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RESEARCH ARTICLE

Shock and Flexural Strength of Composite Materials Reinforced by Kevlar Fiber

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Abstract

Composite materials in this regard represent nothing but a giant step in the ever-constant endeavor of optimization in materials. The research aims to study the mechanical properties (shock strength and Flexural strength) of composite materials (epoxy resins with phenolic formaldehyde resin) supported by graphite or silica particles or both, and reinforced with Kevlar fibers.

Introduction

Strictly speaking, the idea of composite materials is not a new or recent one. Nature is full of examples wherein the idea of composite materials is used [1]. In the 20th century, modern composites were used in the 1930s when glass fibers reinforced resins. Boats and aircraft were built out of these glass composites, commonly called fiber glass.

Since the 1970s, application of composites has widely increased due to development of new fibers such as carbon, boron, and aramids and new composite systems with matrices made of metals and ceramics [2]. Phenol formaldehyde resins is a type of polymer is made from two main substances: phenol and formaldehyde. Phenol is a colorless solid compound, but when exposure to oxidation in the air it's colored by pink then brown.

It has strong odor and penetrating. Phenol is widely used in the manufacture of materials for plastics, including drinking water bottles, as well as in the clothing industry. Phenol is used in the installation of nylon. It has medical uses; it is used in the manufacture of disinfectants, lotions, ointments, topical anesthetics and the pharmaceutical industry [3]. The water solution which contains a concentration of 40% formaldehyde is called formalin. this is used as a preservative for tissues and in embalming, with a boiling point of 21 ° C, it is used in veterinary and in dentistry as well as in the production of chemicals and polymers and is often used in the manufacture of coatings and explosives [4].In general, phenol-formaldehyde produced by two ways, for manufacture two types of polymers, namely Novolac and Resole [5].

Novolac is a type of polymers produced by mixing formaldehyde (37% water solution) with phenol by added an acidic helper (sulfuric, phosphoric or oxalic acid), and heated to the required degree and then equivalent the reaction mixture, and remove the water by distillation (in its final stages under discharge) to a temperature Estimated 160 ° C . Resole is a type is produced by added basic helper with more formaldehyde relative to phenol. Initially, its consists (Oligomer) is called a resole and it is not needed to a hardener (HMTA) but it need just heat treatment [3, 6].

In (2011), M. F. Khdeer., investigated the effect of the weight fraction and grain size of SiO_2 on the thermal conductivity of epoxy. The results show that the thermal conductivity increases with increasing the weight fraction and reduces with increasing the grain size of silica particles in nonlinear relationship and maximum difference between the unreinforced epoxy and reinforced epoxy was (0.445 W/m. oc) at weight fraction of (20%) and grain size of (20 µm) of silica particles, where at this value of weight fraction and grain size the thermal conductivity was maximum value at (k= 0.61 W/m. oc)[7].In (2012) Farag M. and Drai A. Demonstrate the effect of graphite filler contents on the mechanical and tribological behavior of glass-polyester composite system.

The tensile strength was studied according to ASTM-D 638-87and the wear rate and wear resistance were investigated according to ASTM-D 5963 using pin on disc machine to present the composite tribological behavior. They showed that the mechanical and tribological properties behavior was improved when the graphite filler content was increased [8]. In (2012), Mohammed Ismail et. al., fabricated epoxy resin reinforced with 20% weight fraction carbon fiber and (0, 2, 4) % weight fraction of fly ash chemosphere (CSP) having particle size 25 to 50 µm by hand lay- up technique followed by compression molding.

The solid particle erosion characteristics of the (CSP) filled (C-E) composites were studied and the experimental results were compared with those of unfilled (C-E) composites. For this, an air jet type erosion test and Taguchi orthogonal arrays (L27) were used.

