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# Studying The Effect of Gamma Rays on The Impact Strength and Wear Properties of Silicon Carbide SiC and Graphite Gr Nanocomposites

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**ABSTRACT**

In this paper, composite materials were prepared using epoxy as a base material supported by nano - silicon carbide and nano - graphite particles with different weight fractions (2%, 4%, 6%) for each separately by manual molding method. Some mechanical properties (Impact strength, wear resistance) of the samples were studied under natural conditions and after exposure to gamma rays at different doses (6,8,10 kGy). In normal conditions, it was found that the values of impact resistance increased for all samples of the composites reinforced with (SiC) and decreased for the composites reinforced with (Gr) and it increased for all samples when exposed to gamma rays. It was found that the wear values decrease with increasing reinforcement percentages for all samples and values decrease for all superimposed samples when exposed to gamma rays and continue to decrease with increasing irradiation period and be less than it is in circumstances. The materials prepared in this study can be used in sliding and rotating places because their wear coefficient is very low. They can also be used to attenuate low doses of gamma rays. They can also be used as containers for transporting goods because their impact strength is high.

## Introduction

Composite materials can be defined as those solid systems resulting from the mixing of two or more materials of different shapes or composition, provided that they do not interact chemically with one another, but they cooperate physically to form a new material [1, 2]. The choice of plastic, ceramic, or mineral additives (strengthening materials) is according to the type of use whether it is structural or industrial uses or thermal or electric fields), wool, or fillers, or particulate [3]. Nano - composite materials are considered one of the most important categories of advanced materials that emerged at the end of the last century, as a result of the fusion of the human mind with modern technologies in the fields of metal production and engineering materials, and to open up bright future prospects for the world in its third millennium and to add broad hopes in solve intractable problems in all fields of life and industry.

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In recent years, there has been interest in irradiating composites with high energy and studying the effects of X-rays, gamma and beta rays on the generation of ion formations and free radicals that can generate cross-linking or chain scission degradation processes, as well as gas liberation processes. And its emission (Gas Evolution) from those materials [4, 5]. In this research, gamma rays were used specifically, and their effect on the polymeric composite materials that were made was observed, as it was found to affect the mechanical and physical properties, and the effect of these rays varies according to the dose of gamma rays [6].

## 2. Experimental Part

### 2.1. Materials used

#### 2.1.1. Matrix Material (Epoxy Resin EP)

The resin used in this study is Sika - 52 manufactured by Sika company, Australia. It solidifies when a solid Metaphenylen Diamine (DPDA) is added in a ratio of (2:1) at laboratory temperature. It is one of the types of thermosetting polymers and its properties are shown in Table 1.

**Table 1**: Some physical and mechanical properties epoxy EP.

| Type | Density ($\frac{gm}{cm^3}$) | Thermal Conductivity ($\frac{W}{m.°C}$) | Tensile Strength (MPa) | Percent Elongation (%) |
|---|---|---|---|---|
| EP | 1.1 | 0.19 | 25 | <6 |

### 2.1.2. Reinforcement Materials (Silicon Carbide SIC and Graphite Gr)

#### 2.1.2.1. Silicon Carbide SiC

Silicon carbide (SiC), also known as carborundum, is a semiconductor compound of silicon and carbon. It is found naturally in the form of the extremely rare mineral moissanite. Industrial carbide powder has been mass-produced since 1893 for use as an abrasive. Silicon carbide grains can be bonded together by sintering to form extremely hard ceramics that are widely used in applications requiring high endurance, such as car brakes, clutches and ceramic plates in bulletproof vests. Electronic applications of silicon carbide such as light-emitting diodes, lamps and detectors in early radios, circa 1907. In the current research, nano silicon carbide powder (Nano SiC) was used, its nano size (64.85 nm). (SiC) powder has an electrical classification as it is classified among semiconductors and there are two phases (α and β) and the α phase is more stable than the β phase and is sometimes called carborundum and is classified within insols. The β phase is classified as a semiconductor. The (SiC) powder used in this study is β type and its most important properties are shown in Table 2. Silicon carbide powder is manufactured by the Chinese company (EV NANO Technology Co.,Lt).

