Study The Effect of Tungsten Carbide Nanoparticles on The Morphological, Mechanical and Tribological Properties of WC/Epoxy and WC/ TBCP/ Epoxy Nanocomposite.

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Abstract :

In this paper, we reported on the effect of a polyethylene glycol-block-polypropylene glycol-block-polyethylene glycol (EO-PPO-EO) triblock copolymer (TBCP) on phase separation, mechanical properties of Epoxy based on bisphenol F-(epichlorohydrin) and hardener(1-methylethyl-1,1'-biphenyl) (izoforon diamine) system. In this work TBCP content used at 3%,6%,9%and 12%wt for epoxy matrix. The optimal TBCP concentration was discovered to be 3%wt in order to produce a good balance of mechanical characteristics. Also The comparative study of morphology and mechanical properties of two systems tungsten carbide (WC) reinforced epoxy resin and WC /triblock (TBCP) /epoxy nanocomposites has been examined. WC added at two systems in three different weight proportions (1%, 2% and 3%). Specimens were fabricated by hand layup technique by pouring epoxy resin and reinforcement mixture into silicon molds .The addition of nanoparticles had no effect on the miscibility of the copolymer on the resin. Tensile ,impact and weaer tests were performed to ASTM standards. From results it was observed that WC reinforcement in epoxy resin results in high tensile strength and modulus also increase impact strength and wear resistance compared to neat epoxy.

Key Words: epoxy, triblock copolymer (TBCP), nanoparticle WC, tensile strength , impact strength , morphology, DSC, ASTM, wear rate

Introduction:

Epoxy resins are frequently utilized as a matrix for numerous filler reinforced composites Because of their high mechanical strength and modulus, strong adhesive properties, and dimensional stability. However, because to their extensively cross-linked structure, these materials are brittle, have poor crack resistance, and have low

fracture toughness, which limits their uses in some fields. As a result, much research has been conducted to improve the toughness of cured epoxy resins while minimizing the loss of other properties. Several techniques for enhancing the toughness of epoxy resins have been proposed, and one of the more effective options is the addition of a second component capable of phase separation, such as reactive liquid rubber, thermoplastic polymer, or core-shell particles[1]. Many efforts have been made to increase the fracture toughness of epoxy resins by using amphiphilic block copolymers [2], [3]. By adding amphiphilic BCP, the structures can be made that increase the plane strain critical stress intensity factor (K_{IC}) and the critical strain energy release rate (G_{IC}) in a big way [2], [4] For example, the T_g, the modulus of elasticity and transparency of matrix can be effectively kept due to the creation of different structures such wormlike, spherical micelles, vesicles, as well as their overly complex structure in the matrix, which is a result of microphase separation[4].Block copolymers (BC) are the most recent generation of compliant modifiers [5]. They are an advanced sort of core–shell rubber particles(CSR) and are composed of at least two chemically distinct elements that combine to produce tailored, block-wise built macromolecules, such as diblock (AB), triblock (ABA, ABC), multiblock, alternating, or even tapering copolymers[6], [7]. Matrix and reinforcement are combined to generate a material called Composites with improved mechanical characteristics. To keep the reinforcement firmly in place, the matrix acts as a powerful binding agent [8]. Enhancing the material's properties is the primary function of reinforcement. Thermoplastic and thermosetting polymers may be employed as a matrix in polymeric composites. There is a clear preference for thermosetting polymer matrices over thermoplastic because of their superior stiffness and strength[9]. Epoxy resin is extensively used in composite manufacturing, automotive and coating industries because it has excellent mechanical qualities and a superior adhesive property than other thermosetting matrix elements [10] Epoxy's poor impact strength and low wear resistance make it unsuitable for tribological applications, thus it is reinforced with appropriate reinforcing particles to improve its tribological characteristics. Epoxy nanocomposites include a nanoparticle with a wide surface area to enhance the epoxy resin's ability to interact with the filler. As a result, nanocomposites are lighter in weight than microcomposites since micro additive fillers are heavier. Wear and mechanical characteristics are improved by hard oxides and carbide nanoparticles, such as silicon oxide, alumina, and tungsten carbide[11].Tungsten carbide (WC) is a very desired material due to its appealing mechanical, physical, and chemical qualities, which include high hardness, high melting point, strong electrical and thermal conductivity, and great corrosion resistance[12]. M. Kameswara Reddy et.al[13]. The incorporation of Tungsten Carbide (WC) nanoparticles changes the performance of epoxy polymer nanocomposites, such as mechanical and physical characteristics. Particles of various weight percentages (1%, 2%, 3%, and 4%) percent were mixed into the pure epoxy. The findings of the experiments demonstrate an improvement in both tensile and flexural strength at 2% particle loading. While Mechanical features have been reported to decline when the amount of particles loading increases .V. Suresh Babu et.al[14]. Investigated tungsten Carbide (WC) nanoparticles reinforced epoxy polymer nanocomposites'tribological performance. The addition of WC nanoparticles resulted in a considerable decrease in erosion rate. Furthermore, the inclusion of WC nanoparticles increased the hardness of epoxy nano composites. Nanocomposites performed better in erosion wear properties and hardness when WC nano filler

was used at 2% weight. While using 3wt% WC filler, the poor adhesive bonding between the matrix and filler resulted in the lowest hardness performance. Kishi et al[15] found a completely distinct set of structures for ABA-toughened epoxy (Bisphenol A-based and cured with Phenol Novolac) at the nanoscale. They studied the morphology and fracture mechanics characteristics of the material. Spherical micelles, cylindrical micelles, and curved lamellae were created, and cylindrical structures had the maximum fracture toughness. These investigations demonstrate the diversity of the nanostructures of EP/ block copolymer(BCP) composites as well as the corresponding fracture toughness. Epoxy/PEO-PPO-PEO mixes were found to have microscopic and nanoscopic phase separations by Mijovic et al [16]. Wei-Cheng Chu et.al[17]blending flexible epoxy resins with the triblock copolymer poly(ethylene oxide–b–propylene oxide–b–ethylene oxide) (F127). The presence of various microphase-separated structures inside the epoxy resin/F127 blends at different compositions was shown by TEM and AFM pictures. The modulus data gave evidence for the micelles developing, resulting in enhanced toughness. Jyotishkumar Parameswaranpillai et al[18]. Blended Poly(ethylene oxide)-poly(propylene oxide)-poly(ethylene oxide)(PEO-PPO-PEO) amphiphilic triblock copolymer (TBCP) with diglycidyl ether of bisphenol-A (DGEBA)/ 4,4'-diaminodiphenylmethane (DDM) system were nanostructured. Self-assembly of PPO blocks was followed by reaction-induced phase separation of PEO blocks as the means of achieving phase separation. Tg and modulus of thermosets were reduced by TBCP, which has a high plasticizing action on matrix,An ideal level for balanced mechanical performance was found to be TBCP at 5 phr, which enhanced impact strength and tensile characteristics.