The result showed that the tensile modulus and flexural modulus of fly ash ecosphere filled (C-E) composites are high compared with that of the unfilled (C-E) composites, this enhance is due to higher silica content (60%), therefore a good interfacial adhesion between the ecospheres particles and the matrix occurs. The samples of composite materials (epoxy resin – carbon fiber) and (epoxy resin + carbon fiber+ CSP) shown ductile erosion behavior and the peak erosion rate was found at 30° impingement angle.

The erosion rate increased when the impact velocity increased. Also, the filler content had the greater effect factor than impact velocity, particle size impingement angle, and time of erosion during the erosive wear process [9]. In (2013), Hamid S., studied the mechanical properties (tensile, bending, and hardness) of unsaturated polyester resin reinforced with silica particles in different weight fractions (10, 20, 30 and 40) %.

Results showed decreasing in tensile strength and flexural strength with increasing particle concentration, increasing in hardness, tensile modulus and bending modulus with increasing in particle concentration [10]. In (2014), Najwa J et al, prepared Epoxy/ SiO2 Nano composites with different volume fractions of SiO2 Nano particles (1%, 3%, 5%, 7% and10%). The fatigue behavior of unirradiated and UV irradiated composites was reported in the ambient temperature for (240 hours).

Minimum roughness of the composites was found for composites with 3% vol. fraction of SiO2 nanoparticles. Then, Epoxy/ SiO2 Nano composites were reinforced with 6 layers of chopped mat E-glass fiber to study their fatigue behavior. Values of fatigue strength, fatigue life and fatigue limit of the tested composites were investigated. The results showed that the addition of SiO2 nanoparticle enhanced the fatigue behavior, however more enhancements was obtained for Epoxy/ SiO2 Nano composite reinforced with 6 layers of chopped mat E-glass fiber.

This study indicated that the UV radiation enhance the fatigue life of tested samples due to the formation of cross linking structure in the presence of the UV radiation [11]. In (2015), A. Vikram et al studied the influence of different content ratios and lengths of carbon fiber reinforced epoxy composites. Carbon fiber is taken in the 3, 5, 7 % weight in order to suspend on epoxy resin with different fiber lengths such as 1, 2, and 3 cm.

Moreover they studied the thermal properties such as TGA and DSC to investigate the influence of change in fiber length on Carbon fiber–epoxy composites. Significant improvement in tensile and flexural strengths of Carbon fiber–epoxy composites has been observed by the different fiber lengths.

Flexural strength, flexural modulus, tensile strength and modulus were increased correspondingly up to 5%wt and 2 cm length of carbon fiber reinforced epoxy and decreases with further addition of fiber contents i.e., 7% wt. they concluded that Carbon fiber-epoxy composites can be used for high strength, stiffness, and bending applications in aerospace, automobile, and marine and lightweight article applications.

Overall studies indicated that the carbon fiber reinforced composites at 2 cm length of carbon fiber and 5%wt loading are promising candidates for structural applications where high strength and stiffness is indispensable [12]. In (2015), Jweeg et. al. Designed a new athletic prosthetic foot.

The foot was manufactured by using epoxy reinforced by carbon fibers and that gives good mechanical response. The impact tester was designed and manufactured to perform the test. For the same dropped level, the impact response of the samples with glass fiber and carbon fiber have the same peak load for different drop angle but. In addition, it was clear that the responses of the sample manufactured with carbon fiber were more smoothness than the sample manufactured with the glass fiber [13]. In (2016), Jagadale U.S. and Raut L.B., investigated the mechanical properties (tensile strength and shear strength) of glass fibers reinforced polymer matrix with different fibers volume fraction (40, 50 and 60) %, hand lay-up and compression molding were used to prepare the samples. Results showed better mechanical properties at volume fraction (50%), further increase in the fiber content leads to increase in the mechanical properties but the composites start to delaminate [12].