**Table 2.** The properties of Silicon carbide SiC

| Product Name | SiC Powder Nano Grade |
|---|---|
| Appearance | Green powder |
| Particle Size | ≈64.85 nm |
| Purity | 99% |
| Density | 3.22 g/cm$^3$ |
| Specific surface area | 90 $m^2$ /g |

#### 2.1.2.2. Graphite Gr

Graphite is one of the forms of crystalline semi-metallic carbon with a hexagonal crystalline shape, and it is the most stable among the forms of carbon in celiac conditions. Graphite is a low-density and cheap material used in the manufacture of pencils. It has distinctive characteristics such as high electrical conductivity, as well as good thermal and structural properties [7]. Graphite is a multi-layered material and has a flat structure. Its atoms are bonded together, contributing three valence electrons, while the fourth electron remains free, which explains its high electrical conductivity. The bonding between the layers of graphite is the Van der Walls forces, which make it easy to separate of its layers, and because of the distinctive mechanical and electrical properties that it possesses, it is widely used in industries based on nanotechnology, and the crystal consists of graphite with high electrical resistance [8]. The graphite nanomaterial manufactured by Skyspring Nanoparticle (C) of American origin was used with a gray nono-size (87.85 nm) with good purity. Table 3 shows some of the properties of graphite used in this research:

**Table 3**. The properties of Silicon carbide SIC

| Product Name | Gr Powder Nano Grade |
|---|---|
| Appearance | Gray powder |
| Particle Size | ≈87.85nm |
| Purity | 93% |
| Density | 2.09-2.23 g/cm$^3$ |

## 3. Preparation of Samples:

The hand lay-up molding method was used to prepare polymeric composites because it is one of the easy and commonly used methods. This method is summarized as follows:

1. Create the template:

To prepare the mold used for casting the overlapping materials, we follow the following steps:

• Cut two glass panels with dimensions (30 x 30) cm and a thickness of (6 mm). One of them represents the base on which the pouring is done and the other represents the cover.
• Clean the two glass plates before starting the pouring process with soap and water well in order to remove suspended matter and dust, then the two plates are dried in a drying oven at a temperature of (50 °C) for (15) minutes in order to evaporate the fats and other organic materials.
• Cover the two glass panels (the base and the cover) with thermal paper to ensure easy extraction of the casting material from the mold and to prevent it from sticking to the mold after the completion of the hardening process.
• Put the template in a flat place and it is ready to make samples.

2. Preparation of superimposed samples (Figure 1 shows the dimensions of samples):

Silicon carbide SiC and Graphite Gr powders were added to (Ep) according to the weight ratios shown in Table (4), and a sensitive electronic balance of the type (Sartorius) manufactured by the German company (Sartorius) was used, and it is sensitive to four grades (0.0001 g) .A glass rod was used in the mixing process to ensure that air bubbles did not form and to reach a state of homogeneity. Then, the superimposed material samples were prepared by adding the two ceramic materials, which are two reinforcing materials in three different proportions for each reinforcing material for the polymeric mixture. Adding each percentage to the epoxy, then mixing with continuous stirring for (10 min), after which the hardener is added and mixed for a period of (5 min). This process is done for all percentages of addition and for both reinforcement materials in the same way. An hour after that, the heat treatment process was done to complete the polymerization process.
3. Put the samples in a drying oven at a temperature of (50 °C) for a period of (6 hours) to reduce the internal stresses formed during shrinkage and also to obtain the best crosslinking.

