

## Effect of Nanoparticles and Fibers Types on Hybrid Blend Composite Materials Behavior of Epoxy and Phenol-Formaldehyde

Mustafa A. Rajab<sup>1</sup>, Sabah A. Salman<sup>2\*</sup>, Maher N. Abdullah<sup>3</sup>

<sup>1</sup> Technical Institute of Baqubah, Middle Technical University, Iraq.

<sup>2,3</sup> Department of Physics, College of Science, University of Diyala, Iraq.

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### ABSTRACT

*Phenol-formaldehyde resin was mixed with epoxy resin in different proportions to form a hybrid mixture of composite materials. It was reinforced with carbon fibers, glass fibers, Kevlar fibers, magnesium oxide and zirconia nanoparticle particles. This research investigates the effect of fibers and nanoparticles on the behavior of hybrid composites, namely, tensile, bending, hardness and toughness. The results showed an improvement in the properties of the hybrid mixture after the use of fibers and nanoparticle enhancement.*

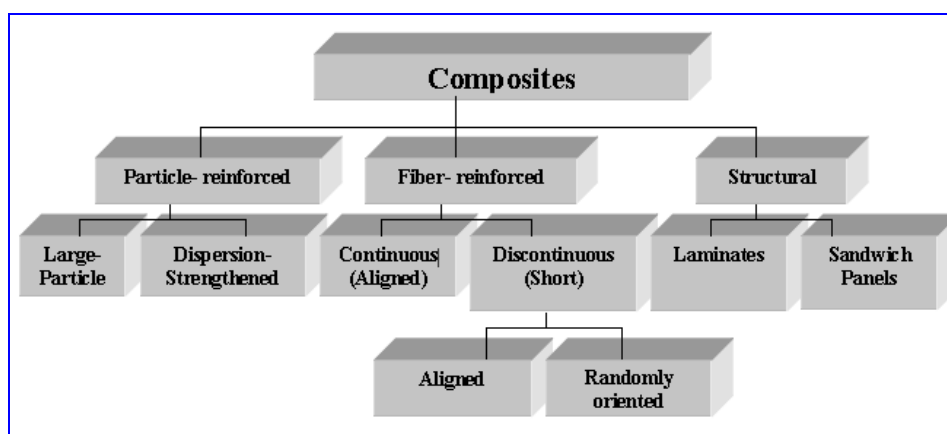
**Keywords:** Hybrid Blend, Mechanical Properties, Phenol Formaldehyde Resin, Epoxy Resin.

### 1. INTRODUCTION

Technological development depends on advances in materials. One does not have to be an expert in the design of sophisticated cars or airplanes, but one must realize that there is sufficient material to withstand external loads and stresses [1, 2]. A composite material consists of a combination of two or more substances that often have very different properties than the original materials, which work together to give the unique properties of composite materials [3, 4]. Figure 1 shows the classification of composite materials. Composite materials are used not only for their mechanical properties but also for electrical, thermal, technological, environmental and other applications. Composite materials are usually optimized to achieve a certain balance in properties for a particular set of applications. Considering the wide range of uses through which composite materials can be designed; the applications of these materials have increased after strengthening them with fibers and nanoparticles [5, 6].

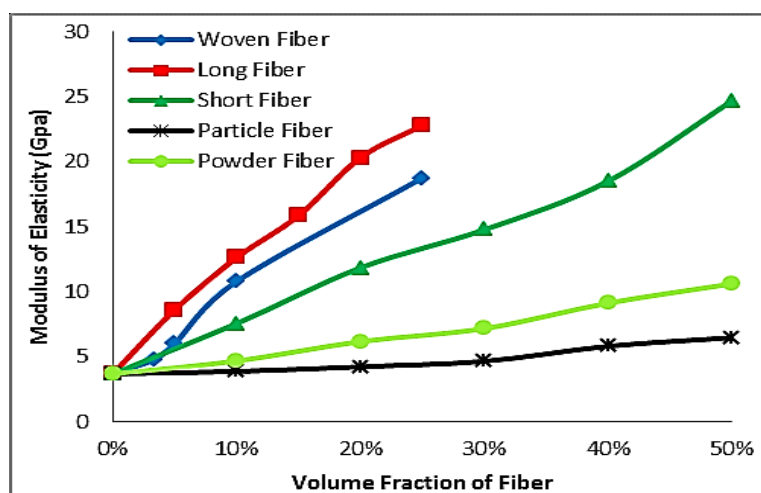
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\*Corresponding Author: [pro.dr\\_sabahanwer@yahoo.com](mailto:pro.dr_sabahanwer@yahoo.com)



