19.33	20.39574	7.95	7.79899
3	30.00	33≤d≤45	4.14	4.57915	2.6	2.51823	3.1	3.33583	24.91	26.7956	6.66	6.40049
4	40.00	33≤d≤45	5.5	5.68964	3.5	3.24714	3.95	4.24359	32.11	33.19546	5.01	5.00199
5	10.00	50≤d≤62	2.51	2.28746	1.2	0.76875	1.44	1.26555	11.49	10.21735	9.44	8.42981
6	20.00	50≤d≤62	2.99	3.39794	1.83	1.49766	1.88	2.17331	14.43	16.61721	8.21	7.83685
7	30.00	50≤d≤62	3.88	4.50843	2.31	2.22656	2.78	3.08106	22.86	23.01706	7.33	7.24389
8	40.00	50≤d≤62	4.93	5.61892	3.12	2.95547	3.71	3.98882	27.16	29.41692	6.02	6.65093

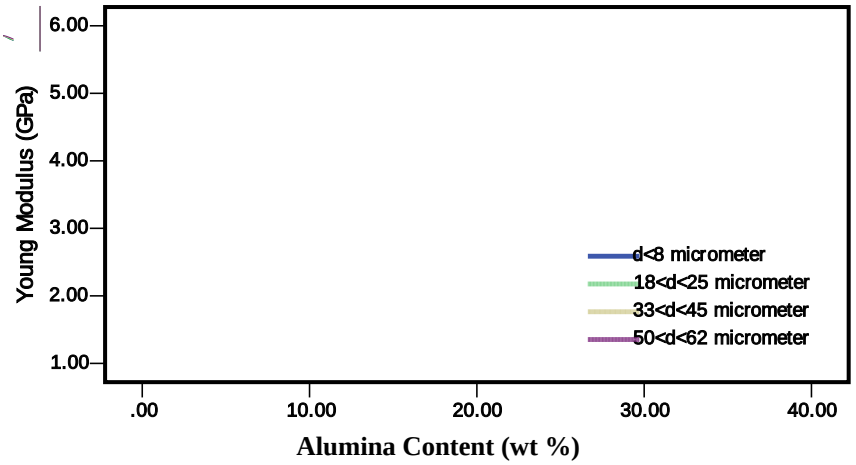

Figure 1: Variation in flexural modulus of different particle size alumina with varying concentration

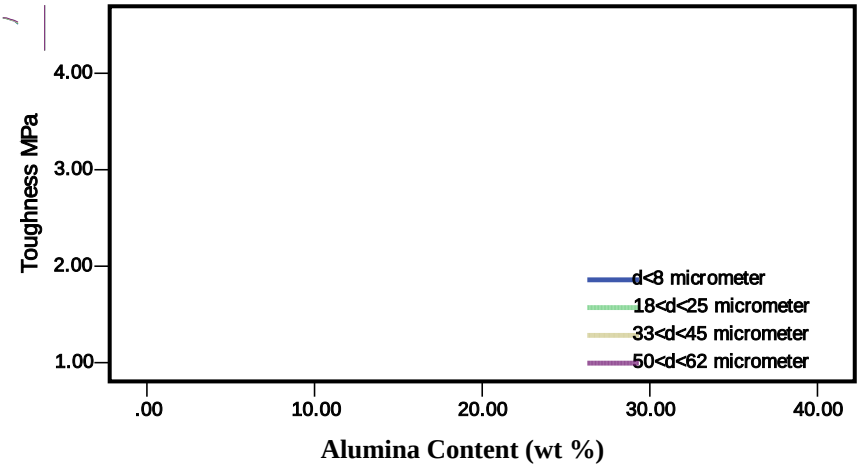

Figure 2: Variation in toughness of different particle size alumina with varying concentration.

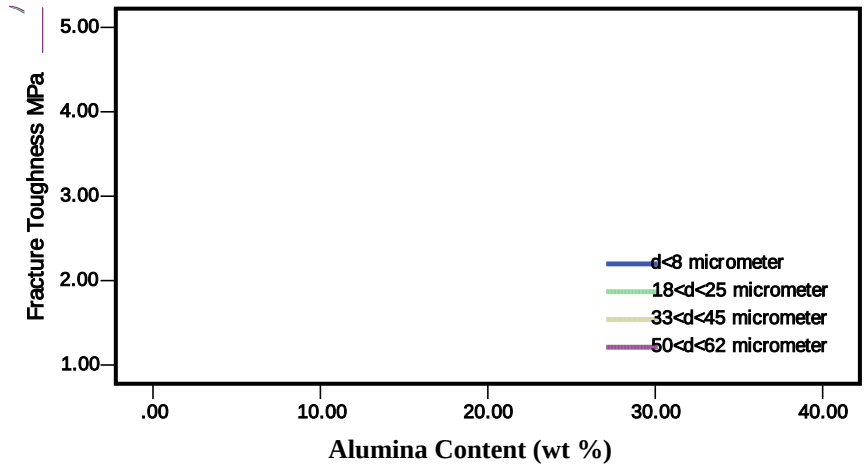

Figure 3: Variation in fracture toughness of different particle size alumina with varying concentration.