**Table 4.** Weight fraction of samples.

| Weight of Composite (g) | Weight of SiC (g) | Weight Fraction Ψ | No. |
|---|---|---|---|
| 245 | 5 | 2% | 2 |
| 240 | 10 | 4% | 3 |
| 235 | 15 | 6% | 4 |
| **Weight of Composite (g)** | **Weight of Gr (g)** | **Weight Fraction Ψ** | **No.** |
| 245 | 5 | 2% | 5 |
| 240 | 10 | 4% | 6 |
| 235 | 15 | 6% | 7 |

The composites were prepared according to the following equations [9] :

$$\Psi = \left(\frac{w_p}{w_c}\right) \times 100\% \quad (1)$$

$$w_c = w_p + w_m \quad (2)$$

Where: $\Psi\ is\ weight\ fractio.$

$w_c$, $w_p$, $w_m$ : weight fraction for composite material, reinforcement material and matrix material respectively.
Figure (1) shows the dimensions and image of samples.

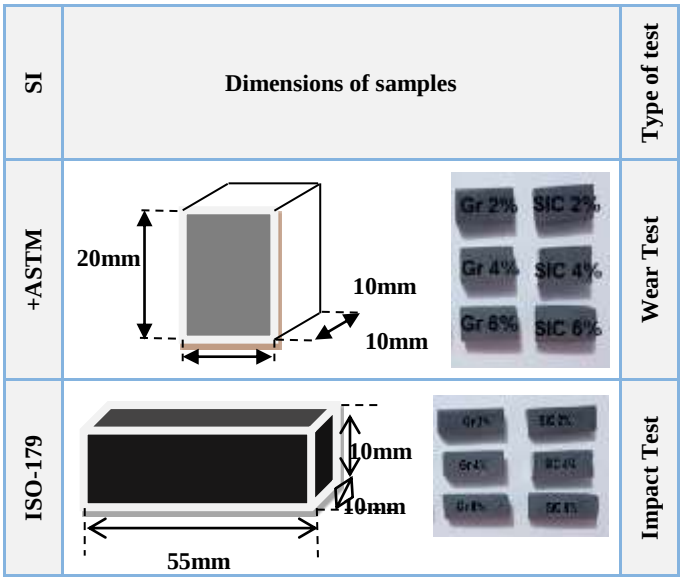


**Figure 1.** Dimensions of samples

## 5. Mechanical Tests

### 5.1. Impact strength

Charpy device was used to perform the impact test on the samples prepared for research. The potential energy will be converted into kinetic energy by swinging motion, and the pointer meter will read part of the

energy value of the sample. This test was performed at room temperature; This test is calculated from the relationship (3) [9] :

$I.S = U / A \quad (J / m^2)$ ( 3 )

Where I. S. is impact strength

U is Energy of fracture in (J), A is Cross section area in ($m^2$).

### 5.2. Wear Test

The sliding wear device shown in Figure (2) was used, which consists of a flat metal arm that contains a clamp to fix the sample and a rotating disc of aluminum whose hardness is (86 HB) connected to an electric motor, the speed of the disc is 500 (rpm).

$$\text{Wear Rate} = \frac{\Delta w}{S_D}\left(\frac{gm}{cm}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$\Delta w$ : The difference in mass before and after the test.

$S_D$: Sliding distance. $S_D = 2\,\pi\,r\,n\,t$ where r : radius (cm)., n : number of rot. (rpm)., t : time of test (min).