With the goal of creating toughening thermoset system with good mechanical characteristics, polyethylene glycol-block-polypropylene glycol-block-polyethylene glycol (EO-PPO-EO) (TBCP) was used as a modifier of the epoxy matrix. The TBCP proved to be an excellent modifier for epoxy resins, resulting in a significant enhancement in the toughness value and impact strength. In order to investigate the effect of block copolymer content on the morphological and mechanical characteristics of the epoxy system, different concentrations of a triblock copolymer up to 12 % wt percent were added to the matrix. As a result, scan electron microscopy (SEM) was used to analyze the morphology of blends .The universal testing machine was used to measure mechanical characteristics. An investigation into the probable synergistic effects of tungsten carbide nanoparticles and block copolymers (miscible/immiscible) on mechanical and morphological qualities was carried out. The suitable incorporation of triblock copolymers (EO-PPO-EO)is thought can change the epoxy matrix into a variety of various morphologies, which might be changed dispersion and adherence of nanoparticles in the matrix. It was found that the addition of WC nanoparticles to an epoxy resin matrix had distinct effects on the wear behavior of two nanocomposite produced in this research.

2. Experimental

2.1 Material

Epoxy Sikadur 52 (TR Producted) based on bisphenol F-(epichlorohydrin) and hardener (izoforon diamine), (1-methylethyl)-1,1'-biphenyl) was purchased from the Company agent Sikadur . Polypropylene glycol block polyethylene glycol block polyethylene glycol block structure (EO-PPO-EO) was employed in this investigation as a soft segment with number average molecular weight ($\overline{M}_n$) of 2000 g/mol and functionality 2.0 of the triblock copolymer, were supplied by dow Chemicals. The tungsten Carbide nanoparticles ((WC) ,99.9 % , 55nm , 15.63 g/cm^3) was purchased from US Research nanomaterials ,Inc ,Houston ,TX USA.

2.2 Sample preparations

Epoxy resin / (izoforon diamine), (1-methylethyl)-1,1'-biphenyl) (hardener) were mixing (with ratio 2:1) for 10 minutes using a mechanical stirrer and the mixture put in the degassing system under vacuum at room temperature for 10-15 minutes to eliminate bubbles, and then the mixture was poured into the silicon mold, which was previously prepared, and left it for 24 hours at room temperature , to obtain unmodified epoxy samples. In ordered to prepare modified epoxy systems, 3%,6% 9% and 12% wt of (EO-PPO-EO) triblock copolymer was added to epoxy resin using mechanical stirrer for 10 minutes, then the hardener (with ratio 2:1) was added and mixed for 10 minutes using a mechanical stirrer. The prepared mixture put in the degassing system under vacuum at room temperature for 10 – 15 minutes to eliminate bubbles, and then the mixture was poured into the silicon mold and left it for 24 hours at room temperature and then obtain different samples of modifier epoxy polymer blends see table1 .

Table1: Sample composition of toughening agent /epoxy blends prepared in this study

Sample number	Matrix Polymer blends	Toughening agent	Samples Composition
0	Unmodified epoxy (neat epoxy)	No toughening agent	**EP**
1	Modified epoxy	(EO-PPO-EO)	**3% TBCP/EP**
2	=	=	**6% TBCP/EP**
3	=	=	**9% TBCP/EP**
4	=	=	**12% TBCP/EP**

Two groups were prepared from nanocomposite materials .The first group was mixing epoxy with nano-tungsten carbide, while the other group was mixing tungsten carbide nanoparticle with a blend of (epoxy with 3% TBCP). In first group, the WC nanoparticles (were weighed in an amount corresponding to 1, 2, and 3 wt %)were dispersed in ethanol and WC nanoparticles solution was sonicated using ultrasonic device at 35°C and sonic frequency 40 (kHz) for 30 min and then nanoparticales solution simultaneously added to the matrix as

was epoxy and mixing by mechanical stirrer for 15 min. In order to violate the ethanol, the mixture was put on magnetic stirrer at 70°C for more than one half hour until the weight is fixed after that let mixture cool at room temperature then added hardener with mechanical stirrer for 10 minutes and put it again in degassing vacuum to avoid bubbles and last pour in silicon mold at room temperature for 24 hours to obtained samples see(table2)

To prepare the second group, the same procedure for the neat epoxy /nano composite system was followed but the matrix be (TBCP/ epoxy), the best percentage of TBCP /epoxy blends gave good mechanical properties of epoxy system (3% wt) was taken and mixing with WC nanoparticle solution. Shown Figure (1) Schematic of the (WC nanoparticles /epoxy)two systems composite preparation process.

Table2 : Sample composition of WC/ epoxy nanocomposite prepared in this study

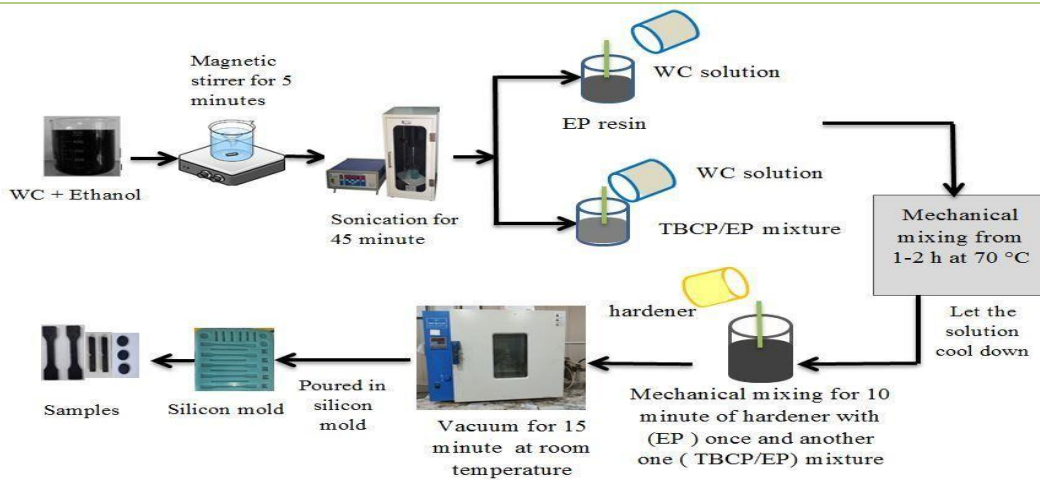| Sample number	Type of composite	Matrix nanocomposite	Reinforcement Nano particle reinforcement	Samples composition
1	Unmodified Epoxy Nano composite	Neat Epoxy	Tungsten carbide	**1% WC/ EP**
2	=	=	=	**2% WC/EP**
3	=	=	=	**3% WC/EP**
4	Modified epoxy Nano composite	Epoxy/3% wt TBCP	=	**1% WC/TBCP/EP**
5	=	=	=	**2% WC/TBCP/EP**
6	=	=	=	**3% WC/TBCP/EP**