Experimental Procedure

The practical part includes preparation of raw materials and how to prepare them, as well as mechanical tests conducted on composite materials. The epoxy resin was mixed with phenol formaldehyde resin (called resole). Different mixing ratios were used to obtain samples as follows:

Specimen No	Specimen
ER_1	(Epoxy/Resole) (100/0)%
ER_2	(Epoxy/Resole) (95/5)%
ER_3	(Epoxy/Resole) (90/10)%
ER_4	(Epoxy/Resole) (85/15)%

Material Used

The material used in this work divided to two matrix material: Epoxy resin, Phenol formaldehyde (resole) resin. After the mechanical tests on the previous samples (different mixing rates), the best case was chosen, and at mixing rates: (Epoxy / Resole) (95/5) %

The selected samples will then be supported: (Epoxy / Resole) (90/10) %, with graphite or silica or both. The composite material (epoxy +resole) was selected by both graphite and silica, as it gave the best mechanical properties. The composite material (epoxy + resole), supported by both graphite and silica, is then combined with Kevlar fiber. Kevlar Fibers (KF): is a high-performance fiber that is widely used to support advanced polymer-based composites, because of: * Kevlar fiber has the highest value in the coefficient of flexibility and durability compared with the all types of fibers.

- Kevlar fiber has a variety of physical and chemical properties. *Fabrication of composite and fibers is relatively inexpensive. The final case is the composite material (epoxy + resole), supported by both graphite and silica, together with Kevlar fiber, as the ideal case
- All this mixing ratio reinforced by Cuffler fiber with volume fraction of 20% accepted ER3.

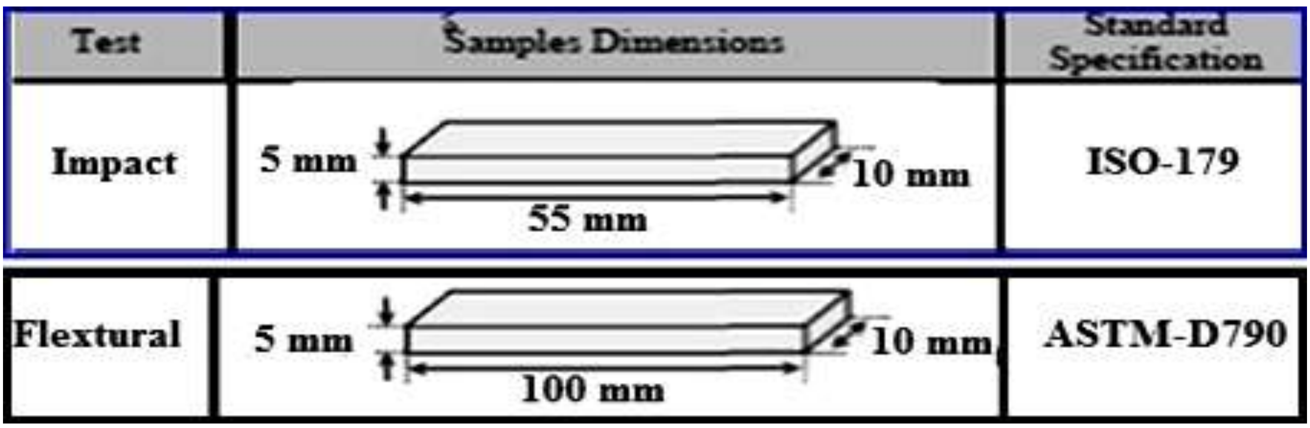

Fig.1: Samples dimensions and standard specifications of the testing specimens [5]

Technical Testing Procedures: There are several instruments and equipment utilized to measure and determines the mechanical properties of the materials under investigation. Mechanical Testing Instruments: Mechanical properties were measured at room temperature (25) °C.

$$I.S = \frac{Uc}{A}$$

Impact strength test: Mechanisms of failure occurring in material due to quick stress, the material is ductile under static stress and becomes brittle under dynamic quick stress. Impact strength (I.S) is calculated by applying the relationship:

Where: Uc: is the fracture energy (Joule) which is determined from Charpy impact test instrument.