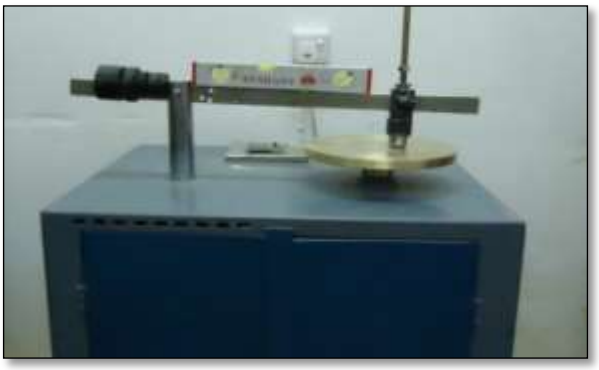

**Figure 2.** Wear device

## 6. Results and discussion

### 6.1. Impact Strength

### Before Irradiation (In Normal Condition)

Table (5) notes that the impact toughness of the (SiC)-supported samples had a higher impact toughness than the (Graphite)-supported samples, as shown in Figure (3), due to the (SiC) particles having high fracture toughness compared to (Gr) particles, which are fragile and easy to break. The brittle fracture nature of the reinforcing materials plays an important role in determining the impact energy [9]. We note that the impact resistance of graphite composites decreases with increasing the reinforcement percentage. This is due to the increase in the graphite filler, as it will reduce the ability of the polymer system to absorb energy, which reduces the durability. The reason is that the graphite particles concentrate the stress instead of distributing it, which begins with failure, this is due to the low flexibility of the polymer structures, which reduces their ability to change their shape (deformation), and thus the structures are weak to resist impact, i.e. the inability of the polymer system to absorb energy, which reduces the impact energy [10].

### After Irradiation

The superimposed samples were exposed to gamma rays with different radiation doses of kGy (6-8-10) for different periods at room temperature. The practical results are shown in table (5) and Figures (4) and (5) which illustrate the effect of gamma irradiation on the impact strength of polymeric composite materials. From this figure, we notice that the impact strength increases for all samples when these samples are exposed to gamma rays for five days. Because the absorption of gamma rays leads to the relaxation of the bonds between the particles of the superimposed material and its sliding movement, and this leads to the possibility of absorbing part of the energy and then increasing the energy required for breaking [11]. The gamma rays will penetrate the sample into the interior, which leads to an increase in crosslinking and bonding between the polymeric chains, and between them and the support materials at the interface between the two phases, thus increasing the impact resistance [12].

**Table 5.** Impact strength in Normal conditions and irradiation

| Sample No. | Composition | Impact Strength kJ/m² | | | |
|---|---|---|---|---|---|
| | | Normal Condition | Radiation Dose kGy | | |
| | | 0 | 6 | 8 | 10 |
| G 1 (EP+SiC) | EP+2%SiC<br>EP+4%SiC<br>Ep+6%SiC | 1.36<br>2.54<br>3.09 | 2.8<br>3.9<br>4.5 | 3.72<br>4.54<br>5.09 | 4.09<br>5<br>6.18 |
| G 2 (EP+Gr) | EP+2%Gr | 1.08 | 1.33 | 1.52 | 1.74 |