**Figure 1.** Types of composites.

Normally, fillers are used to change the thermal, electrical and mechanical properties of the matrix. The coefficients of particulate composites near the minimum values of composites reinforced with fibers are shown in Figure 2. Sand mixed with polymer is much cheaper compared to well-arranged glass fibers in the same polymer. For this reason, the slight increment in the hardness as a result of particle addition is economically important [5].



**Figure 2.** The change in the elasticity coefficient for particulate composites with volume fraction change [5].

## 2. THE AIM OF THE RESEARCH

The general use of composite materials depends largely on the mechanical and physical properties of these materials. Therefore, the study of these properties under the influence of the forces and loads of different types of fibers and the reinforcement of nanoparticles is of great importance to determine the suitability of these properties to the workplace in these materials. The epoxy was mixed with phenol-formaldehyde resins according to different mixing ratios for the purpose of manufacturing the test samples needed to obtain the mechanical properties, analyze and compare them to the best.

### 3. EXPERIMENTAL PROCEDURE

**Materials:** epoxy resin, phenol-formaldehyde (resole) resin, carbon fibers, glass fibers, and Kevlar fibers.

**Preparation of samples and properties of tensile, impact and hardness:** epoxy resin and phenolic formaldehyde resin were mixed with different weight fractions as shown in Table 1a, Tensile strength samples were manufactured according to ASTM D 638, and the tensile test used the universal testing device as shown in Figure 3. While hardness samples with a diameter of (25 mm) and a thickness of (10 mm) were used to test for hardness shore (D) according to ASTM D790 by using the testing device as shown in Figure 4. The Charpy durability samples with root radius (0.25 mm) and a depth of (0.5 mm) were used to test for Charpy accordance with ASTM E23 by using the testing device as shown in Figure 5, and the Table 1b shows the mechanical properties (tensile, bending, toughness, hardness) of the composite materials according to the mixing ratios between epoxy and phenol-formaldehyde.

**Table 1a** Composition of epoxy-phenol formaldehyde hybrid blend

Sample No.	Composition
E1	(Epoxy/Resole) (85/15)%
E2	(Epoxy/Resole) (90/10)%
E3	(Epoxy/Resole) (95/5)%
E4	(Epoxy/Resole) (100/0)%

**Table 1b** Testing of epoxy with phenol-formaldehyde at different ratios

Ratio	Tensile Test		Bending Test		Impact Energy (Joule)	Shore (D) Hardness
	Stress (Map)	Strain	Stress (Map)	Strain		
0%	25.40985	3.378	0.21684	34.31733	0.37	68
5%	26.01369	1.7106	0.2597	33.60467	0.15	70.2
10%	24.26089	3.0093	0.30076	41.04733	0.133	64.6
15%	11.12752	2.168	0.10888	35.772	0	62.8

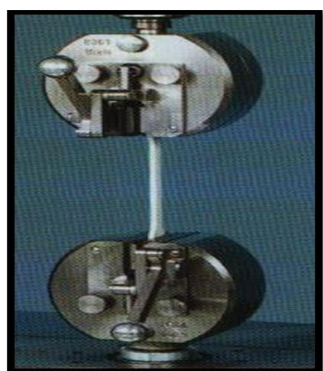
**Epoxy risen and resole resin preparation:** firstly, epoxy resin and resole resin are weighted for suitable mixing ratio and manually mixed. Then, the epoxy resin and resole resin were mixed by magnetic stirrers at (800 rpm) for (15 minutes). Finally, the hardener with a suitable mixing ratio was added in order to have good homogeneous of hybrid resin as shown in Table 2.

