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The Influence in Tensile and Impact Strength of Composite Material in Case of Curing Fiberglass with Nano Silica

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ABSTRACT

In the resent decade, the composite materials became commonly used in different fields and sectors, specially in the airplane industry, military industry and spacecraft manufacturing. This widespread of using composites make scientists focusing their attention on studying the methods for improving the mechanical properties. In this research, the study concerned the growth and degradation in tensile and impact strength when curing the fiberglass with N. silica and used these fibers as a reinforcement material with epoxy in composite material. The methodology that adopted in research is preparation nanoparticle suspension that contains (1wt%, 3wt% and 5wt% SiO2 respectively) and H2O. The mixing of SiO2 and H2O done by using magnetic stirring and ultrasonic for disperse nano particles after that drying the fibers to remove the moisture, after that using the fibers as a reinforcement material with epoxy. The key findings were increasing the impact strength with percentage 43% as compared to control case (EP+2layers fiberglass) in the case of using samples fabricated of epoxy and 2 layers fiberglass immersed in (N.P.S) contains 1wt%SiO2 and 99wt% H2O. In general results of tensile decreased after curing the fibers with (N.P.S).

1. Introduction

In resent, the demand for composite materials has increased due to their wide applications in industrial and military fields, including the automotive , aircraft and spacecraft industries, as well as in the construction structures of large buildings and in the medical field, due to the good specifications of composite materials, such as high strength, specific strength to weight, light weight, thermal stability, high shock resistance for some types, relatively low price, thermal insulation, etc. These properties have made composite materials a good alternative to metals such as iron, copper and aluminum [1].

The composite materials consist of material that form the matrix like polyester, epoxy, vinyl ester, and polyurethane are used to protect the fiber from harm and transfer the stresses to fibers.

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Scientific experiments and researches have demonstrated that composite materials are more durable and stronger when fiber is used as a reinforcement material for composite material. The increase in weight ratio or volumetric ratio of fibers means the more durable the composite material is, unlike materials that do not contain fiber [2].

Many researchers have begun to study the factors that affect the mechanical properties and weaken them in composite materials in order to avoid or reduce their effects, such as temperature, humidity, the effect of chemicals that interact with composite materials, whether from the environment or through direct with composite materials, as in marine oil pipelines, or the effect of storage period on mechanical properties, or exposure of composite materials to high temperatures for a long period.

[3] Explained the effects of immersion composite materials in HCl and (NaOH) in the mechanical properties of fiberglass reinforced polymer. The study was conducted that the flexural strength and flexural modulus decrease with exposure time, the decrease was more in case of alkaline solutions than acids solutions. The same tendency was noticed in impact strength.

[4] Several researchers have found that water absorption by composites causes degradation of matrix dominated quasi-static properties.

In the same vein, many researchers have been studying the improvement of the mechanical properties of composite materials by adding nanomaterials to the composite materials.

[5] The researchers were used unsaturated polyester resin (UPR) and added nano silica with 10nm particle size with different weight ratios (0.5,1,2,3,and 4%),The results were gained that 0.5% nano silica addition is the best by development the mechanical properties of composite, up to 30.45% for tensile, 33% for compression, 17.8% for flexural, a slightly 10% increase for impact test and it showed an overall 27% better performance than the pure UPR. This enhancement in mechanical properties created from the ability of nano silica particles with their small size to fill porous regions crack and voids which give good adhesion with the matrix.

[6] In this study the researchers were studied the effect of nano SiO2 with epoxy on tensile and flexural properties. The nano silica was added with epoxy in different weight percentage (0,2,4,6 and 8%). The composed were produced using hand lay- up method. The results were done on the samples indicated that nano SiO2 with epoxy up to weight fraction 4% gives better result as compared to neat epoxy, more than 4% decreases due to agglomeration. The tensile strength was increased up to 30.57%, flexural strength was increased up to 17% and flexural modulus was increased up to 76% as compared to pure epoxy.

[7] The research showed the growth in mechanical properties of thermosetting epoxy polymer when adding nano SiO2 ranging from 1 to 4 weight percentage. The tests (tensile, impact resistance, hardness, flexural) results indicated that weight ratio 3 % of nano SiO2 gives best result as compared to 1% and 2%, in 4wt% of nano SiO2 results began decreasing due to agglomeration. The development in mechanical properties was created from increase the bonding force between nano silica particles and matrix and the distribution for nano particles was homogeneous when nano SiO2 ranging from 1 to 4 weight ratio, beyond this point, the agglomeration starts to form and cause weak areas in matrix and finally decreasing the values of mechanical properties.