Figure 1: Schematic of two epoxy system of nanocomposite preparation process

2.3 Mechanical Test

Regarding mechanical characteristics of unmodified epoxy(neat epoxy), TBCP/ epoxy blends and two systems of epoxy /WC and epoxy/ TBCP/WC nanocomposite, tensile test were carried out following ASTM D-638-03[19] standard test method and using micro computer controlled electronic universal testing machine model (WDW-5E) China with a 5 N load cell is supplied. The tensile strength and elastic modulus were calculated using the following equation :

$$S = P/A \dots\dots\dots\dots\dots(1)$$

- S is the tensile strength in MPa unit

- P is the force required to break in N unit

- A is the cross-sectional area in mm^2 unit

$$E = \sigma_2 - \sigma_1 / \varepsilon_2 - \varepsilon_1 \dots\dots\dots\dots(2)$$

- E is the modulus of elasticity (represent the slope of the stress-strain curve up to the proportionality limit) in MPa unit

- where stress (σ) is force divided by the specimen's cross-sectional area

- strain (ε) is the change in length of the material divided by the material's original gauge length

Impact test were carried out according to the ISO 179[20]. The used instrument of Charpy test German, gant (HAMBURG) company, Model WP 400. The Charpy impact strength of unnotched test specimens a_{cu}, in kilojoules per square meter, using the following equation (Eq. 3):-.

$$a_{cU} = \frac{W_B}{bh} \times 10^3 \qquad \dots\dots\dots\dots (3)$$

where

h is the thickness, in millimeters, of the test specimen

b is the width, in millimeters, of the specimen

W_B is the energy at break, in joules.

2.4 Differential scanning calorimetry

Differential scanning calorimetry measurements (DSC) measurement was carried out according to ASTM D3418-03 under nitrogen gas atmosphere. using SH1MADZ-4 DSC-60 device. The prepared samples with

weight of (8-10)± 0.5 mg was mounted in aluminum pans and heated up from 25 to 250 °C with a heating rate of 10 °C/min.

2.5 Scanning electron microscope (SEM)and Field emission scanning electron microscope (FESEM)

Scanning electron microscopy (SEM) was utilized to evaluate the fracture surface of the unmodified epoxy and TBCP/epoxy blends analyzed. An accelerating voltage of 20 kV was used in the tests. To prevent charging, the samples were covered in a gold coating before examination. FESEM was used to analysis fracture surface of two system nanocomposite were conducted at 10 Kv. The FESEM device product, TA company, model Q600 made in America and SEM device used to analysis fracture surface of epoxy/blends, it was from Seron technology company, South Korea Manufacturing , AIS2100 Model.

2.6 wear test

Wear test was achieved according to ASTM G99-17 [21]. A micro-test pin-on-disc was performed on an American MT4003 version 10 machine. Steel pin (16 Mn Cr5) of diameter 6 mm, hardness HRC 56, and surface roughness R=3.2 μm were used to slide against a polymer disc of 40 mm diameter and 4 mm thickness, with a vertical load of 30 N. The pin was moving at 300 rpm on a track that was 24 mm in diameter with sliding distance (235)m and time slip (25)min. The wear rate may be determined using the following equation [22],[23],[24]:

$$W.R = \Delta W / S.D .... (4)$$

Where:-

W.R:- wear rate is the weighted (gm/mm).

Based on the following equation, the experiment's weight change(ΔW) may be computed as follow :-

$$\Delta W = W1 - W2 .... (5)$$

Where:-

W1:- Weight of sample before the test (gm).

W2:- Weight of sample after the test (gm).

S.D: a sliding distance determined by the following law :-

$$S.D = S*t .... (6)$$

Where:- S:- the speed of sliding (mm/min).

t:- time slip (min).

3. Result and discussion

3.1 SEM micrographs

In Figure2(a and b):SEM micrographs demonstrate a typical featureless one phase morphology, consistent with the amorphous single phase structure of epoxy networks. Similar SEM pictures have previously been observed[25], [26]. Figure2 (c,d,e and f) shows the blends examples for two picture scales at low and high TBCP content. Several spherical formations are seen, indicating phase separation and the creation of immiscible TBCP structures in the matrix[27].At low and high percentages of TBCP, a microphase separation can be detected. PPO microseparated phase that is not miscible with the epoxy matrix, which is represented by dark areas[28]. Furthermore, the PEO block was spread across two phases since it is miscible with the epoxy matrix while still being covalently connected to the segregated PPO block.