**Table 2** Hybrid blend mixing ratio of epoxy risen and resole resin

No.	Mixing Ratio of Epoxy Risen	Mixing Ratio of Resole Resin
1	100%	0%
2	95%	5%
3	90%	10%
4	85%	15%
5	80%	20%
6	70%	30%
7	60%	40%
8	50%	50%

**Composites Preparation:** The hand lay-up technique was used to prepare sheets of epoxy composites pure or reinforced with many types of fibers mat and with nanoparticles filler. The casting mold consists of glass plates with dimensions (200 × 200 × 4 mm) and under the casting

mold placed nylon sheets to prevent adhesion of the composite material. All the test specimens were completed by abrading the edges on a fine carborundum paper. Neat epoxy preparation; firstly epoxy resin and hardener are weighted for suitable mixing ratio, and manually mixed, then the epoxy resin and hardener were mixed by magnetic stirrers at (800 rpm) for (15 minutes) to have good homogeneous between epoxy resin and hardener. The mixture was combined with Kevlar fibers, glass fibers, and carbon fibers to determine the effect of fibers on the characteristics of hardness and impact. The two-layers reinforcement was shown in Figure 6, where (95%) of epoxy resin and (5%) formaldehyde resin as the best mixing ratio in terms of the mechanical characteristics. After selecting this best percentage, it was reinforced with fibers to determine the effect of the fibers type on the properties of hardness and impact as shown in Table 3. The nano magnesium oxide particles and nanoparticles of zirconium oxide were then amplified to demonstrate the effect of nanoparticle reinforcement on the electrophoresis of the hybrid mixture.



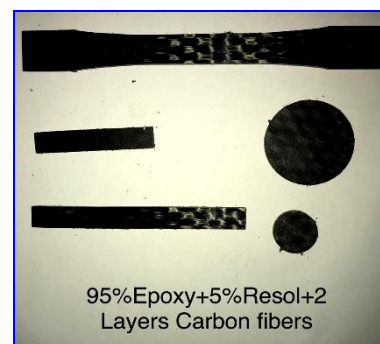
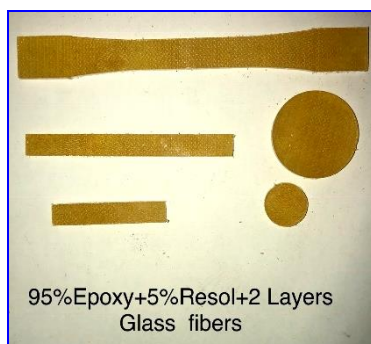
**Figure 3.** Tensile test instrument.



**Figure 4.** Hardness test instrument.



**Figure 5.** Impact test instrument.



**Figure 6.** Tensile, toughness, and hardness test samples with different types of fibers (carbon, glass, Kevlar).

The fibers reinforcement materials are:

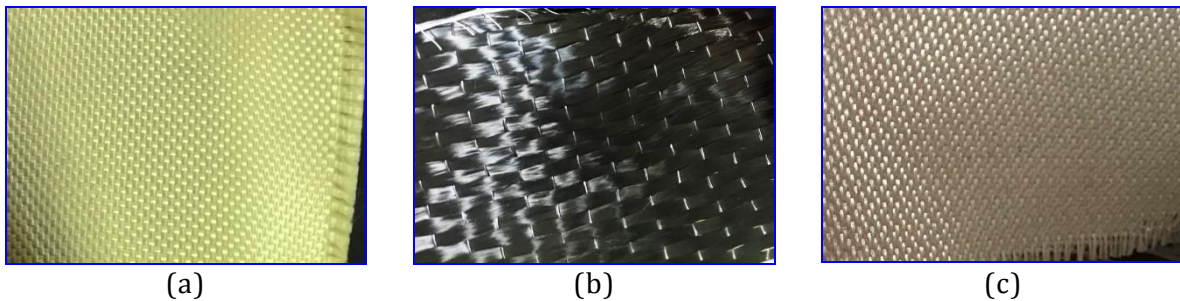
- i. Glass fibers (E-glass fibers, glass fibers biaxial fabric 0/90), the basis of textile-grade glass fibers is silica,  $\text{SiO}_2$ .
- ii. Carbon fibers precursors for the production of carbon fibers include polyacrylonitrile (PAN), isotropic pitch, mesosphere pitch, and regenerated cellulose, among others.
- iii. Kevlar fibers (Kevlar-49 fibers), materials used as thermoplastic matrix are: (i) P1 - thermoplastic (styrene-acrylonitrile), (ii) P2 - ASTALAC® ABS (acrylonitrile butadiene styrene) 2029-2, and (iii) P3 - DOWLEX® polyethylene resins. The fibers materials used in this work are shown in Figure 7 and its properties are shown in Table 4.

**Table 3** Hardness and impact properties of different fibers

Fibers	Hardness	Impact (J)
Kevlar Fibers	69.2	3.2
Glass Fibers	71.4	2.4
Carbon Fibers	78.1	1.2

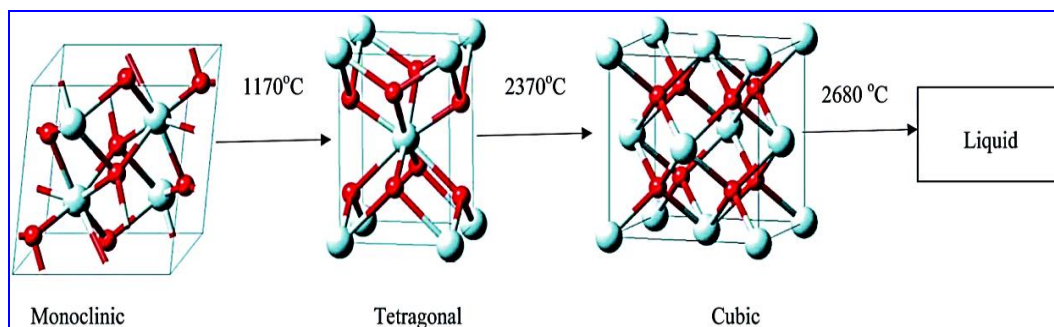
**Table 4** Properties of different fibers

Property	Tensile Strength	Compressive Strength	Elastic Modulus	Density (g/cm <sup>3</sup> )
E-glass fibers	3445(MPa)	1080(MPa)	73(GPa)	2.58
Carbon fibers	(3–7 GPa)	(1–3 GPa)	(200–935 GPa)	1.75–2.20
Kevlar fibers	2757.9(MPa)	517.1(MPa)	151.7(GPa)	1467(kg/m <sup>3</sup> )



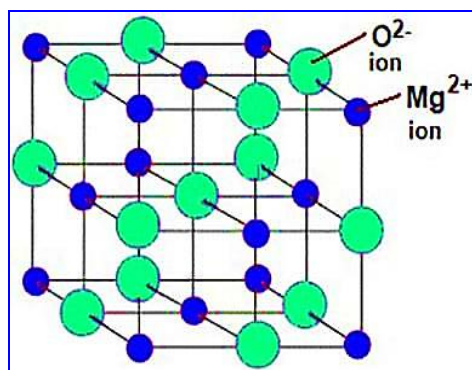
**Figure 7.** (a) Kevlar-49 fiber, (b) Carbon fiber and (c) E-glass fiber.