A: is the cross-sectional area of the specimen. Table (1) Show the Effect of mixing ratio on the Impact Strength.

Table 1: the Effect of mixing ratio on the Impact Strength

Sample No.	Impact Strength (I.S.), KJ/m^2
ER_1	70.05
ER_2	88.16
ER_3	69.9
ER_4	44.05

Flexural Test

This test was performed according to ASTM (D-790) at room. The samples were tested two times and the average measurement values were taken. Table (2) Show the Effect of mixing ratio on the flexural Strength.

Table 2: the Effect of mixing ratio on the flexural Strength

Sample No.	Flexural Strength (F.S), Mpa	Flexural Modulus (Eb), Gpa	Shear Stress (τ), Mpa
ER_1	**123.87**	**1.186**	**2.225**
ER_2	**587.34**	**8.158**	**15.564**
ER_3	**769.33**	**10.125**	**16.386**
ER_4	**951.8**	**14.492**	**17.228**

Results and Discussions

Shock Test

The shock test is one of the important dynamic mechanical tests in which the material undergoes a very rapid motor load. The shock test of the samples was carried out in a Charby method at room temperature, which is one of the three-point bending test images. The shock resistance of the Composite material (Gc) and the shock breaking strength of the Composite material (Kc) were calculated using the energy needed to obtain the fracture in the sample (Uc), which was measured by the probe and using the Eb curve bending coefficient obtained from the bending test,

In the previous studies and the current study, the samples are divided into two parts, which suffer from fragile fracture at the point of impact of the sample with pendulum, while other samples have a fractional fracture, where the values of resistance to the shock decreases with the increase of fractional volume of the graphite and silica minutes, The minutes are weak in the scalability of the resistor The fracture of both graphite and silica was confirmed in this study. Therefore, the shock resistance values for the samples supported by graphite and Kevlar fiber are higher than the values their samples are supported by silica and Kevlar fiber.

This may be due to the nature of the samples supported by graphite and Kevlar fiber reinforced with high shock resistance and durability compared to silica-supported and Kevlar fiber-reinforced samples that have the characteristic Easy to break into small pieces. As for the effect of the particle size of the supporting particles on the shock resistance values of the samples, the shock resistance values decrease with the increase in the minute size of the minutes due to the difficulty of penetrating those large minutes inside the base material and into the fiber mesh interface, which reduces the wettability of the base material of the reinforcing materials.

The contact area and then the weak bonding between the components of the composite material prepared as well as creating a lot of defects, which act as centers to focus the stresses and reduce the energy needed to break and thus reduce the values of resistance to shock. The severity of the shock fracture, as indicated by previous studies, indicates a small increase in the increase of the fractional fraction of the reinforced particles by the composite material (graphite and silica). The increase in the fractional energy of the composite material prepared to withstand the reinforcement materials is part of the shock stress this material is based on the strength of the bonding between the reinforcing materials and the base material for the transfer of the fracture during the interface around the substrate.

For minutes in case of failure of minutes, in addition to the dependence of this relationship on the fraction of volume, shape, size and distribution system within the base material, then the last value of the durability of the shock break down the material slightly to increase the percentage of minutes that lead to weak mixing with the base material, And the increase of the interfaces between the base material and reinforcement materials will lead to increased defects and decrease in the amount of energy needed for the occurrence of fracture and this is what the researcher (BF Blumentrit) that the material is torn when there are cracks in the base material and at the boundary between the base material and materials The previous studies have indicated the effect of the minute size of the graphite on the strength of the fracture, where the fracture strength was found to decrease with the increase in the size of the graphite minutes. This is due to the fact that the use of minutes in small sizes will facilitate the base material mixed with the minutes of the graphite penetration to the inside of the interwoven network within the fiber network and facilitate the process of wetting the base material for all surfaces of the materials of the reinforcement and thus will increase the demand and increase the strength of bonding between the reinforcing materials and the base material, which eventually lead to withstand shock stress with higher values and the contrary.