In the case of a 3wt% TBCP/epoxy system, certain black spherical domains were tiny in size and evenly dispersed, however when the concentration of block copolymer increased, these spherical domains got larger, wider, and more apparent in the epoxy matrix [29]. FESEM micrographs figure 3(b,c and d) demonstrate that the nanoparticles utilized with block copolymers had no effect on the distribution of the copolymer in the matrix, nor did they interfere with miscibility at the circumstances used in this work. That suggests the EO - PPO - EO 3 percent block copolymer may be enhancing the nanoparticle's adherence to the matrix. Martin-Gallego et al.(2015) discovered the same thing[28]. In figure 3(c)for 2 percent wt WC/TBCP/epoxy systems (sample number 5 in table 2) observed a lower agglomeration degree, good spread of nanoparticles and distribution inside the matrix ,this related to the presence of TBCP which aided uniformly distribution nanoparticle and possibly affected the interaction between the nanoparticle and the matrix as recommend in [30]. As a result of their amphiphilic nature, the block copolymer present between the tungsten carbide nanoparticle (WC) partly inhibits the nanoparticles from adhering back together after dispersion. As a result, at 2 wt. percent of WC nano particles for two systems nanocomposites prepared, the dispersion of nano particles inside the matrix is more regular and homogenous. As the tungsten carbide loading percentage is raised, the quantity of agglomerations rises, as does their size. It also demonstrates that at large nanoparticle loadings, the likelihood of lump formation is quite high due to a deterioration in material characteristics caused by heterogeneous dispersion of WC nanoparticles in the matrix. Many other scholars have made similar observations.
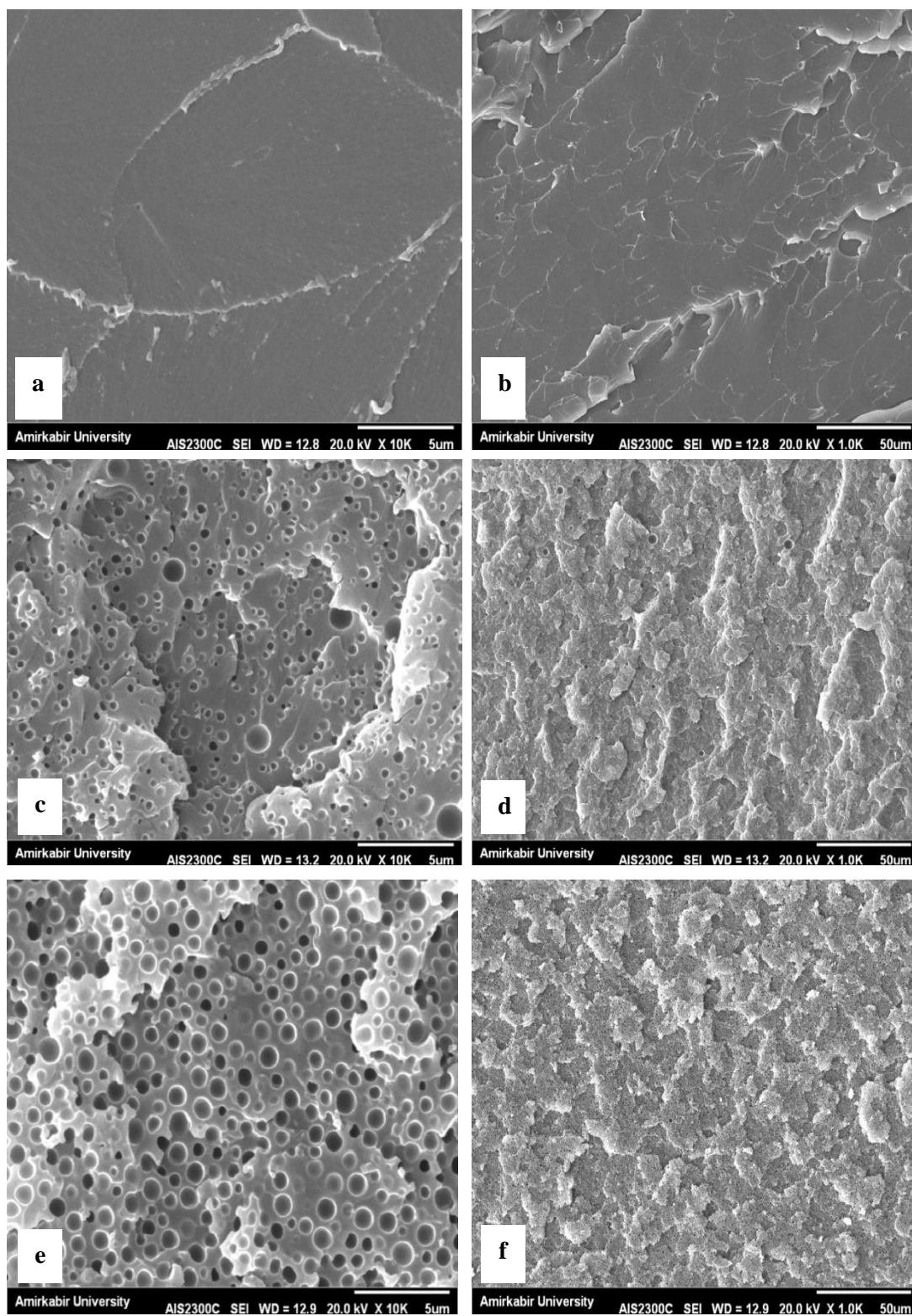
Figure 2 :SEM micrographs of a and b) unmodified epoxy ,c and d) 3 wt % TBCP/epoxy, e and f) 12 wt % TBCP /epoxy at 5μm scale and 50 μm scale ,respectively
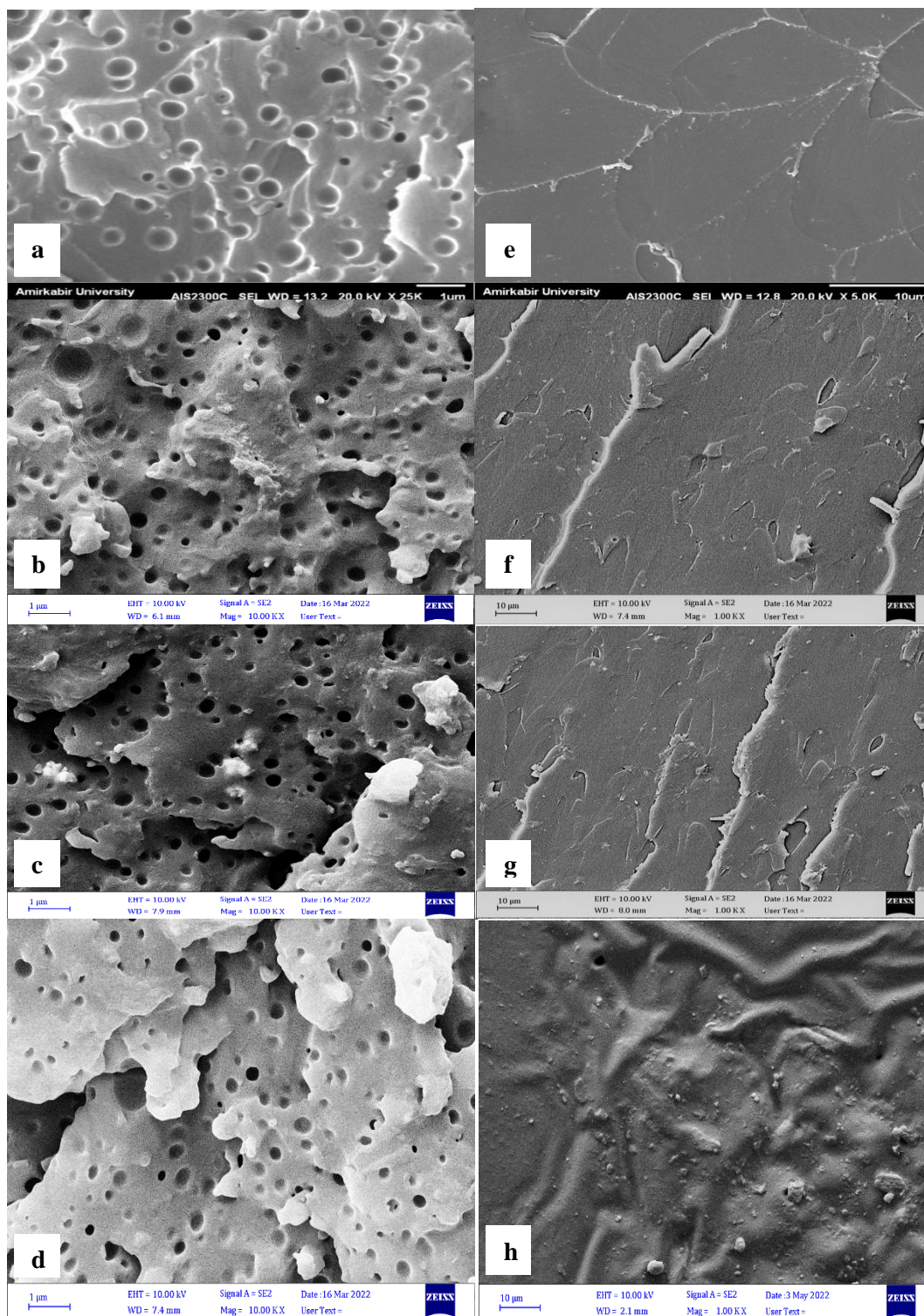
Figure 3: SEM and FESEM micrographs of a)3 wt % TBCP/epoxy, b)1 wt % WC/TBCP /EP, c)2 wt % WC/TBCP/ EP ,d) 3 wt % WC/TBCP/EP, e) unmodified epoxy, f) 1 wt % WC/EP ,g) 2 wt % WC /EP , h) 3 wt % WC /EP.