Zirconium dioxide ( $ZrO_2$ ), which is also denoted to as zirconium oxide or zirconia, is an inorganic metal oxide that is largely used in ceramic materials. There are many different ways of producing  $ZrO_2$  nanosize powders, such as hydrothermal processing sol-gel processing and ion exchange manufacture methods [7]. Pure  $ZrO_2$  exhibits three crystalline forms. Pure zirconia is monoclinic (M) at room temperature. This phase is stable up to ( $1170^\circ C$ ). It will transform into a tetragonal (T) phase under higher temperatures and later into a cubic phase (C) at ( $2370^\circ C$ ) as shown in Figure (8) which illustrate  $ZrO_2$  nanoparticles in three main crystalline structure phases: (a) cubic, (b) tetragonal and (c) monoclinic [8]. Zirconia was used in different fields of chemistry such as ceramics and catalysis. Nano-zirconia ceramics are of great attention due to their obvious enhancement in strength and toughness. Its high hardness, low reactivity and high melting point ( $2715^\circ C$ ) changed the mechanical property, thermal performance, electrical performance and optical performance of ceramic components [9].



**Figure 8.** Illustration of three polymorphs of  $ZrO_2$ : (a) cubic, (b) tetragonal and (c) monoclinic [9].

The magnesium oxide (MgO) is a very suitable material for insulation applications due to its low heat capacity and high melting point (2850°C). MgO was obtained by thermal decomposition of different magnesium salts. The crystal structure of magnesium oxide is cubic, as shown in Figure (9). MgO was used as a dielectric layer due to its excellent properties such as high dielectric constant (~9.8), large bandgap in the range of (7.3 eV-7.8 eV) and higher breakdown field (12 MV/cm) compared to the commonly used dielectric layer. Magnesium oxide nanoparticles can be applied in electronics and coatings fields [10].