The work of the large minutes to create a lot of defects and gaps and aerobic space, which reduces the wetness as well as the creation of areas for the concentration of stresses, which helps to accelerate the growth of the fracture and thus to break the sample with a lower shock load, and also notes through the current study that the values of fracture strength of samples supported by graphite minutes Silica and Kevlar fiber are higher than their counterparts in graphite or silica particles, given the high durability of Kevlar fibers and shock tolerance. Fig. (2) Show the Impact Strength of Composites Blends.

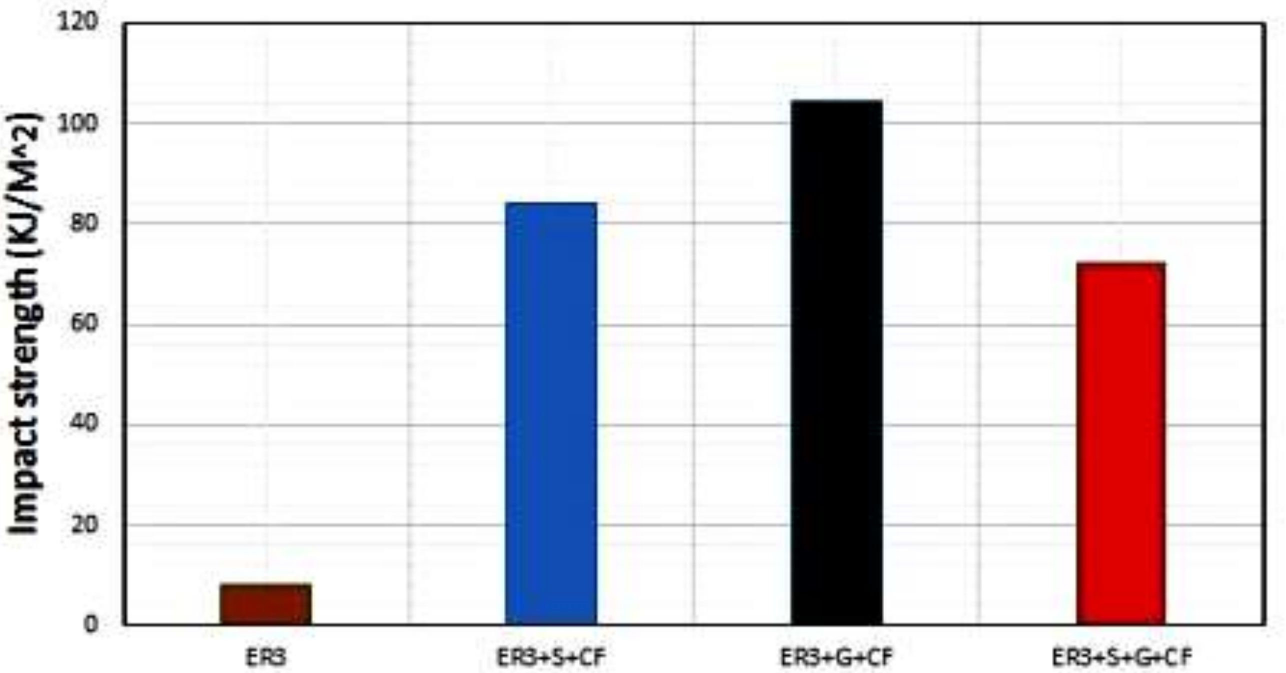

Fig. 2: Impact Strength of Composites Blends

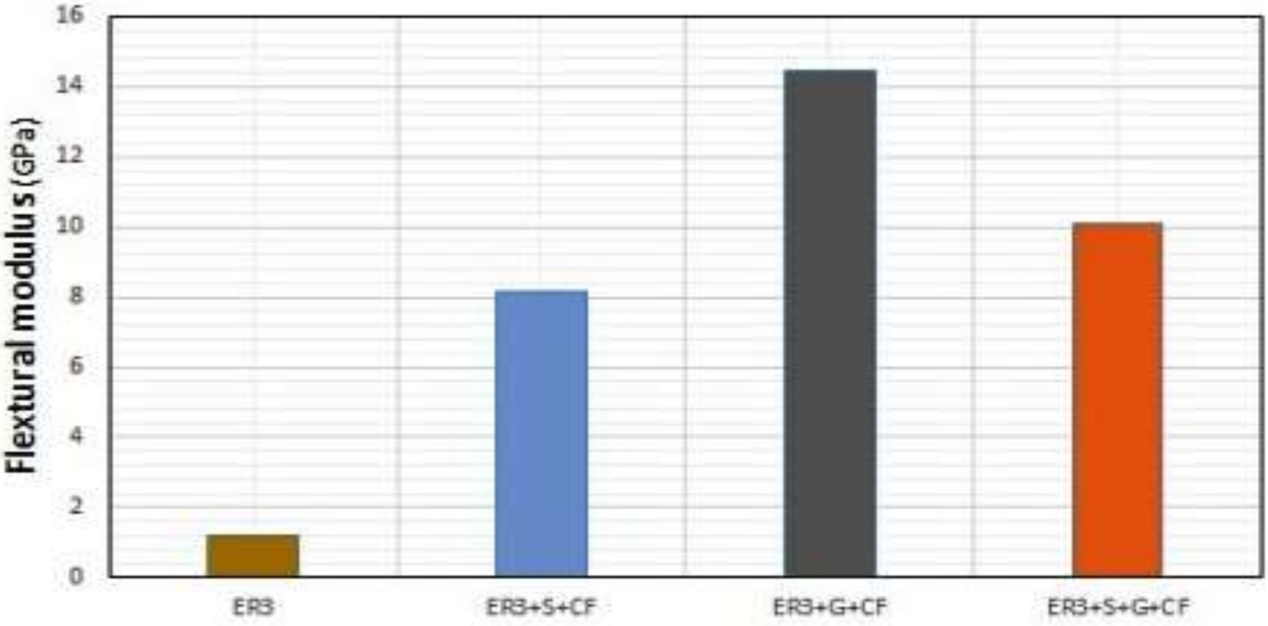

Fig. 3: Show the Flexural modulus of Composites Blends

In this study, the shock strength of GC and the shock strength of Kc were calculated based on the absorption energy obtained from the shock absorber and the E_{bend} curve (obtained from the bending test). It was observed that the shock strength of the material showed a marked increase in the thickness of the graphite particles compared to the silica minutes, and the increase rate when reinforced with the graphite and silica minutes is higher compared with the Kevlar fiber armament, as shown above, Showed that the rate of increase in the durability of the shock increases with the increase of the fracture of the fiber because of the possession of this fiber of the properties of high durability and shock [11].

In addition to the effect of the nature of the surface, the more rough the surface the more durability because it contains fibrous filaments accurate, leading to a mechanical link between the fiber and the base material, which in turn requires additional energy to remove the fiber from the base material [3].

The study showed that the samples supported by Kevlar fiber with a statistical pattern (0^{o} -90^{o}) gave the best values of the durability of the shock compared to the samples supported by carbon fiber in the random format. This is due to the fact that the direction of the fiber parallel to the direction of the force of the percentage (50%), to absorb the (CF 15% GF 15%).

It was found that the laminating system in armaments did not significantly affect the shock strength values of fiber-reinforced samples [4]. However, noting that the rate of increase is slight and increases slightly with the increase in the number of layers of reinforcement. In the present study, it was found that Kevlar fiber reinforcement after the reinforcement in the minutes of the graphite and silica has no effect, the strength has decreased after the reinforcement with Kevlar fiber.