[8] The research studied the effect of addition of silicon dioxide filler in different weight percentage with vinyl ester and aramid fiber composites. The percentages

weights were [0,5,10,20 and 30%). The laminated produced using hand layup process. The results of tests (tensile, hardness, flexural resistance) that adding silicon dioxide filler produces an increasing in the results as compared to pure specimens and the best results were at 20% of silicon dioxide, more than 20% decrease in the results. This is because filler particles act as a bulkhead in transferring stress from one point to another, and an increase in silica weight ratio beyond 20wt% result increasing the transfer of stress through matrix to fibers.

[9] Experimentation was done to discover the effect of filler material like Titanium oxide and silicon carbide with glass/epoxy fiber reinforced polymer composites. The nanomaterials were added in different weight percentage (0,5, and 10%). Composites were produced using hand layup. The targeted tests were (tensile strength, flexural strength, and impact strength), then compared the results with the results that were gained from pure specimens. The better results were in weight ratio 5% of silicon carbide in tensile test, after 5% the results decreased. In weight ratio 5% of silicon carbide the highest flexural strength and impact strength. In the hardness test, the highest value was in 10% of silicon carbide.

There are also a group of scientists and researchers worked on studying the development of the mechanical properties of composite materials by processing fiberglass.

[10] In this work, Jute fiber has been used as a reinforcement and epoxy as a matrix material, the composite was manufactured by using hand layup, Firstly the natural fibers were heated at 80C to remove the moisture, The research focused in heating the composite at temperature ranging from (80C to130C). The researchers were conducted that with increasing in curing temperature the impact strength decrease but tensile and flexural strength increase. This result is compatible with the inversely relation that connect tensile with impact strength in composite materials.

[11] This research depended on additional surface modifications to fibers to enhance the mechanical properties of the composite material. The basalt fibers were immersed in the chemical for a different length of time. The laminates were produced by using a wet layup process and compression cured. The research was explored that immersing the fibers in nitric acid improve the tensile, impact, and flexural strength of the BF/Epoxy composites. The mechanical properties of the laminate improved when nitric acid treatment time was increased to 30 min from 15 min. This due to increase the area of reaction and increase the bonding force between fibers and epoxy.

Before delving into the aim of research and research topic, we will expose to nanomaterial, fiberglass and polymers.

1.2 Nano Materials: The key elements of nanotechnology are the nanomaterials. Nanomaterials are defined as materials that at least one of their dimensions is in the nano scale as example smaller than 100nm based on their dimensionalities. We can divide nanomaterials into four different classes according to their size as follows.

1. Zero-dimensional nanomaterials:
   The nanomaterials in this class have all their three dimensions in the nanoscale range as example nano particles.
2. One-dimensional nanomaterials(1-D): the nanomaterials in this category have one dimension more than nano scale for example nanotube and nanowire.
3. Two-dimensional nanomaterials(2-D): the nanomaterials in this category have two dimensions more nano scale, for example nano sheets and nano films.
4 Three dimensional nanomaterials(3-D): in this category, the materials are not confined to the nano scale in any dimension, this category contains bulk

powders, dispersion of nano particle arrays of nanowire.

We can classify the nano particles in three categories according to their composition (organic, carbon-based and inorganic)

There are two factors that cause nanomaterial to make significantly differently than the same materials at larger dimensions, surface effects and quantum effects, these factors make nanomaterials display developed or novel mechanical, thermal, magnetic, electronic, optical and catalytic properties. Nanomaterials have different surface effects compared micromaterials or bulk materials. This behavior of nanomaterials is due to a very large surface of dispersed nanomaterials and high particle number per mass unit and the increasing fraction of atoms at the surface in nanomaterials and the atoms situated at the surface in nanomaterials have direct neighbors. As a consequence of these reasons, the chemical and physical properties of nanomaterials changed compared to their large-dimension counterparts.

The major factors of increasing the reactivity of nanomaterials are the large surface area and large surface to volume ratio of nanomaterials, this due to the larger reaction surface and lead to significant effects of surface properties on their structure.

