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Sudad I. Younis

Department / Registrar of University of Technology Baghdad, Iraq

Jawad K. Oleiwi

Department of Materials Engineering**,** University of Technology , Baghdad, Iraq

Reem A. Mohammed

Department / Registrar of University of Technology Baghdad, Iraq

ra_aljubory@yahoo.com

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Some Mechanical Properties of Polymer Matrix Composites Reinforced by Nano Silica Particles and Glass Fibers

Abstract- *This research studied the effect of nano silica particles on wear behavior test , ultimate tensile strength ,impact strength, fracture toughness and hardness shore D of specimens composite material. The hand-lay-up method is used to preparation of specimens established from unsaturated polyester resin matrix reinforcement with 4% weight fraction glass fiber (chopped / woven) mat and 1%, 3%, 5% weight fraction of nano silica particle. The nano silica particles used in this study has an average size of (less than 45nm). The results showed that the specimen (up+4% woven glass fiber+5% nano SiO_2) gives better mechanical properties include ultimate tensile strength, impact strength, fracture toughness and hardness shore D (110 MPa, 13.7 K.J/m^2, 18.92 MPa.$m^{1/2}$, 85 shore D) respectively,when compare other specimens. The wear rate decreased from (22.5×10^{-4} cm^3/N.m) for specimen (pure unsaturated polyester resin) to (0.18×10^{-4} cm^3/N.m) for specimen (UP+4% woven glass fiber +5% nano SiO_2) under parameter 7N (load), 15 minutes (sliding time), 2m/s (sliding speed) and (7 cm) sliding distance.*

Keywords- *Nano composites, Wear rate behavior, Tensile strength, Impact strength, Hardness shore (D).*

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1. Introduction

Composite materials can be defined as a heterogeneous material consists from two or more solid phases, that is in close contact with each other on a microscopic scale. It can also be consider homogeneous material on a microscopic scale and in the sense that any part of it will have the similar physical properties. The most composite material consists of a bulk matrix and reinforcement of some kind added primarily to increase the hardness and strength of the matrix [1]. Nano composite materials are a class of materials that are one or more of the phases with nano scale dimensions 0-D, 1- D, and 2-D embedded in ceramic, metal, or polymer matrix. The properties of nano composites are based on a variety of variables, especially matrix material, which can show dimensions of the nano scale, the degree of dispersion, size, loading, shape, orientation of the Nano scale second phase and interactions between the matrix and the second phase [2-4]. Nano materials have a typical grain size of less than100 nm,whilst micro materials is characterized by grain size of less than 500 nm [5]. The unsaturated polyester resins are widely used in various applications, making the thermosetting polymers very important. This resin strengthens with different fiber and filler in order to improve mechanical and physical properties, also the chemical properties of this polymer depend on cross- linking agents, initiators, diced, and other additives [6,7]. Silica commonly occurs in nature, such as silica sand, sandstone, and quartzite. Silica is used in the production of ceramics and silicate glasses, which are found in amorphous and crystalline form [8] .The silica is formed by strong directional covalent bonds and four oxygen atoms are arranged in quadrilateral angles around the central silicon atom [9]. The wear behavior is damage to the hard surface, usually involving gradual damage of materials because the relative movement between this the material contact and surface [10]. The wear resistance of polymer composite material may be increased or decreased according to size distribution, size particle, type of the particles, state of dispersion the particles in the composite , particle content and interracial actions between matrix resin and particle. Pin on disk mode wear test based on different conditions like sliding velocity; load applied load; sliding distance; counter face and