Previous studies have shown that the strength of the shock fracture of the material showed a significant increase in the thickness of the graphite minutes compared to the silica minutes for the same reasons mentioned earlier in the material durability article, because of the tolerance of the force attached to the composite material.

In addition, the strength of the shock fracture is affected by the values of the bending elasticity coefficient and the shock strength of the material. The high or low value of both the bending elasticity coefficient and the material shock strength will result in fluctuation of the shock breaking strength [3]. mechanism of failure in the article with rapid stresses is a mechanical characteristic that has received considerable attention from many researchers because there is always a risk that such polymeric materials may be ductile under the influence of static stresses but may appear brittle under the influence Rapid Stress [6] As previously shown, the Charpy Impact test is one of the tests that can be used to study the behavior of materials under the influence of rapid forces.

If we observe in this test, it is one of the three (Dynamic Three-Point Flexure Test). Therefore, increasing the speed of the examination plays an important role in influencing the mechanical properties of the material. Therefore, the most important mechanisms that are responsible for the failure of the material exposed to the static bending test also stand out clearly when the material is subjected to a probabilistic test. In fact, the composite materials that are subject to Charpy's assay are described as the resistance to cutting the inner layers and low value compared to the composite materials subjected to the static bending test.

Harris concluded that the resistance to cutting the inner layers of the composite material decreases with the loading rate. Harris demonstrated this through His suggestion was that large cut stresses arise at the free Edges in the material exposed to the static bending test and may be somewhat dissipated by Creep occurring in the polymeric base material, while at high loading rates it is observed that sufficient time is not available for this to occur.

Harris' suggestion shows a loading rate, which means a decrease in the resistance of cutting the inner layers of the composite material [7]. Thus, it is clear that the problem of fragile fracture arises at high load rates and therefore the trauma test using the Jarbi method has been initiated on all models prepared for this purpose. The impact resistance was calculated as the composite material supported by the graphite minutes possessed higher breaking energies than that of the composite material supported by silica minutes because when an external force is deposited on the overlapping substance, it affects the fragile material (silica), dispersing the granule and thus destroying it , While the distance between the granules is large and the polymer (rizol) to absorb this energy and fade, while in the other case the distance between the granule - granule (silica) is small, so dispersion spread to the other granule quickly so it breaks fast [8].

In general, the failure of the unsupported resin material under the shock test results in the breakdown of the bonds or forces in the polymer by the growth of the initial cracks of the shock stress. In fact, these cracks grow and proliferate rapidly towards the interfaces between the polymer chains because the forces between these polymeric chains (Waal - Vander), which require a small amount of energy to overcome them, and the strands extending in the vertical direction on the direction of the polymer chains, destroying these chains during the propagation process. It is worth mentioning that this Demand more energy to overcome those responsible for linking the structural units of Covalent bonds forces [10].