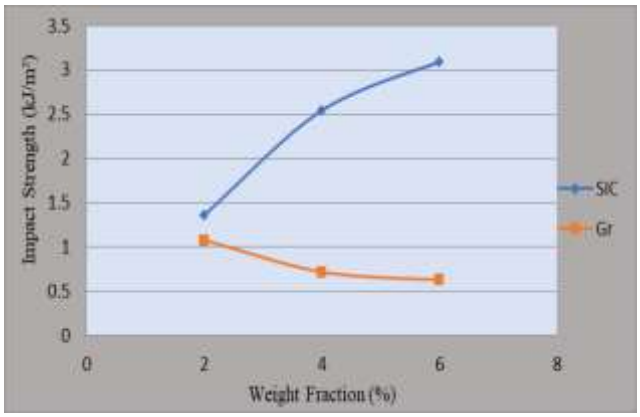


**Figure 3.** Impact strength for SiC-reinforced epoxy & Gr-reinforced epoxy with weight fraction.

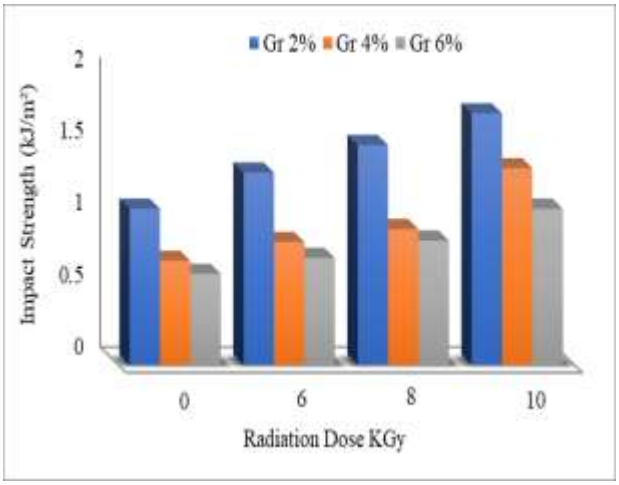


**Figure 4.** Impact strength for Gr-reinforced epoxy with weight fraction after irradiation with different doses of gamma rays.

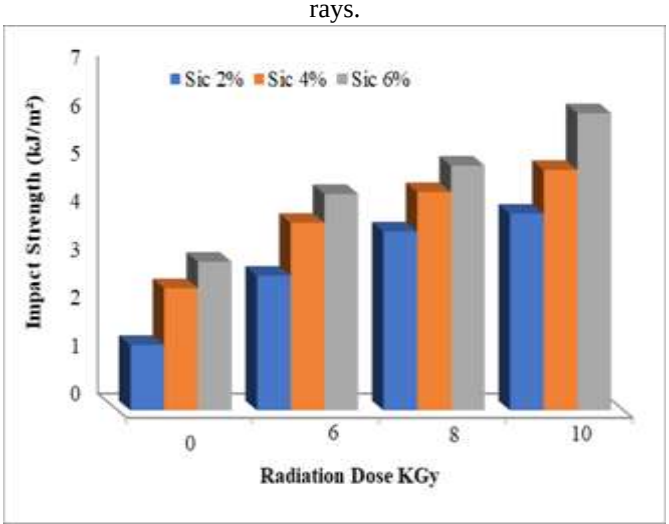


**Figure 5.** Impact strength for SiC-reinforced epoxy with weight fraction after irradiation with different doses of gamma rays

## 6.2. Wear Test

**Before Irradiation (In Normal Condition)**

Based on the experimental results, the rate of wear under natural conditions is shown in Table (6) and Figure (6). From this, note that the samples have a wear rate that decreases with an increase reinforced materials, due to effects resulting from the tension between the two contacting surfaces that are in contact with the sample and the disk when the sample is on the disk at a speed of (3.14 m/s) and a projected load of (20) newton. The clearest amount is (10) because the two surfaces friction contacts are made up of bumps and grooves, and the beginning of the contact between the product of the two surfaces takes place at the useful bumps without force. When the sample rotates on the disc, pressure and stress are concentrated on the sharp edges, which leads to obtaining a result of the softness of these bumps at their peaks in the area near the surface until they separate from the sample. Friction between the two surfaces leads to an increase in the temperature of the sample, which leads to increased breaking of bonds between atoms and molecules, and then to increased erosion of debris [13]. The reason for this is that this sample has the highest surface hardness value. This means that there is a strong bond between the polymeric chains with each other and their strong reinforcement of (silicon carbide and graphite) on the other hand to fill and close all the gaps and voids and reduce the ease of the different construction. The polymer molecule is in its free state, which leads to reduced mobility and rigidity, which means that it is tiring to separate it from the sample surface. When comparing the two reinforcement materials in improving wear resistance, (SiC) is considered better than graphite for all addition ratios. The reason is that the hardness of silicon carbide is higher than the hardness of graphite

.

**After Irradiation**

To find out the effect of irradiation on the wear rate of polymeric composite materials, the irradiation was done with gamma rays at a dose of (6-8-10 kGy) for different periods at room temperature. The practical results of changing the wear rate with the irradiation period are shown in Table (6). It is noted from table (6) and figures (6), (7) and (8) that the wear rate decreases with increasing irradiation duration for all samples and the

reason for that is due to the fact that the sample's absorption of gamma rays leads to bonding, and this means an increase in the hardness of the samples and thus less wear, (hardness is inversely proportional to the wear rate).