The dispersity of nanomaterials is a major factor for the surface effects. When the size of nano particles decreases to the nano scale, the surface forces be a major reason in their adhesion, contact, and deformation behavior. The small size of nanoparticles offers the ability to fill cracks and voids that occurred in composite material. This behavior of nanomaterials improves the mechanical properties by increasing the bonding force. strong attractive interactions between particles cause the agglomeration and aggregation of nanomaterials which weaken the surface area of nanomaterials and the nanoscale properties. Agglomeration can be canceled or reduced by increasing the zeta potential of nanomaterials by optimizing the PH and the ionic strength of the suspension medium. Zeta potential is the potential difference existing between the surface of a solid particle immersed in a conducting liquid (e.g. water) and the bulk of the liquid [12].

1.3. Fiberglass:

Fiberglass is of brittle nature, being eminently covalently bonded material. In the stress-strain diagram of fiberglass is elastic complete and transfer directly to rupture. The most widely used forms of fiberglass are chopped strands, continuous or discontinuous mats or felts and fabrics or woven cloths. E-glass is the most widely used as a reinforcement in glass fiber reinforced polymer (GFRP) due to the relatively high properties and to the moderately low cost. The ultimate stress of (GFRP) is 130 KP/mm^2 and the modulus of elasticity is 45000 KP/mm^2. The main disadvantage of (E-glass) as compared with other more advanced fibers, is the value of Youngs Modulus which prevents composites of high specific stiffness

from being obtained. Below the average compositions of (E-fiberglass) [13].

Table (1) Average compositions for fiberglass-E

No.	Component	The quantity of component % in fiberglass
1	SiO2	52-56
2	Na2O	0-2
3	K2O	0-2
4	CaO	16-25
5	B2O3	8-13
6	Al2O3	12-16
7	MgO	0-6
8	TiO2	0-0.4
9	Fe2O3	0.05-0.4
10	F2	0-5

1.4. Polymers:

Polymeric composite materials are one of the most important materials used in the manufacture of mechanical parts because light weight, high specific strength as compared to metal, and poor conductivity. We can classify polymers in three categories according to technical specifications:

1. Thermosetting plastic: this polymer is characterized by low cost, resistance to heat and electricity, no recyclability and insoluble in organic solvent. Epoxy is used in this study and classified as thermosetting plastic.
2. Thermoplastic: the more features of this type of polymer are soften on heating, recyclability, and soluble in organic solvent.
3. Elastomers are characterized by the ability to restore its natural shape after being stretched to high elongation easily when the force removed from it, and high yield strength [14].

In this article, we will study the development in mechanical properties in composite materials named tensile and impact when using Epoxy and fiberglass treated with nano silica SiO2 with different proportional (1wt%, 3wt% and 5wt%) and H2O. The scientific rationale of using nano silica with fiberglass is the structure of fiberglass contains silica SiO2 therefore we expect there is harmony between fibers and nano silica. This will be done by testing and examining the manufactured samples and comparing the results occurred with results of samples that was not treated with nano silica and were considered as control case to knowledge the growth and degradation in the mechanical properties.

2. Experimental Work

2.1 Material used in preparation of composite material

Epoxy was used in a matrix type (sika Dur 52) produced by Sika company in (UAE), density of epoxy and hardener was 1.1kg/l, the mixing ratio was 2:1.

Epoxy resin was reinforced by two layers of fiberglass type E-Randomly have density 2.5 g/cm^3 and the nano material was silica SiO2, the particle size of nano silica was (30±5) nm and purity 99% and produced of Changsha San tech company in China. The nanoparticle suspension consists of water and weight ratios 1%, 3% and 5% silica respectively, the two components of mixture were mixed in magnetic stirring for 10 minutes, after that in ultrasonic for 15

minutes, finally fibers immersed in nanoparticle suspension for 1minute. The process of fabrication of samples was done by hand lay- up. The preparation of samples processed at room temperature and normal humidity. Table (2) shows the structural of samples produced in the research as mentioned below.