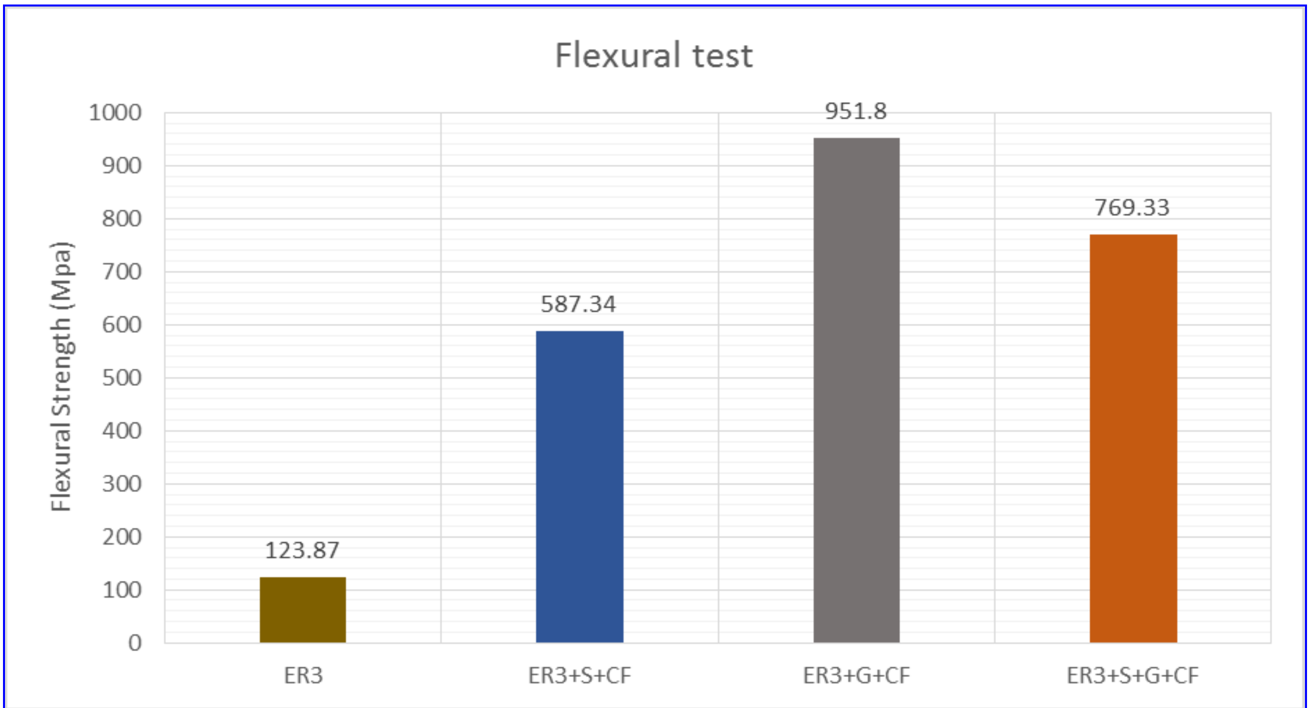

Fig.4: Flexural Strength of Composites Blends

Bending Strength and Flexural Strength

The bending strength test is a complex test because the sample is subjected to several stresses at the same time: the tensile stress at the outside of the sample, the pressure stress on the inner surface of the sample and the shear stress that occurs at its interface. The composite material fails under the influence of one of these three stresses Depending on the type of reinforcement material and the strength of the bond between them and the base material where it was found through previous studies that the values of bending strength and the values of the shear stress increased when adding the minutes of graphite and silica to the base material armed with Kevlar fiber.

The graphite and silica graphite are highly resistant to compressive stress and gypsum compared to Kevlar fiber, but increasing the fraction of the graphite and silica minutes reduces wetting within the base material, making it a concentration of stresses, thus increasing defects and cracks, thus weakening the bond between the base material And the reinforcement material and the sample fails completely.

The effect of the perpendicular size of the graphite and silica particles on the bending strength values and the stress weight values showed that the use of minuscule minutes in small minute sizes (75µm PS PS> 25µm) and volumetric fracture of the graphite (10%) resulted in increased bending strength values, With the values of their counterparts supported by the graphite minutes and fractional size (10%) with large minuscule sizes (106µm PS PS> 90µm). This is due to the fact that the use of small-size graphite minutes will facilitate the wetting of the base material of the reinforcement materials, the overlapping material is prepared and then z the higher the bond strength between them and ultimately increases their tolerance to external stresses.

The lower bending values and shear stress values are also observed with the increasing size of the graphite minutes because the use of large minutes reduces the wetting of the base material and increases the formation of air defects and spacing. Overlapping of external loads [9].

Conclusions

The results obtained can be summarized as follows:

- Low values of mechanical properties of phenolic formaldehyde resin.
- The mechanical properties of phenolic formaldehyde resins are enhanced after silica and graphite reinforcement and Kevlar fiber reinforcement.
- The values of mechanical properties increase with the increase of the weight ratios added.

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