We note that wear is less for all samples when exposing these samples to gamma rays compared to normal conditions, because gamma rays lead to strengthening the bonding between the components of the superimposed materials represented by the base material and the reinforcing materials, and the longer the irradiation period increases, the gamma rays absorbed by the sample will increase, and this leads to the entanglement of the material overwhelms its decomposition characteristic, and thus as the surface resistance increases, that means the hardness increases, thus the material becomes more brittle [14].

**Table 6.** Wear test in Normal condition and irradiation

| Sample No. | Composition | Wear Rate (g/cm) x $10^{-6}$ | | | |
|---|---|---|---|---|---|
| | | Normal Condition | Radiation Dose kGy | | |
| | | 0 | 6 | 8 | 10 |
| G 1 (EP+SiC) | EP+2%SiC | 5.83 | 5 | 4.10 | 3.96 |
| | EP+4%SiC | 5.60 | 4.8 | 3.83 | 3.7 |
| | Ep+6%SiC | 5.30 | 4.71 | 3.30 | 2.97 |
| G 2 (EP+Gr) | EP+2%Gr | 5.20 | 4.06 | 3.77 | 2.80 |
| | EP+4%Gr | 3.71 | 2.65 | 2.24 | 2 |
| | EP+6%Gr | 2.98 | 2.35 | 2.10 | 1.77 |

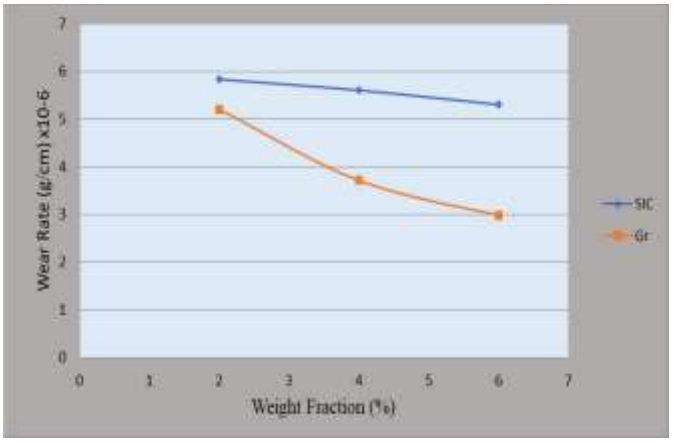


**Figure 6**. Wear rate for Gr-reinforced epoxy & SiC-reinforced epoxy with weight fraction.

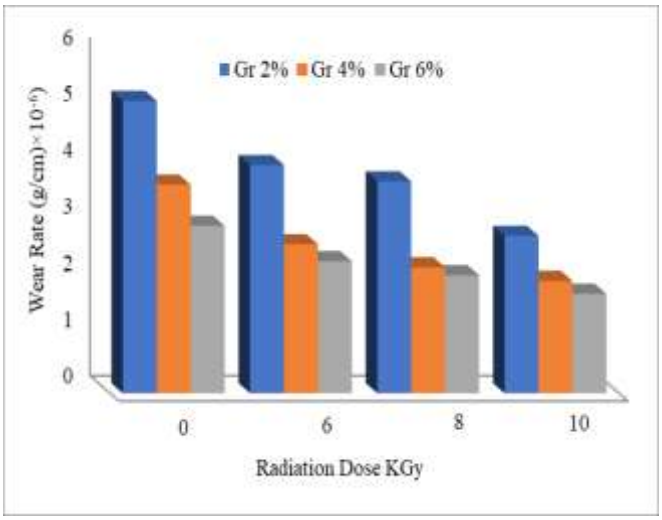


**Figure 7.** Wear rate for Gr-reinforced epoxy with weight fraction after irradiation with different doses of gamma rays