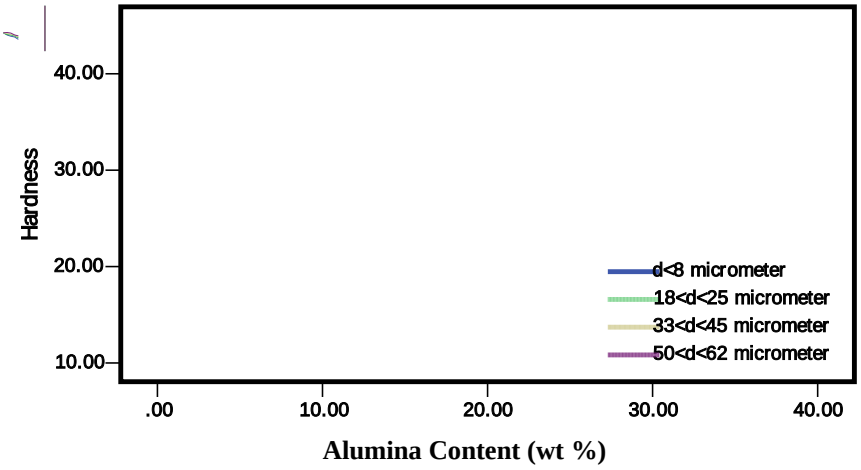

Figure 4: Variation in hardness of different particle size alumina with varying concentration.

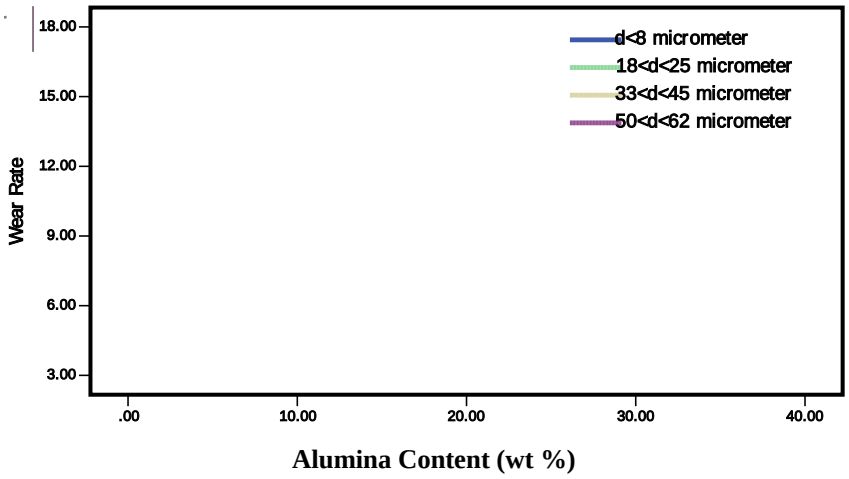

Figure 5: Variation in wear rate of different particle size alumina with varying concentration.

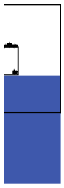

Figure 6: comparison between hardness and wear rate of Epoxy composite

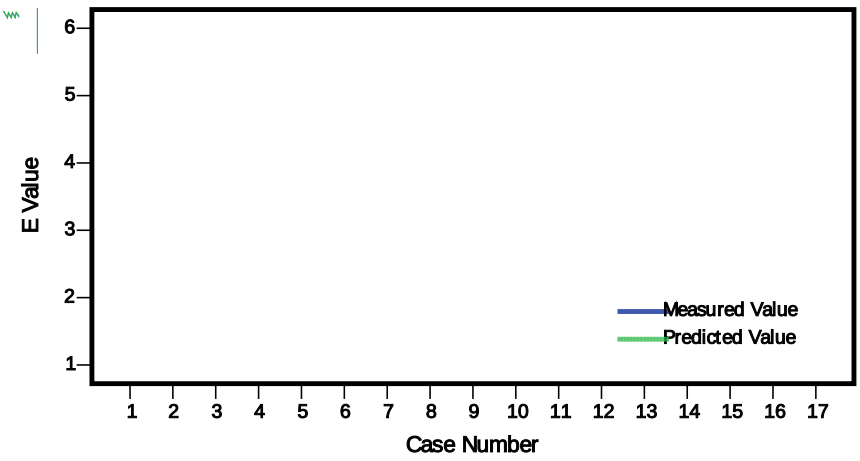

Fig 7: Comparison between Measured and Predicted values for the experimental data for flexural modulus of material