3.2 Thermal test (DSC analyzises)

As can be seen, all curves show a drop in heat flow indicating the presence of a curing reaction between epoxy and the hardener as shown in figure 4. The reaction was considered complete when the isothermal DSC thermograms leveled off to the baseline[31]. With increasing block copolymer content in the epoxy resin, the curing reaction was slowed down, resulting in a noticeable decrease in heat flow drop .Increased block copolymer content obviously slowed down the curing reaction .agree with [29]. While the T_g values in nanoparticle-filled samples are greater than in epoxy samples (see Table 2), this may be explained by the strong nanoparticle and matrix interaction as seen in figure 5 (a and b) (upper and lower image). In comparison to unmodified epoxy, a temperature rise of 15 °C was recorded for the samples (WC/TBCP/epoxy).
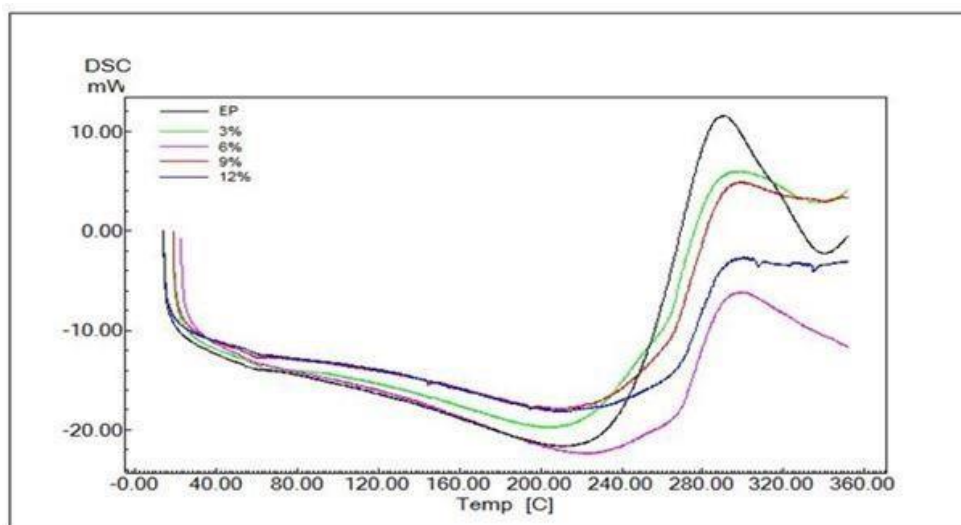

Figure 4: Curves of DSC of TBCP/epoxy blends

Table 2 : Values of Tg of blend and nanocomposite

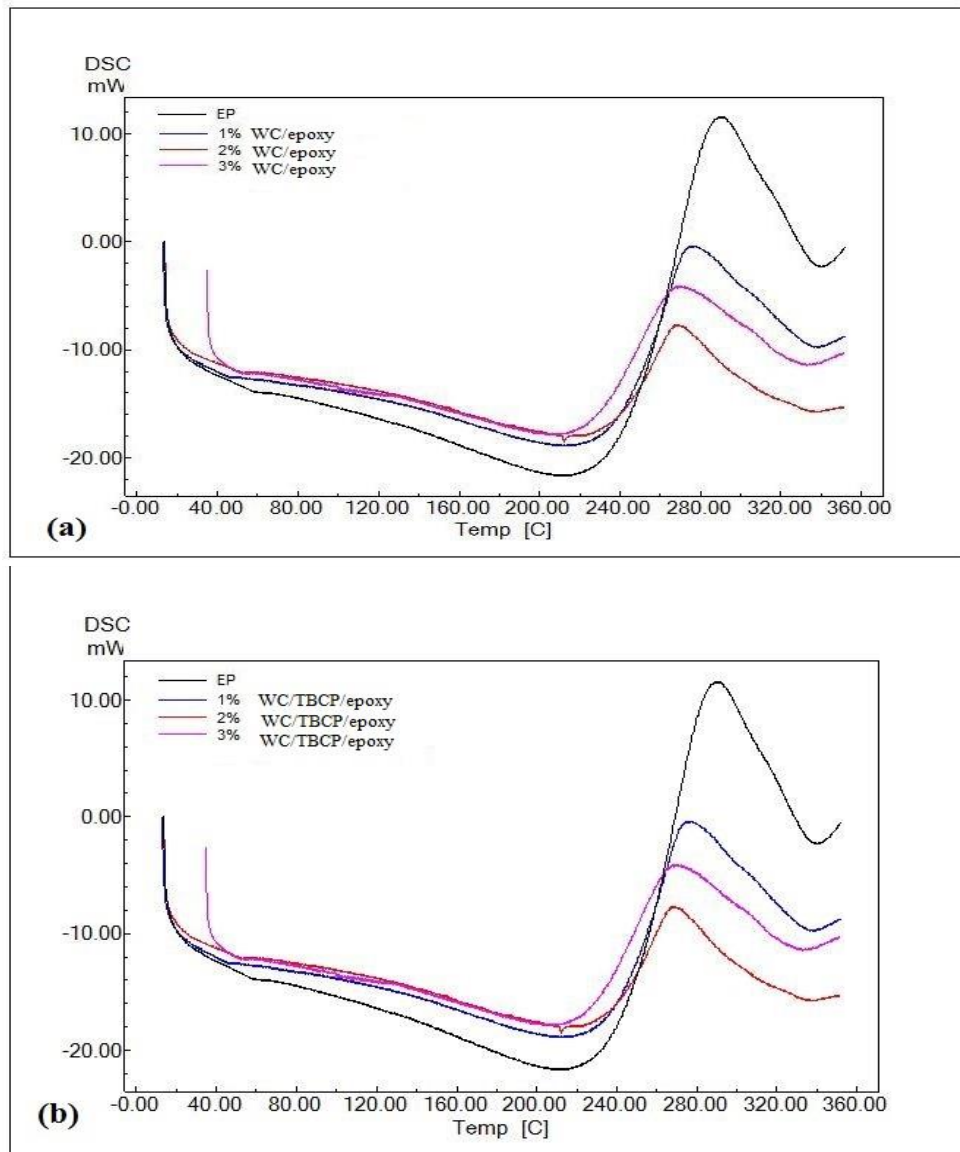|		EP	3%wt TBCP	6%wt TBCP	9%wt TBCP	12%wt TBCP
TBCP/epoxy blends	T_g	83.76	60.89	58.95	56.54	53.10
		EP	1%wt WC	2%wt WC	3%wt WC	
WC /epoxy nano composite	T_g	83.76	90.22	93.36	94.86	
WC /(3%wt TBCP)/epoxy nano composite	T_g	83.76	89.64	94.76	98.83	

Figure 5: Curves of DSC (a) WC /epoxy nano composite and (b) WC/TBCP /epoxy nano composite