humidity [11]. S. Basavarajappa , et. al [12]studied the effect of the graphite and silicon carbide on dry wear behavior for epoxy resin matrix reinforced with glass fiber composite materials. The method used in the manufacture of polymeric composite is hand lay up method. The composition of composite material was (40% epoxy, 40, 50, 60% glass fiber, 10% SiC and Graphite),sliding distance (3,4,5 m/s), load (20 , 40 ,60 N) and sliding distance (1000 , 2000, 3000 m). The authors concluded that the sample (40% epoxy + 40% v.f glass fiber + 10% v.f SiC + 10% v.f graphite) has wear resistance higher when compare with other composite samples. Also,it was noted that the sliding distance and load is more effect in the wear of the composite than sliding speed. Jawad [13] studied the wear rate of polyester resin reinforced by silica ceramic particles. A Pin -on- disc wear testing machine of variable speed has been used. The composite specimens were made from unsaturated polyester resin as a matrix and silica particles as the reinforcement with different weight fractions (5%, 10%, 15% and 20%) with two different grain sizes (25 μm and 125μm).The results show the wear rate increases with load and sliding speed increase, also the author found that the wear rate decreases with weight fraction increase and decrease the grain size of the reinforcing particles. The optimum wear resistance has found in the sample (UP+ 20% SiO_2) with grain size of (25 μm). Srinivasa Moorthy and Manonmani [14] studied the dry sliding wear behavior for glass fiber filled with TiO_2 powder in the (UP) resin matrix. Composites content of 30%, 40% and 50% weight fraction glass fiber with 2%,5% and 9% weight fraction TiO_2 powder and used different fiber lengths 1, 2 & 3 cm . The result shows the experiments using the Taguchi's orthogonal array the fiber content has main greater effect on wear, also the increasing of fiber content the wear resistance increases. Other parameters such as speed and load have a large role in wear rate. The aim of this research is a studying the effect of nano silica reinforced with two kind glass fiber (woven,chopped) into unsaturated polyester resin matrix on some mechanical properties of composite materials that used mainly in the different application such as gears, helicopter blades, artificial joints and many bearing applications.

2. Experimental Work

I. Materials Used in Preparation of Composite Materials

The unsaturated polyester resin is used as the matrix in this research has density(1.1gm/cm^3) supplied by (PERFECT POLYMERS FZ-LLC / UAE - Dubai) reinforced with two types of glass fiber (woven / chopped) mat supplied by Tenax company, England and it was density of (2.48 gm/cm^3). The Nano-silica particles are used as filler in the preparation of specimen polymer composite materials provided by the Nano Shell Company (USA) has a density of (2.7 gm/cm^3) and the average size was (less than 45 nm). The dimensions of the mold used in this study to preparation the specimens composite materials were (160×160×4 mm). Table (1) displays the designation and composition of unsaturated polyester resin, glass fiber and nano SiO_2 particles.

Table 1: Compound of the specimens

Specimens	Compound
1	Pure unsaturated polyester resin
2	UP+4% Woven Glass fiber
3	UP+4% Woven GF+1% Nano SiO_2
4	UP+4% Woven GF+3% Nano SiO_2
5	UP+4% Woven GF+5% Nano SiO_2
6	UP+4% Chopped Glass fiber
7	UP+4% Chopped GF+1% Nano SiO_2
8	UP+4% Chopped GF+3% Nano SiO_2
9	UP+4% Chopped GF+5% Nano SiO_2

II. Wear Behavior Test

The wear behavior test is carried on a Pin-On-Disc as per ASTM G 99 [15]. To guarantee intimate connect between the specimen surface and the disk surface of the rotor must be polished all the specimens by emery paper. Also, before the test both the specimens and rotating disc must be clean with acetone. Test wear behavior done at different variables, normal load 3N, 5N, and 7 N, sliding velocity 2 m/s, sliding time 15 minutes (900 second) and sliding distance 7 cm. The specimens used in this test have been cut into the dimensions (30*10*4mm). The equation (1) and (2) is used to determine the wear behavior rate [16]. $Wr \frac{Wv}{Vs.Fn}$ (1)

$$Wv = \frac{\text{Mass loss}}{\text{Density} * \text{time}} \quad (2)$$

Where:

Wr: Wear rate (cm^3/N.m).

Mass loss: Weight specimens before and after running (gm).

Density: Density of composite material (gm/cm^3).

Time: Duration of the test (sec).

Vs:Sliding velocity (m/sec).

Fn: Load (N).

III. Tensile Strength Test

The tensile strength test for specimens were prepared according to the ASTM (D-638) at room temperature [17]. The dimension of tensile strength is shown in figure (1).

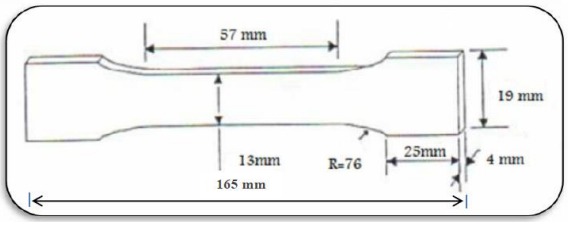

Figure 1: Standard specimens for tensile strength test

IV. Impact Test

The impact test for specimens were prepared according to the ASTM D4812, ISO180 at room temperature [18-20]. The dimension of impact specimen is shown in figure (2). Impact strength and fracture toughness can be calculated using the following relationship [21]:

$$Gc = \frac{Uc}{A} \quad (3)$$

Where

G_c= Impact strength (J/m^2).