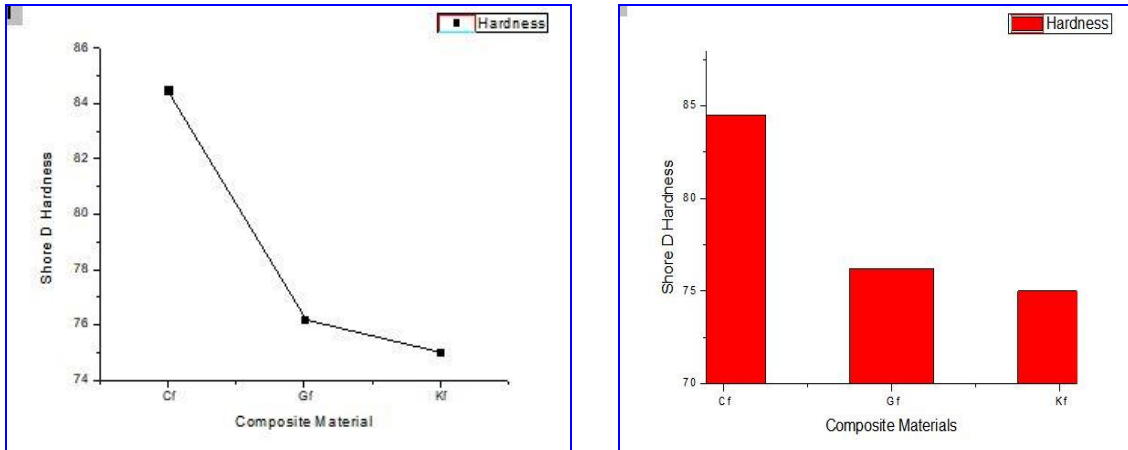


**Figure 9.** Molecular structure of a magnesium oxide (MgO) nanoparticle [10].

#### 4. RESULTS AND DISCUSSIONS

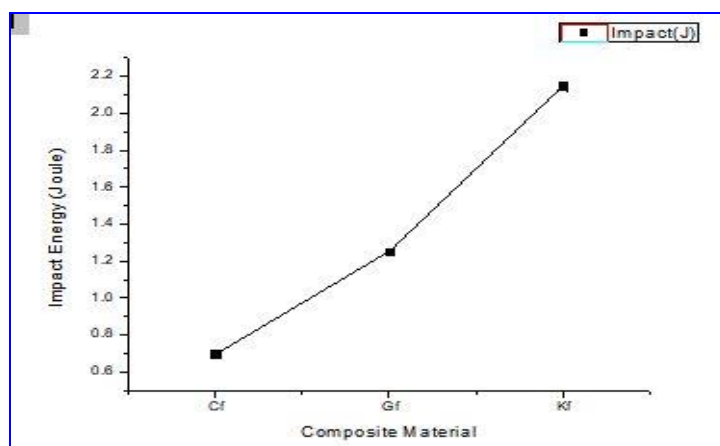
The most common mechanical properties for the purpose of the examination of any material are the hardness which is the resistance of the material to penetrate by an earlier material, durability which is the ability of the material to absorb the impact of the impact, and formation of a formation before the occurrence of fracture [7,8]. The resin is fragile and its resistance to external loads is very low. But when phenol-formaldehyde is added, the resistance to composite material will improve significantly because it is characterized by its low elasticity. This resistance is increased by increasing the added weight ratio because it occupies more space inside the resin, allowing better distribution of the load. It is known that fragile materials contain a small elastic deformation area. The elasticity coefficient values increase with the increase in the ratio of the reinforced material due to the increase in bonding density, which greatly affects fibers elasticity. Therefore, the material becomes solid at low voltage rates and thus increases the elasticity coefficient. As for the hardness characteristics of the mixtures, the resin is a low-hardening material, but when reinforced with fibers, the hardness properties of the compound material are clearly improved because they occupy more space within the resin, allowing better distribution of the load. Figure (10) shows the hardness of composite materials by the type of fibers, where it is observed to be fairly close, and the highest values of the hardness were composite materials supported by carbon fibers followed by glass fibers and then Kevlar fibers [9].





**Figure 10.** The hardness of compound materials by fibers type.

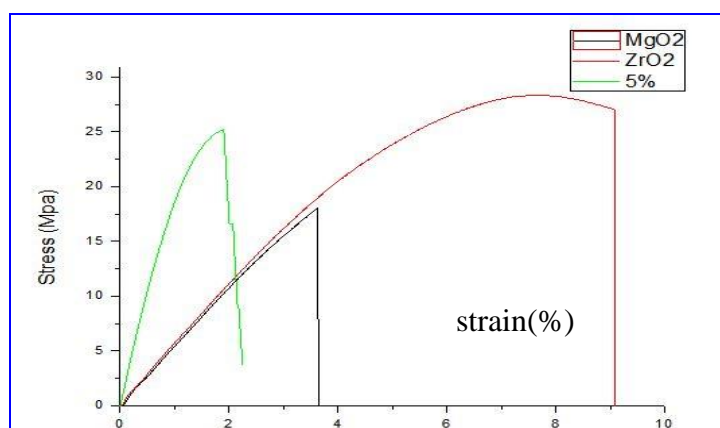
The nature of fibers has a great role in determining the values of hardness because the hardness of these fibers vary by type. Some fibers are made of ceramic materials while the other fibers are made of polymeric materials. The hardness test was carried out using the regression method and by four readings per sample. This was the most suitable method for measuring hardness because the hardness values obtained reflect the condition of the material as a whole and not just the surface state. Fibers' orientation has an influential role in hardness values. The statistical pattern ( $90^\circ - 0^\circ$ ) gave the highest values of hardness compared to samples of the random pattern. This indicates that the use of fibers in a concrete pattern gives more positive results in the reinforcement process. It is also noted that the fibers reinforcing system increases the hardness value of the fracture specimens. Its total volumetric volume increases the hardness value with the increasing number of layers of reinforcement, which confirms the positive effect of the arming process with these fibers [10]. Figure 11 illustrates the impact of fibers on impact resistance. Kevlar fibers gave the highest impact values of glass fibers and carbon fibers. The reason for this is that Kevlar fibers have the greatest ability to absorb shock energy. The shock test is one of the most dynamic mechanical tests in which the material is subjected to rapid engine load. Shock testing of Charpy samples was performed at room temperature, where the value of shock resistance decreases as the volumetric fraction of the supporting molecules increases because they are weak intolerance of the permissible load [11].