The use of block copolymers to stabilize nanoparticle dispersion is a non-covalent modification procedure that has no effect on the nanoparticles' electronical structure or mechanical characteristics[30]. Block copolymers can contain a lyophobic portion that is adsorbed on the surface of the nanoparticles and a lyophilic portion that has epoxy affinity, preventing nanoparticle approximation and improving transfer between nanoparticle and matrix. [30], [32]. It is claimed in the literature that nanoparticles that are stiff might impede the movement of polymer chains and/or alter interactions near the nanoparticles' surfaces in a manner that affects the T_g [33]

3.3 Mechanical test

Figure 6 shows tensile properties of TBCP/epoxy blends. From graphs 6(a and b)it is observed that the addition of 3% and 6% of TBCP increases the tensile strength and elastic modulus of epoxy thermoset and increase content of TBCP has decrease these properties. This is due to the fact that TBCP chains of low molecular weight overlap between the epoxy network, giving an impediment to movement inside the matrix, which increases both the modulus of elasticity and tensile strength of the epoxy. Similar results were found by [18], [27], which were justified based on the compatibility between TBCP and epoxy. Figure 6 (c) shows that elongation of epoxy blends decreases slightly with an increase in the TBCP content, especially at a high percentage related to the quantity and size of the chains that hinder the movement and prevent it from elongating significantly.
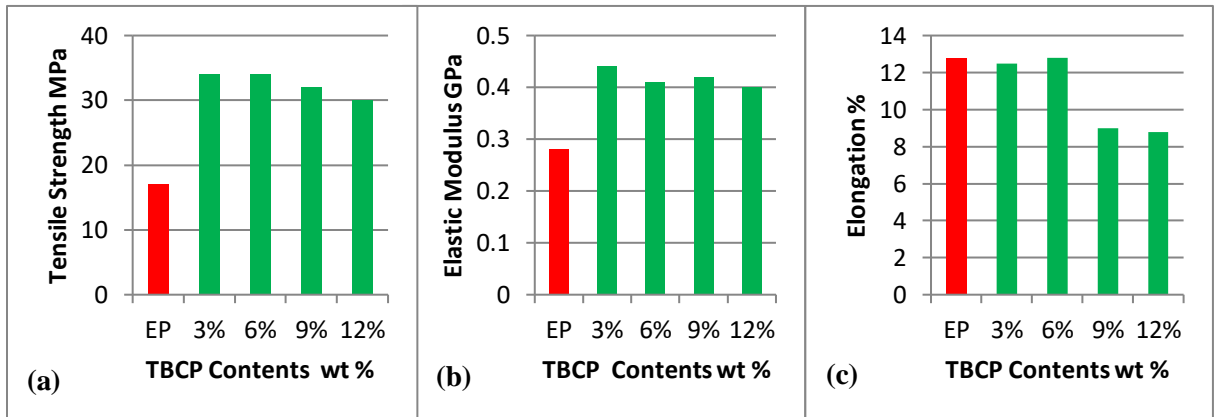

Figure 6: Tensile properties (a) tensile strength (b) elastic modulus (c) elongation of TBCP /epoxy blend

The impact strength of the epoxy increases by the addition of TBCP at 3% wt. (see figure 7 show impact strength of TBCP/epoxy blends).Then, the impact strength decrease with increase the TBCP content but remains high than impact strength of pure epoxy. This result was attained since the blends display phase separation morphology in which TBCP phase forms distributed domains in epoxy matrix, The compatibility and interfacial adhesion between the matrix and dispersed phase, as well as the softening action of the flexible TBCP chains in the rigid epoxy matrix, may explain the small increase in mechanical characteristics brought about by the addition of TBCP[34]. Impact energy is kinetic energy, and when it hits a material that has a second phase with a plastic deformation, like TBCP, it will absorb the impact energy and release it through vibration because its chains are flexible. This makes the material more strength to impact.
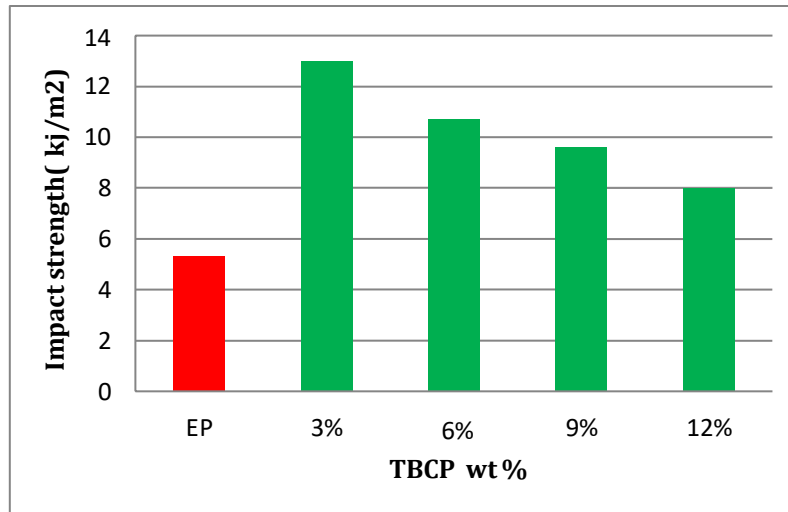
Figure 7: Impact strength of TBCP /epoxy

Nanocomposite tensile strength is enhanced by adding WC nanoparticles to the epoxy. In Figure 8(a), the tensile strength of epoxy composites increases when particles content increase. At 2% particle weight, nanocomposites have the greatest strength ,enhancement in strength ~55 %. Because of 2 %wt give good dispersion of particles, the load is transferred evenly between the particles and the matrix, resulting in increased strength. Eventually, the inclusion of particles weighing more than 2% of the total weight resulted in reduction in tensile strength. It can be explained by the fact that all nanoparticles have a significant propensity to agglomerate in order to reduce their high surface energy[35], [36]. Larger percentages of agglomeration particles create higher stress concentrations at specific places, resulting in a decrease in composite strength[37].It can conclude from the results of the tensile strength test the bond between WC and epoxy is very good.