Table (2) explain the structures of samples that used in the research

Specimen	Component
1	Epoxy+2Layers of fiberglass (without immersion in nanoparticle suspension)
2	Epoxy+2Layers of fiberglass immersed in nanoparticle suspension consists of 1% silica and 99%water
3	Epoxy +2layers of fiberglass immersed in nanoparticle suspension consists of 3%silica and 97% water
4	Epoxy +2Layers of fiberglass immersed in nanoparticle suspension consists of 5% silica and 95% water

Figure (1) electrical scale

Figure (2) magnetic stirring

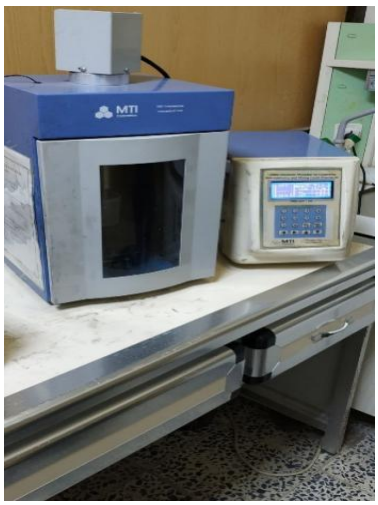


Figure (3) ultrasonic

Figure (4) Sika-dur52

Figure (5) fiberglass-E

Figure (6) Nano silica

2.2. Tensile strength test

The tensile strength test for specimens were done quadrate the ASTM (D638-14) at room temperature, and normal humidity. The tensile mold was fabricated with a sheet dimension (180*230) mm and a thickness of 3mm in two layers. See figure (7)

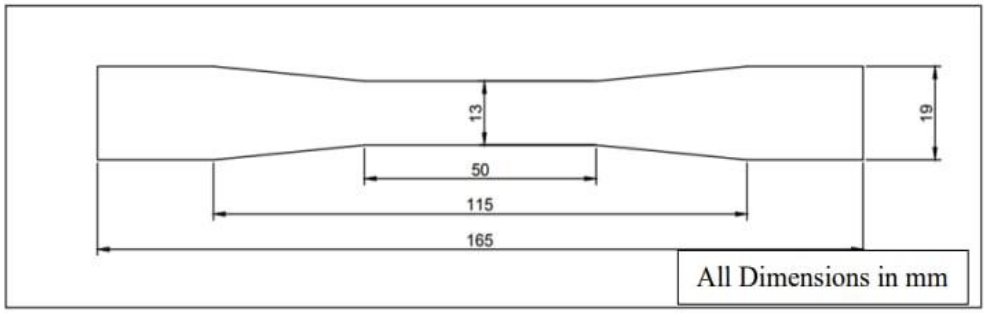


Figure (7) the dimensions of tensile sample

2.3. Impact strength test

The impact test for samples was prepared according to the ASTM (D256-04) at room temperature and normal humidity. The dimensions of impact mold were (120*150) mm and a thickness of 3mm in two layers, see figure (8).

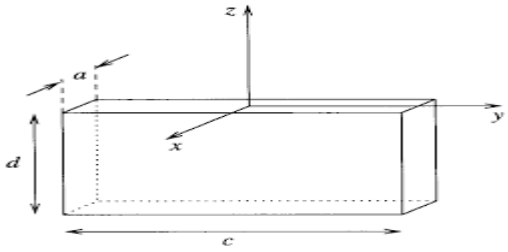


Figure (8) dimensions of impact sample

d=12mm, a=6mm, c=65mmImpact strength can be obtained using the following Role Gc=Uc/A where Gc= Impact strength (J/m^2), Uc= Impact energy (J)
A= cross sectional area.

Figure (9) Sharpy device

3. Results and Discussion

3.1. Ultimate Tensile stress

The resultants showed that the highest value of tensile strength test was in the control case (Epoxy and two layers of fiberglass without immersing in nanoparticle suspension). The maximum value was 45 MPa in the case above, in general the value of tensile strength was decreased when immersing fibers in nanoparticle suspension as shown in figure (10). This result led to the fact that nano particles changed the crystal structure of composite material and weakened the interfacial between the matrix and fibers