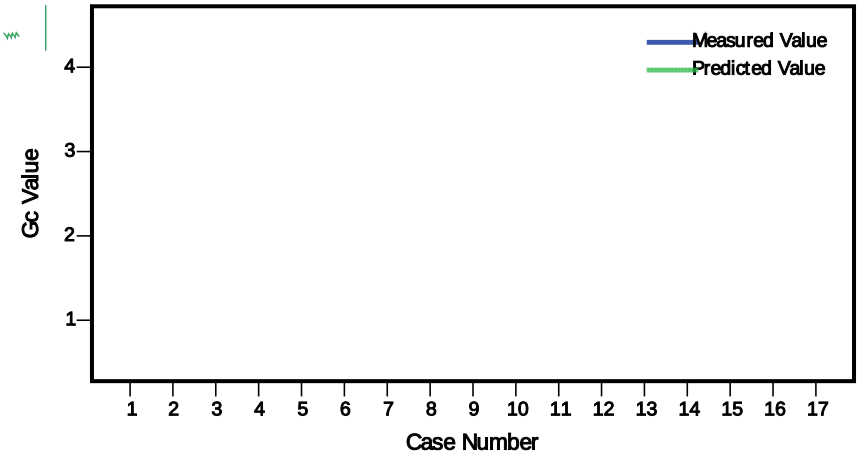

Fig 8: Comparison between Measured and Predicted values for the experimental data for toughness of material

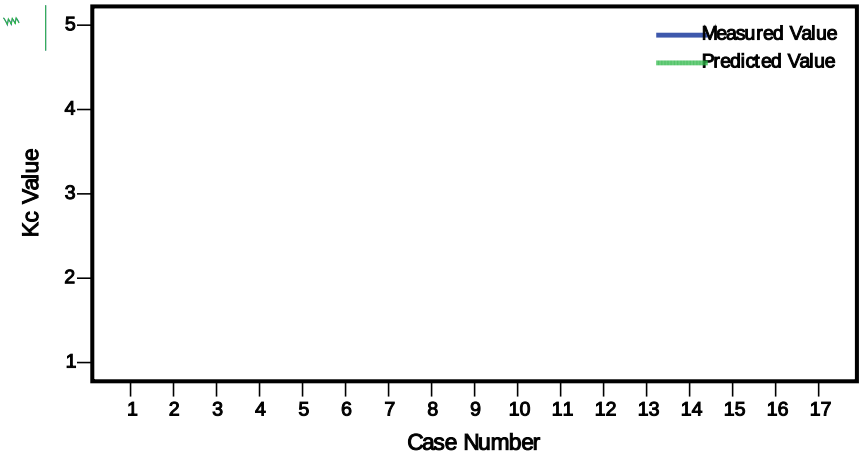

Fig 9: Comparison between Measured and Predicted values for the experimental data for fracture toughness of material

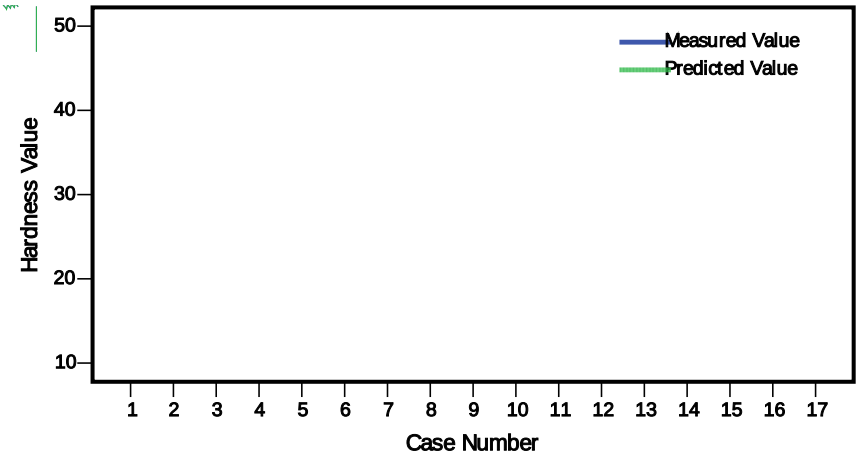

Fig 10: Comparison between Measured and Predicted values for the experimental data for hardness of material