The WC causes a modest reduction in elongation at break of the nanocomposite, implying that the fillers produce a decrease in matrix deformation owing to the introduction of mechanical limitations see (figure 8 (c)). The adhesion of the filler to the epoxy matrix also contributes to rigidity of the polymer chain and hence resistance to expand when strain is applied. The additional propensity for elongation to diminish at a filler level of around 3% wt, implies that matrix deformation is connected to the dispersion condition of the fillers as well as the interface characteristic.
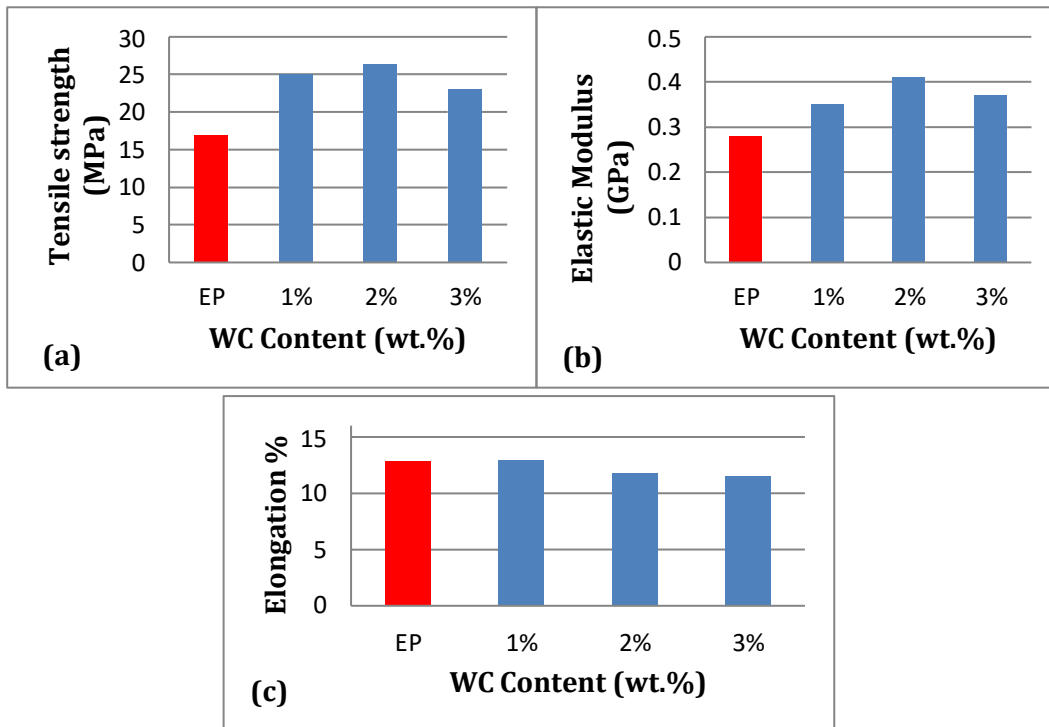
Figure 8: Tensile strength (a), Elastic modulus (b), and elongation (c) of WC/epoxy nano composites.

Figure 8 (b) shows that the Young's modulus of epoxy nanocomposites including WC is greater than that of unmodified epoxy and progressively increases with filler content, from 0.28 GPa (neat resin) to the maximum value of 0.41 GPa (2 wt. percent of WC). Indeed, homogenous dispersion is required for hard particles to acquire stress transfer and hence enhance the young modulus of nanocomposite[33]. This improvement in the modulus of elasticity of the nanocomposite is due to the nature of the hard nanoparticles compared to the brittle matrix
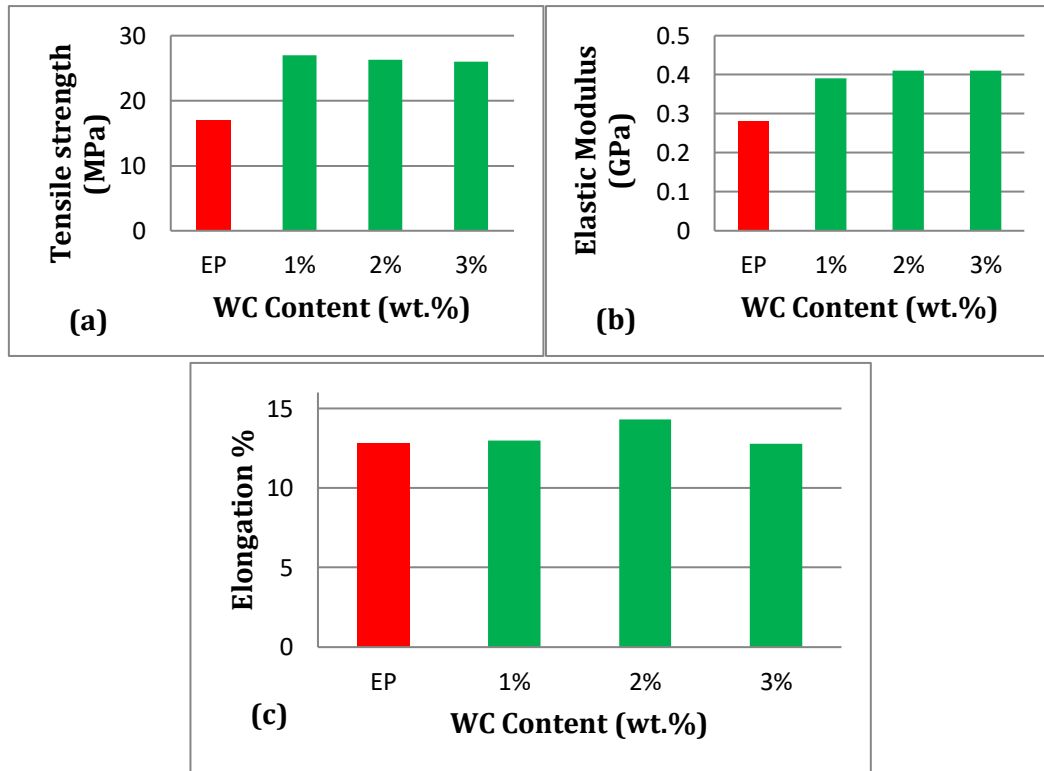
Figure 9: Tensile strength (a), Elastic modulus (b), and elongation (c) of WC/ TBCP /epoxy
nano composites.

Figure 9 (a and b) shows that the tensile strength and elastic modulus rise as the amount of tungsten carbide
nanoparticles in the WC/TBCP/epoxy nanocomposite increases. As it is explained earlier, due to the good
compatibility between TBCP and epoxy, the flexible chains of TBCP help the spread and good distribution of
WC nanoparticles within the matrix of the nanocomposite. This helps transferring the load from particles to the
matrix and reducing the occurrence of positions of stress concentrations within the material, thus increasing the
tensile strength and elastic modulus.