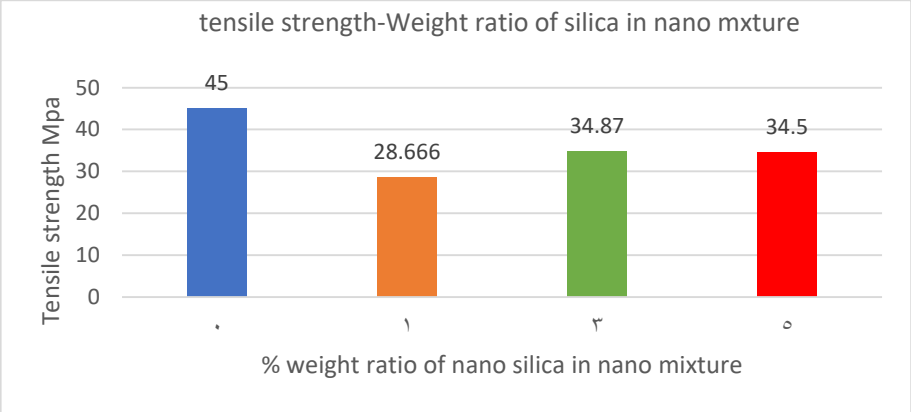


Figure (10) tensile stress-weight ratio of SiO2 in nanoparticle suspension

Figure (10) show relationship between tensile and ratio of silica in nanoparticle suspension and figure (11) showed the picture of tensile samples after testing in the university of Babylon in laboratory of materials Engineering. Table (3) indicate the values of tensile strength according to weight ratio of nano silica in nanoparticle suspension. Any value in Table represents the average value of three values of tensile strength for three samples. The test was done at room temperature and normal humidity.

Table (3) represent the values of tensile strength and the weight ratios of SiO2 in nano particle suspension

The weight ratio of SiO2 in nanoparticle suspension %	Tensile strength MPa
0% control case	45
1%	28.666
3%	34.87
5%	34.5

Figure (11) tensile samples after testing

From the results that obtained and the pictures of (FESEM), figure (12,13) we conclude that bonding force that connecting fiberglass and epoxy without curing with nanomaterial was

in optimize and this reflect the ability of matrix to wet the fibers and the energy surface in matrix and fibers and the adhesion between epoxy and fibers and this compatible to what Richard Young conducted that the wonder material is a single structure glass fiber and an epoxy resin, this apparently occurred in 1947. In this structure of the samples, we used two layers of fiberglass to increase the bonding force and this compatible with the research [15].

In the case of using epoxy and two layers of fiberglass immersed in nanoparticle suspension contains 1wt%silica and 99wt%water, the nanoparticle distribution was homogeneous and there is not agglomeration as shown in the figures (14,15) therefore the bonding force that connecting fiberglass and epoxy in the area that in contact with fibers very high, beside the weak area in matrix that empty from the scattered nanoparticle, this led to generate shear force among two areas added to drag force. This was because the separation between the strong area and weak area during the drag force in the tensile test. The ability of nano silica with its small size to fill voids and porous in area in contact with fibers and formation strong structure in the middle of sample causes to increase the elongation in this case to maximum value. Figure (16) indicate the highest value of elongation was in the case of samples manufactured of epoxy with two layers fiberglass immersed in nanoparticle suspension contains 1wt% SiO2 and 99wt%water. During the tensile test, peeling happened in the weak area, after that the fiber and the area of matrix that in contact with it elongated and finally failed.