U_c=Impact energy (J).

A= cross sectional area of sample (m^2)

Fracture toughness can be expressed as [22,23].

$$Kc = \sqrt{Gc\ E} \quad (4)$$

Where:

K_c= Fracture toughness (MPa.m$^{1/2}$).

E= Flexural modulus (MPa).

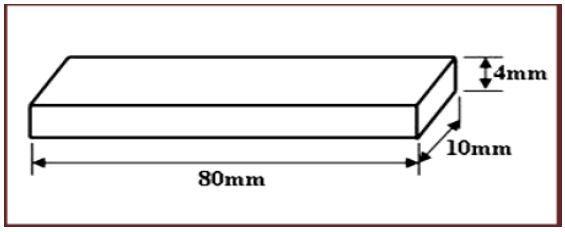

Figure 2: Standard specimens for impact test.

V. Hardness Test (Shore D)

The shore D hardness test was used to measure resistance to permanent indendation depend to ASTM-2240[24, 25].

3. Discussion of Results

I. Wear Rate Behavior

Figures (3 & 4) show the relationship between applied normal load and wear rate for the unsaturated polyester resin reinforced with 4% weight fraction (woven /chopped) glass fiber and (1%, 3% & 5%) weight fraction nano SiO_2 particles. Figures indicate that increases applied normal load (3N to 7N) leads to increases the wear rate values, where wear rate values of the specimen (Pure unsaturated Polyester) was more than specimens reinforced with (woven/chopped) glass fiber and nano SiO_2 particle for all values of normal load. The reason is at these values of loading the fiber and particle acted as a load bearing element between the surface contacts, this result agrees with [13]. From Figure (3) can be seen the specimen (up+4%woven fiber+5% nano SiO_2) give wear rate resistance (0.18×10^{-4} cm^3/N.m) better than other specimens at the same applied normal load (7N), also from Figure (4) can be seen the specimen (up+4% chopped fiber+5% nano SiO_2) give wear rate resistance (0.21×10^{-4} cm^3/N.m) better than other specimens at the same applied normal load (7N). When an applied load on the specimens polymeric composite it is transferred load to the fiber and particle by a shearing mechanism between the reinforced materials and resin matrix. Since the bond was good the shearing mechanism creates the stress distribution across the reinforced / matrix interface [14]. Also form results can be noted the specimens reinfoced with woven glass fiber give wear rate resistance better than specimens reinfoced with chopped fiber, due to the wear rate depends upon both adhesion and abrasion [26], also the incorporation of nano SiO_2 particles into the unsaturated polyester resin with woven glass fibers improves natural bond between the reinforced materials and resin matrix more than compared with specimens reinfoced with chopped fibers.

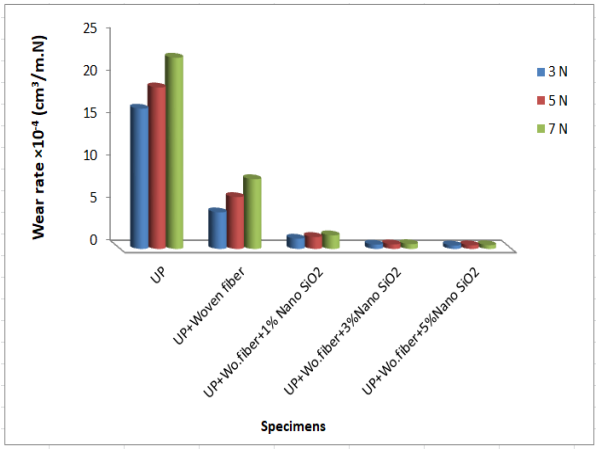

Figure 3: Effect of normal load on the wear rate for specimens reinforced with woven fibers.

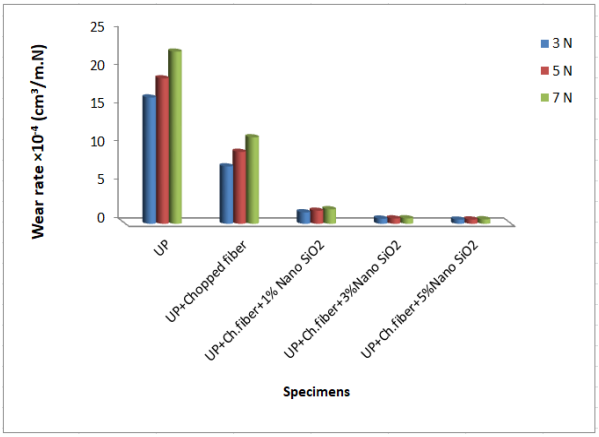

Figure 4: Effect of normal load on the wear rate for specimens reinforced with chopped fibers.