**Figure 11.** The impact of compound materials by fibers type.

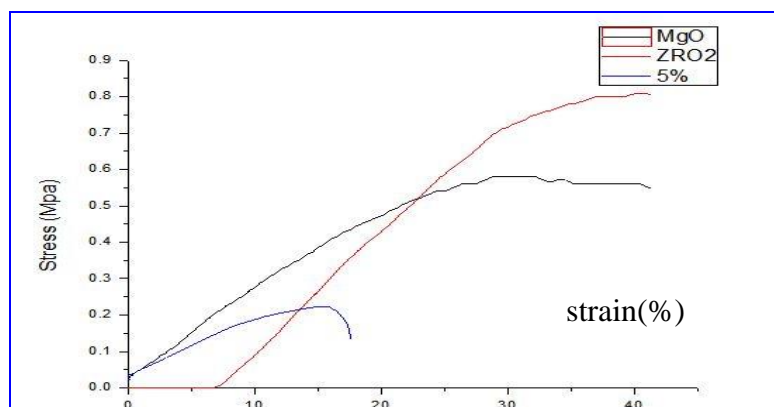
The failure of the non-reinforced resin material under the impact of the shock test results in the breakdown of the bonds or forces in the polymer by the growth of the initial cracks that arise as a result of the impact of the shock pressures. These cracks grow and multiply rapidly towards

the interfaces between the polymer fibers because the forces between these fibers are (Van der Waals), which require a small amount of energy to overcome them, and the cracks extend in a direction perpendicular to the direction of polymer fibers to break these fibers during the propagation process, it is worth mentioning that this requires more energy to overcome covalent bonding. Figure 12 shows the tensile relationship of the stress curve of the composite material to the epoxy resin with phenol-formaldehyde resin by (5%) and the reinforcement of the various nanoparticles (Magnesia and Zirconia Oxide) resulted in improved properties. Zirconia oxide particles gave the best resistance to stress through the stress curve compared to the magnesium oxide and composites without addition, because polymer nanoparticles as an interactive mixture of polymer with nanoparticles are characterized with a small size of fillings leading to a widening of the interstitial area, thus creating a large part of the polymer's interaction with nanoparticles in the structure of polymeric molecules, which play an important role in enhancing the strength of the polymer structure, polymeric nanomaterials improve the mechanical, thermal, electrical and optical properties clearly, without increasing the density [12].



**Figure 12.** The tensile stress-strain curve of compound materials by nanoparticle type.

Figure 13 shows the relationship of the stress-stress curve to the composite material contained on epoxy resins with phenol-formaldehyde by (5%) and the reinforcement of various nanoparticles (magnesium oxide and zirconia oxide). Zirconium oxide nanoparticles gave better bending resistance than magnesium oxide particles and composite matter without addition, assuming that the properties of the material were uniform by uniformly distributed power.



**Figure 13.** The bending stress-strain curve of compound materials by nanoparticle's type.



## 5. CONCLUSIONS

- i. Toughness increases with the increased in the weight ratio of fibers.
- ii. The elasticity value increases when fibers are reinforced due to increased bonding density.
- iii. Fibers-reinforced leads to a decrease in material hardness due to the generation of pores.
- iv. The cracks grow and multiply rapidly towards the interfaces between the polymer fibers because the forces between the fibers are strong Van der Waals.
- v. The reinforcement of the various nanoparticles (magnesia and zirconia oxide) resulted in improved properties.
- vi. Zirconium oxide nanoparticles gave better-bending resistance than magnesium oxide particles and composite matter without addition.

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