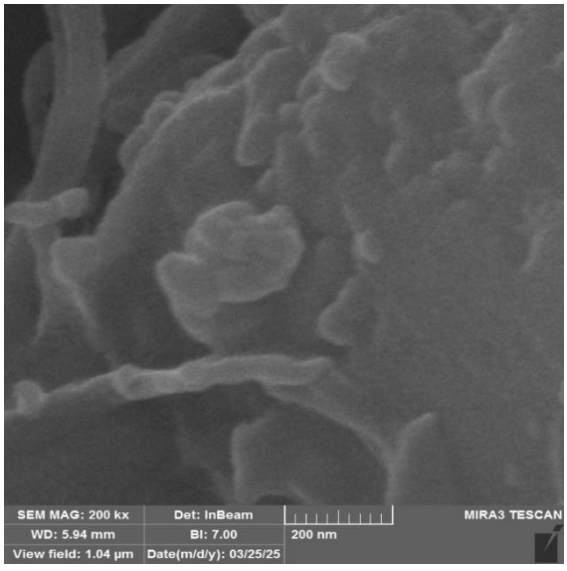


Figure (12) control case

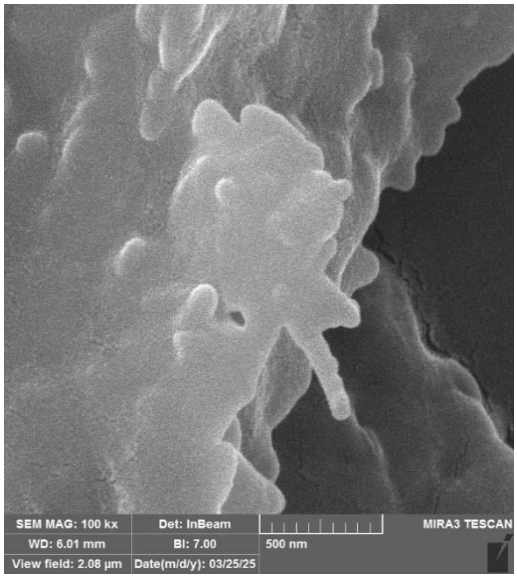
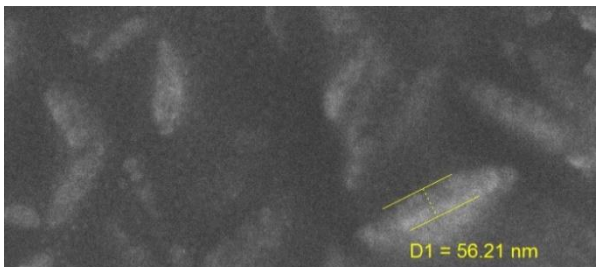


Figure (13) control case



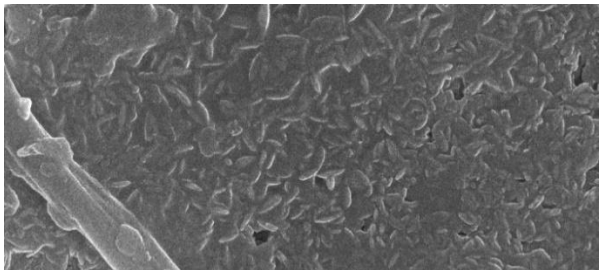


Figure (14) distribution of N. Silica

Figure (15) distribution of N. silica

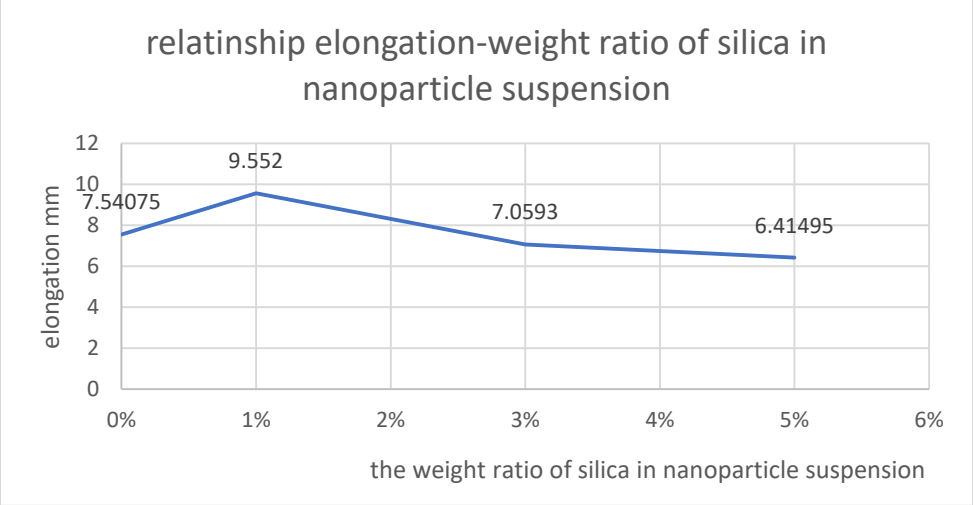


Figure (16) Elongation-weight ratio of N. silica in N.P.S

In the case of samples fabricated of epoxy and two layers fiberglass immersed in nanoparticle suspension contains (3wt% and 5wt% SiO2) and water respectively, the results of tensile strength were approximately equal. The pictures of (FESEM) indicate the formation of clusters that showed in gray color, the particles of nano silica collect together to form the clusters in phenomena named Van der Wals and according to this phenomena, there is attractive force work to collect the nanoparticles and create weak areas in the matrix as a result of agglomeration [16] therefore there is not strong area in the middle of sample and there is not shear force added to tensile force and the composite was more homogeneous from the previous case, this led to increase the value of tensile from 28.6MPa to 34.8MPa. Figure (17) shows the beginning

of formation clusters and figure (18) shows the clusters.