II . Ultimate Tensile Strength

Effect of nano SiO_2 particles strengthened with (woven /chopped) mat,glass fiber into unsaturated polyester resin illustrated in figure (5). The ultimate tensile strength values to improve significantly when addition, 4% (woven / chopped) glass fiber and nano SiO_2 particles than unsaturated polyester resin without any reinforcements. This is because the presence of (woven / chopped) glass fibers in a resin matrix to guaranty transmission of loads from matrix resin to (woven /chopped) fiber glass. Mostly unsaturated polyester resin matrix is much weaker in strength than samples with strengthening fibers and nano particles, since the resin matrix alone is unable to resist the tensile force applied on it and fails with strength, lower than specimens with strengthening with fibers and particles that withstand the tensile load [27]. Then, it can be observed the specimens reinforced with woven glass fiber gives higher value ultimate tensile strength than specimens reinforced with chopped glass fiber, due to the alignment and the length of woven glass fiber leads to distribute the load on the length of fibers this result agree with the work of [28]. Whilst in specimens reinforced with chopped glass fiber the load is concentrated at the end of the short fibers and also the alignment of fibers in the matrix which make the control transmission of the load from the matrix to the fiber through the interface region is weak [29, 30].

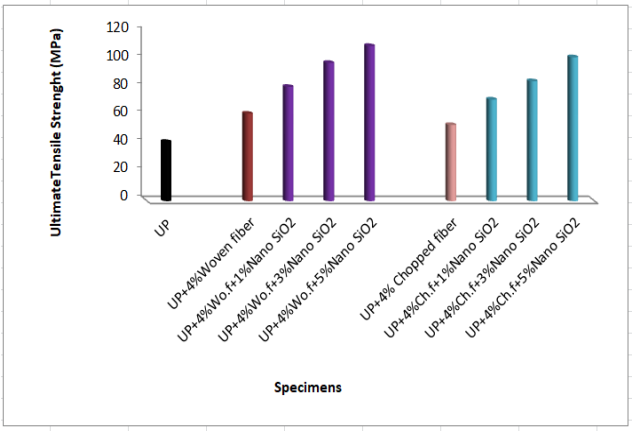

Figure 5: Ultimate tensile strength of specimens composite.

III. Impact Strength and Fracture Toughness

The results of impact strength and fracture toughness for all specimens nano composite can be seen in figures (6&7). The result shows that the specimen pure unsaturated polyester resin has lower value impact strengths and fracture toughness than specimens reinforced with (woven /chopped) glass fiber because the presence of fiber needs more absorbent energy for the fracture [31]. Also,it can be seen that the impact strength and fracture toughness value of the specimens reinforced with 4% woven glass fiber and nano particles are higher than specimens reinforced with 4% chopped glass fiber and nano particles, this is because the presence of nano particles with woven glass fiber leads to a stronger bonding between the matrix material and the reinforcing material this results agree with the work of [32, 33].

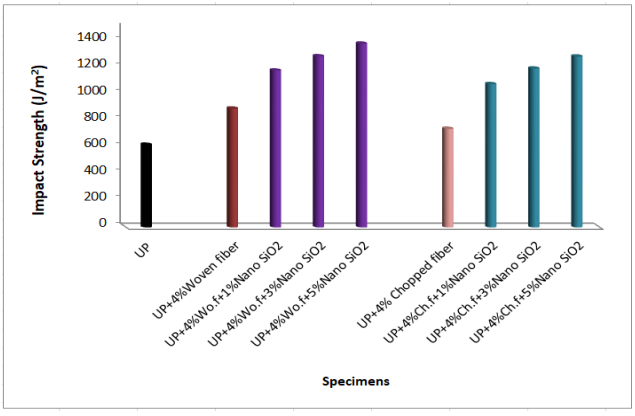

Figure 6: Impact strength of specimens composite.