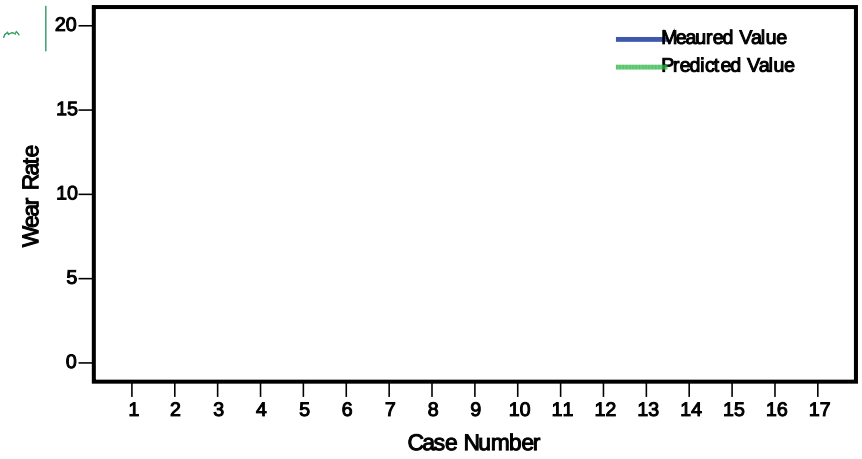

Fig 11: Comparison between Measured and Predicted values for the experimental data for wear rate of material

7. REFERENCE :-

- Alvarez, V.A., Valdez, M.E., Vasquez, A., 2003, "Dynamic mechanical properties and interphase fiber/matrix evaluation of unidirectional glass fiber/epoxy composites", Polymer Testing, Vol. 22, pp.611-615.

- Bennet, J.A., Young, R.J., 1998, "The effect of fiber-matrix adhesion upon crack bridging in fiber reinforced composites", Composites Part A: Applied Science and Manufacturing, Vol.29, pp.1071-1081.

- Borgioli F., Galvanetto E., Iozzelli F., and Pradelli G., 2005, "Improvement of wear resistance of Ti–6Al–4V alloy by means of thermal oxidation,"Materials Letters, vol. 59, no. 17, pp. 2159– 2162.

- Fellahi, S., Chikhi, N., Bakar, M., 2001, "**Modification** of Epoxy Resin with Kaolin as a Toughening Agent", Journal of Applied Polymer Science, Vol. 82, pp. 861 – 878.

- J. O. Osarenmwinda, and J.C. wachukwu, 2010, " Empirical models for estimating properties of developed composite material from agro waste", Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), Vol. 1, No. 2, pp. 179-183.

- Mair L. H., Stolarski T. A., Vowles R. W., and Lloyd C. H., 1996, "Wear: mechanisms, manifestations and measurement. Report of a workshop," Journal of Dentistry, vol. 24, no. 1–2, pp.141-148.

- Mandikos M. N., McGivney G. P., Davis E., Bush P. J., and Carter J. M., 2001, "A comparison of the wear resistance and hardness of indirect composite resins," Journal of Prosthetic Dentistry, vol. 85, no. 4, pp. 386–395.

- Matthews. F.L., Rawlings. R.D., 1994, "Composite Materials: Engineering and Science", United Kingdom: Chapman & Hall.

- Pearson, R. A., Yee, A. F., 1991, "Influence of Particle Size and Particle Size Distribution on Toughening Mechanisms in Rubber-Modified Epoxies", Journal of Materials Science, Vol. 26, pp. 3828 – 3844.

- Seghi R. R., Rosenstiel S. F., and Bauer P., 1991, "Abrasion of human enamel by different dental ceramics in vitro," Journal of Dental Research, vol. 70, no. 3, pp. 221–225.

- S. Jayabal, and U. Natarajan, 2011, "Influence of fiber parameters on tensile, flexural, and impact properties of nonwoven coir–polyester composites", The International Journal of Advanced Manufacturing Technology , Vol. 54, Issue 5-8, pp 639-648.

- Tanimoto Y, Kitagawa T, Aida M, Nishiyama N., 2006, "Experimental and computational approach for evaluating the mechanical characteristics of dental composite resins with various filler sizes", Acta Biomater. Vol.2, No.6, p.633.

- Yap A. U. J., Teoh S. H., Hastings G. W., and Lu C. S., 1997, "Comparative wear ranking of dental restorative materials utilizing different wear simulation modes," Journal of Oral Rehabilitation, vol. 24, no. 8, pp. 574–580.

- Zhang, Man, 2003," A Review of the Epoxy Resin Toughening", Syracuse University, New York.