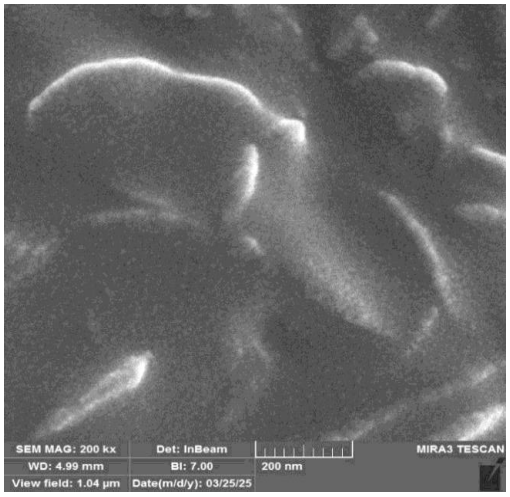


Figure (17) start of agglomeration

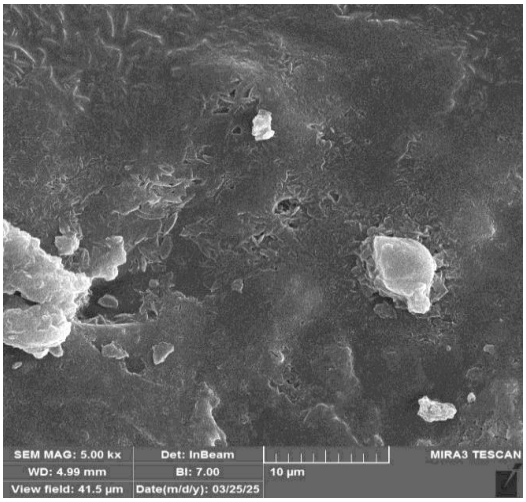


Figure (18) formation of clusters

3.2. Impact strength Test

From the figure (19) and table (4), The highest value of impact strength was in the samples that structured of epoxy and two layers of fiberglass that immersed in nanoparticle suspension contains of 1% SiO2 and 99% H2O. The percentage of increase in the value of impact strength was 43% as compare to the reference case (control case) that consists of samples manufactured from epoxy reinforced by two layers of fiberglass at room temperature and normal humidity. In the samples that produced from epoxy reinforced by two layers of fiberglass immersed in mixture contains 3% and 5% silica. The impact strength decreased. The behavior of composite material returns to the fact that when the weight ratio of nano silica in nanoparticle suspension was 1%, the distribution of nano particles was homogeneous between the fibers and area of matrix in contact with fibers, this cause increasing the bonding force between fibers and matrix. After increasing the weight ratio of silica to 3% and 5%, this led to heterogeneity between fibers and matrix as a reason of agglomeration between nano silica particles . The images of FESEM showed this fact clearly as shown in figures (17) and figure (18).

The values of results for impact strength were the average of three samples. The test of impact was done in laboratory of college of Material Engineering in the University of Babylon. Figure (20) shows the picture of impact specimens after testing.