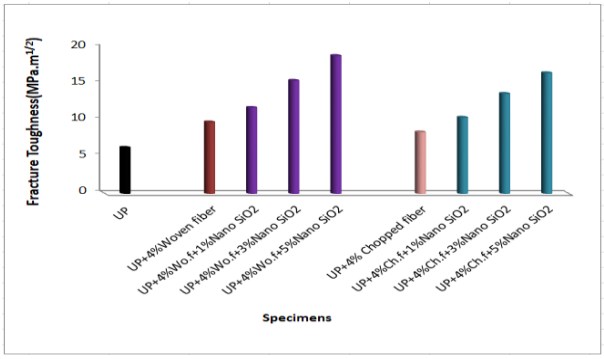

Figure 7: Fracture toughness of specimens composite.

IV. Hardness shore (D)

Hardness shore (D) describes the resistance to surface indentation of the material. The variations on the hardness value of the nano composite materials are shown in the Figure (8). The addition of nano SiO_2 filler improves the hardness shore D, due to the brittleness and high hardness of nano particles as compared to pure unsaturated polyester resin, moreover , related to the bonding strength between the resin matrix and reinforced materials, to make the harder surface by restricting the movement of the unsaturated polyester resin chains towards the stress that is applied on it [34]. The hardness shore (D) value improved to 14% for specimen (up+4%woven fiber+5% nano SiO_2) and (12%) for specimen (up+4% chopped fiber+5% nano SiO_2) when comparing with value hardness shore D for pure specimen. The reason behind this behavior is that the improved mechanical properties associated with the addition, nano particles, as well as has a good compatibility between components of composite materials, this results agree with [35,36].

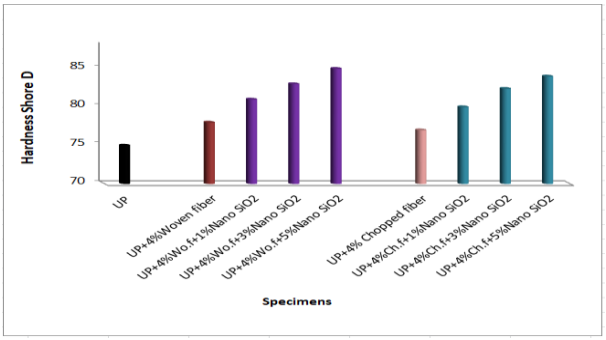

Figure 8: Hardness shore (D) for specimens composite.

4. Conclusions

The most important conclusions of this study are:-

1. The wear behavior rate and ultimate tensile strength , impact strength , fracture toughness and hardness shore (D) can be improved by addition glass fiber mat (woven / chopped) and nano SiO_2 particles
2. Wear rate increases with increases the load, but decreases with increase of weight fraction nano SiO_2 particles.
3. Specimens (UP+4%woven fiber and UP+4% chopped fiber), have better wear rate resistance than specimen (unsaturated polyester resin) and also specimens (UP+4% woven fiber+5% Nano SiO_2 and UP+4% chopped fiber+5% Nano SiO_2) have exhibited better wear rate resistance than other specimens .
4. Specimens (UP+4% woven fiber+5% Nano SiO_2 and UP+4% chopped fiber+5% Nano SiO_2) have the maximum ultimate tensile strength, impact strength , fracture toughness and hardness shore D when compared with other specimens.
5.

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Sudad I.Younis , Faculty member of Department of Laser and Optoectronics Engineering /University of Technology, Baghdad/Iraq . Phd in Mechanical Engineering, his field research interests are fluid mechanics , flow properties , heat transfer , Mechanical and Physical properties of composite materials . Has three published papers in the Journals. Dr. Sudad is member of Iraqi union of Engineers since 1988 , member of Iraq aircraft engineering Advisory organization (2000-2003) and the Registrar of University of Technology since 2009.

Jawad K. Oleiwi, Faculty member of Department of Materials Engineering/ University of Technology, Baghdad/ Iraq. His field research interests are composite materials, biomaterials, implants, prosthetic materials and mechanical tests. He has more than 40 published papers in journals and conferences and has two patents in field of composite materials. Dr. Jawad is member of Iraqi union of Engineers since 1990 and member of Iraqi Society of Nanotechnology.

Reem Alaa Mohammed Faculty member of Department of Materials Engineering / University of Technology, Baghdad/ Iraq. Her field research interests are waste Recycling Materials, Composite Materials, Mechanical and Physical properties. She has published more than 10 articles inside Iraq , Book published in LAMBERT Academic and has Patented in Coating of laboratories Drainage pipe and oil products pipes