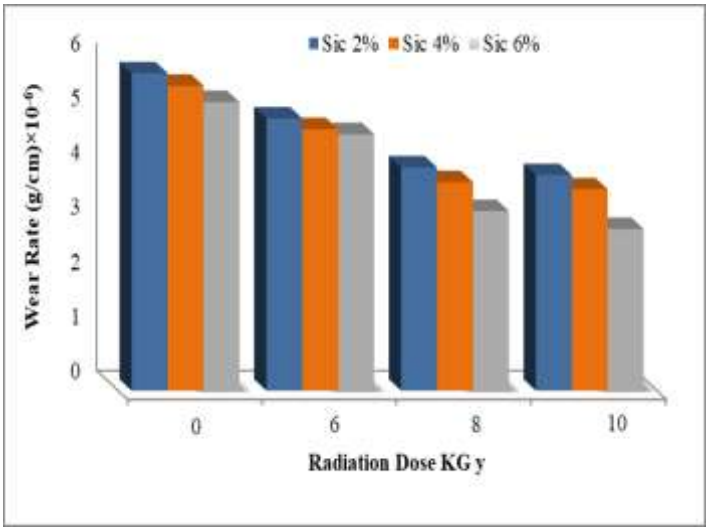


**Figure 8**. Wear rate for SiC-reinforced epoxy with weight fraction after irradiation with different doses of gamma rays

## 7. Conclusion

### Before Irradiation

1. The impact resistance values increase for overlays reinforced with (SiC) and decrease for specimens reinforced with (Gr).
2. The wear values decrease with increasing reinforcement ratios for all samples.

### After Irradiation

1. The Impact strength values of all superimposed samples increase when exposed to gamma rays, this increase is greater than in normal conditions.

2. The wear values of all superimposed and hybrid samples decrease when exposed to gamma rays and continue to decrease with increasing irradiation period.

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# دراسة تأثير أشعة گاما على خاصيتيّ مقاومة الصدمة والبلى لمتراكبات كاربيد السيليكون والگرافيت النانوية

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**الخلاصة:**

في هذا البحث تم تحضير المواد المتراكبة باستخدام الايبوكسي كمادة أساس مدعمة بدقائق كربيد السيليكون النانوية ودقائق الجرافيت النانوية بنسب وزنية مختلفة (2%، 4%، 6%) لكل منها على حدة بطريقة القولبة اليدوية. تمت دراسة بعض الخواص الميكانيكية (قوة الصدمة، مقاومة التآكل) للعينات تحت الظروف الطبيعية وبعد التعرض لأشعة كاما بجرعات مختلفة ( 6kGy،8،10) ولفترات زمنية مختلفة. في الظروف العادية وجد أن قيم مقاومة الصدمة زادت لجميع المتراكبات المدعمة بـــ (SiC) وانخفضت للمتراكبات المقواة بـــ (Gr)، وعند التشعيع بأشعة كاما فإنها تزداد لجميع ، وقد وجد أن قيم البلى تتناقص مع زيادة نسب التدعيم لجميع العينات. وتتناقص القيم لجميع العينات المتراكبة عند تعرضها لأشعة كاما الطبيعية وتستمر في الانخفاض مع زيادة فترة التشعيع وتكون اقل مما هي عليه في الظروف الطبيعية. يمكن استخدام المواد المحضرة في هذه الدراسة في الأماكن المنزلقة والدوارة لأن معامل البلى الخاص بها منخفض جداً. كما تستخدم لتخفيف الجرعات المنخفضة من أشعة جاما، كما يمكن استخدامها كحاويات لنقل البضائع لأن قوة صدماتها عالية.

**الكلمات المفتاحية:** *المواد المتراكبة، اختبار البلى ، مقاومة الصدمة ، اشعة كاما.*