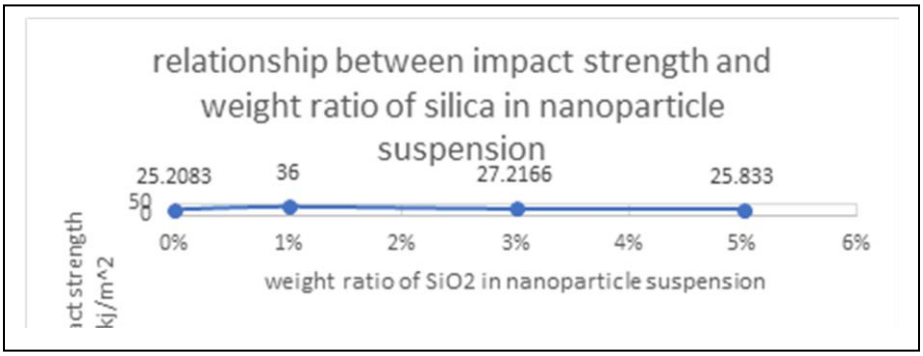
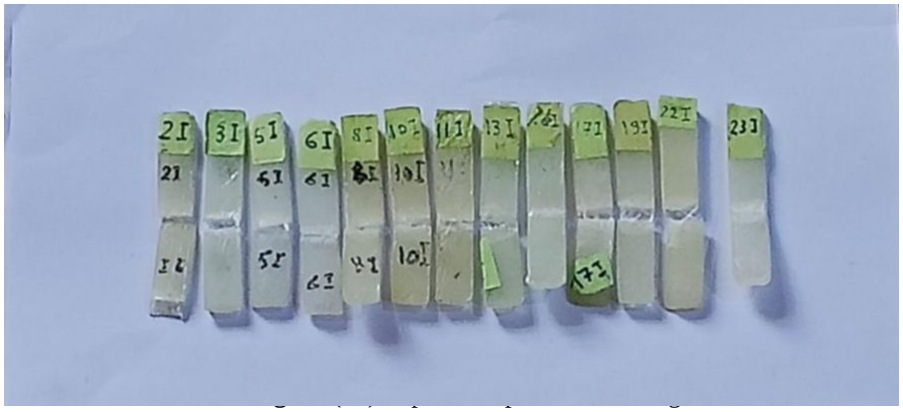


Figure (19) Impact strength-weight ratio of N. silica in N.P.S

Table (4) the values of impact and weight ratio of sio2 in nanoparticle suspension

weight ratio of silica in nanoparticle suspension %	Impact strength (kJ/m^2)
0	25.2083
1	36
3	27.216
5	25.833



In the case of samples that structured of epoxy and two layers fiberglass immersed in nanoparticle suspension contains 1wt% SiO2 and 99wt% H2O, the distribution of nanoparticle of silica was homogeneous and the nano material work to fill voids and porous in the interface and formation a strong layer in the middle structured of fibers and the matrix in contact with fiber as mentioned in the tensile test, but the test in this case is impact test, the force subjected to the sample is perpendicular to the plane of sample. The part of sample that far from the middle is weak, but in the middle is very strong therefore we need high energy absorbed to break the sample, this is the reason for high value of impact strength in this case.

In the case of samples fabricated of epoxy and two layers fiberglass immersed in nanoparticle suspension consist of (3wt% and 5wt% respectively) and H2O, the impact strength decreased due to agglomeration that occurred in the samples and there is not strong area in the middle of sample as mentioned in previous test (tensile test) and there is not require to high energy absorbed to break the samples.

When we review the resultants that achieved in tensile and impact tests, we find the highest value of tensile was in control case and the lowest value was in the case of composite structured of epoxy and fibers immersed in nanoparticle suspension contains 1wt%silica and 99wt% H2O. In the impact test the highest

value was in the case of samples fabricated of epoxy and two layers fibers immersed in nanoparticle suspension contains 1wt% silica and 99wt% water and the lowest value of impact strength in the control case and there is inversely relation between tensile and toughness, where increase in tensile measure decrease in impact and this fact compatible with tensile -toughness diagram.

4. Conclusion

The conclusions that were educed:

1. The impact strength behavior can be enhanced by using weight ratio of SiO2 in nanoparticle suspension 1% and 99% water. When we increase the weight ratio of SiO2 more than 1% in the mixture, the impact strength decreased.
2. The most researches that dealt with improving the mechanical properties of composite material used the weight ratios of nano silica SiO2 as compared to the matrix weight and fibers, in this study, the weight ratio which was dependent on the mixture of silica and water as example, we can use 1 gram of silica in mixture contains 1%silica and 99%water for curing 60 pieces of fiberglass in 30 samples, therefore we can shine the spotlight to the economic side of this process.
3. The maximum value of tensile strength was in the case of sample manufactured of epoxy and two layers of fiberglass without immersing in nanoparticle suspension.
4. The decreasing in the values of tensile strength can be avoided by using another nano material such as titania TiO2 or other nano material or by using another glass with fiberglass to increase the modulus of elasticity, such as using (M-glass) or other glass that have particular properties like (L-glass) which being rich in lead oxide.

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