The elongation at break of WC/TBCP/epoxy nanocomposite figure 9 (c) remains almost unaffected. This is
owing to the tungsten carbide particles not affecting the miscibility of TBCP with the epoxy, as well as the
homogenous distribution and excellent interfacial adhesion between particles and matrix. The introduction of
nano WC filler at 3 wt% with epoxy matrix resulted in a considerable improvement ~30% in impact strength.
Impact test results are shown in figure10 (a).When the filler loading was raised from 1% wt to 3% wt , the
impact properties significantly improved. Ascribed to the outcomes, improved interfacial contact and hence
bonding of nano filler particles with the epoxy matrix to withstand high impact stress/load.
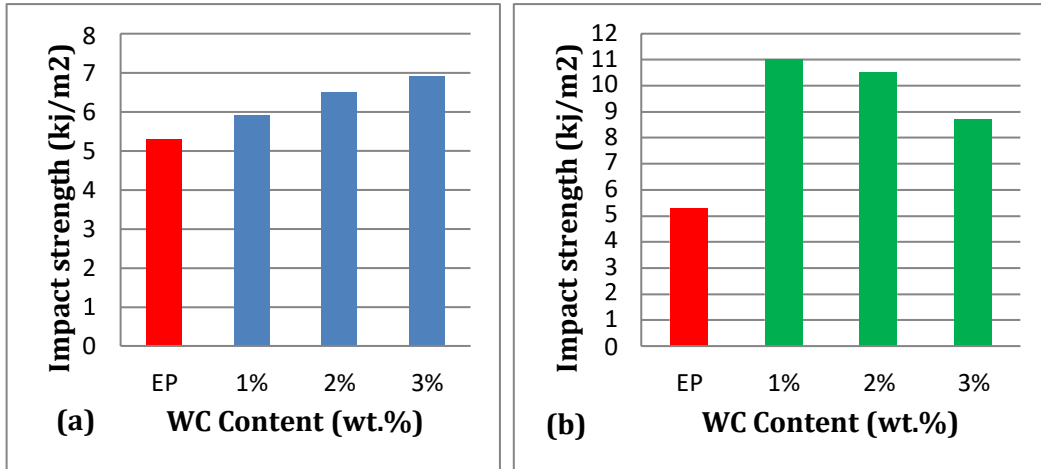
Figure.(10): Impact strength (a) WC/epoxy nanocomposites and (b) WC /TBCP/epoxy nanocomposites

Internal damage induced by low-velocity impacts on epoxy-based composites may lead to serious safety and reliability difficulties, since the resin is very brittle. Since epoxy composites are used in many high-performance applications, it is vital to enhance their ability to resist damage by increasing their impact strength. Using the second phase toughening technique, the modifier may be added as a distinct phase to solve this problem. Depending on the inclusion of an added phase[38].This describes what was note the impact resistance grades for nano tungsten carbide and the toughening agent (TBCP) of the composite material. Figure 10 (b) notch increases impact strength by approximately (107%) at 1% wt WC, and as WC concentration increases, there is a tiny drop in impact property, but it remains greater than pure epoxy. This was associated to the particle-matrix adhesion and good distribution with additive TBCP. In addition, TBCP chains have a role in the plastic deformation inside the matrix, thus absorbing more impact energy, resulting in an increase in the toughness of the sample to fracture.

3.4 Wear test results

Pin on disc tribological test for epoxy and nanocomposite samples have been presented in Table 3. After analyzing the results, it becomes clear that adding fillers to the epoxy matrix enhances the samples' wear properties.

Table 3: Wear rate values for two nanocomposites prepared in this study.

Sample number	Samples composition	Wear rate (gm/mm)
0	EP	6.8085E-09
1	1% WC/ EP	3.4043E-09
2	2% WC/EP	2.5532E-09
3	3% WC/EP	2.5531E-09
4	1% WC/3%TBCP/EP	2.9787E-09
5	2% WC/3%TBCP/EP	2.5532E-09
6	3% WC/3%TBCP/EP	1.7021E-09

Figure 11 demonstrates the effect of the addition of WC nanoparticles on the wear rate of the epoxy resin. This work created two WC/epoxy nanocomposite, as well as a WC/TBCP/epoxy nanocomposite .It has been shown that adding WC nanoparticles to epoxy reduces wear rates. The wear rate of EP decreases from 6.808109gm/mm to 2.553109 gm/mm when WC/epoxy nanocomposite was used, while the wear rate of EP decreases considerably from 6.808109gm/mm to 1.702109 gm/mm when WC /TBCP/EP was used. It is indicating the wear resistance of all samples is increased by employing the tungsten carbide particles. This may be connected to the fact that the hard outer layer protects the surface from intense contact. When the weight percent of WC is increased, the wear rate of the sample lowers. This owing to the epoxy may readily remove at the contact region (sliding surfaces)but in the composite mode the WC particles function as a rough condition compared to the counter surface across which they slide. similar with[39],[40].
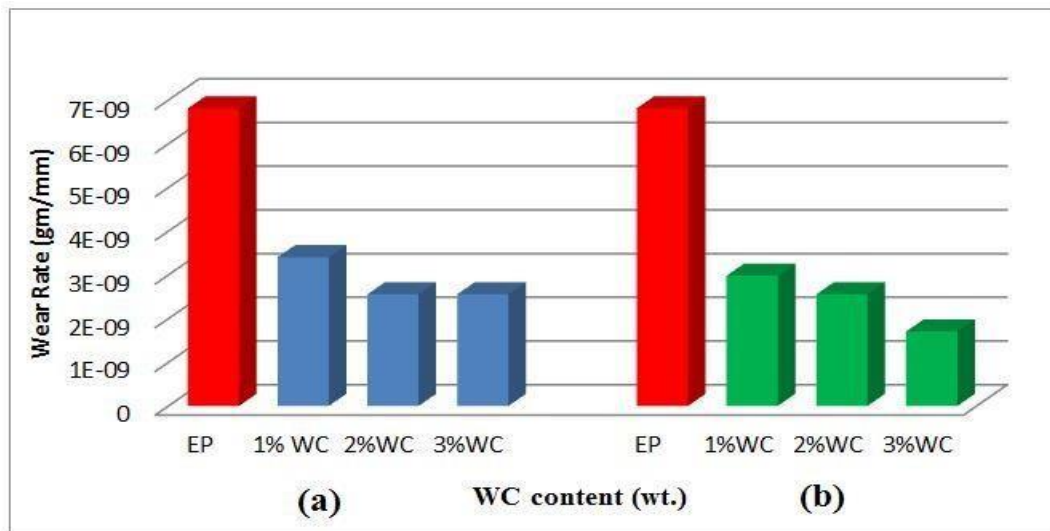

Figure 11: Comparison wear rate values between (a)for WC/epoxy and(b) WC/TBCP/epoxy nanocomposites.

The inclusion of TBCP with WC particles, as previously discussed, resulted in better particle dispersion within the epoxy matrix and decreased agglomeration at high concentrations. Nanocomposites lose their well-dispersed WC and transfer it to the steel ball-nanocomposites interfacial. To prevent the steel ball from coming into touch with the nanocomposites, WC may function as spacers in similar with[41].The improved wear resistance is related to the polymer's uniform distribution of nanoparticle particles, which assists to protect the polymer[42],[43].

Conclusions

At various compositions up to 12 wt percent, an epoxy system was modified with an EO-PPO-EO triblock copolymer. SEM was used to examine the morphology of combinations. When TBCP was added, the tensile and impact characteristics of epoxy blends were greatly enhanced. Because of the influence of the material's flexibility on the polymeric chains, the glass transition temperature dropped to epoxy when a copolymer (TBCP) was added.

The tungsten carbide nanoparticle, on the other hand, had a significant impact on the material's mechanical characteristics. The inclusion of inorganic fillers (WC) has greatly contributed in improving the wear properties of the samples. A synergistic interaction between the TBCP and the nanoparticles was seen, resulting in a considerable increase in the resin's tensile and impact strength. The glass transition temperature (T_g) of epoxy nanocomposite increases as the WC concentration increases, which is due to the nature of the nanoparticles and the strong matrix interface.

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