

## **Bending resistance properties and combustion retardant for unsaturated polyester reinforced with copper powder**

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### **Abstract**

This work investigates the impact of the filler (copper powder) on the flame and resistance of bending for unsaturated polyester. The percentages of fillers (0.5%, 0.8%, 1%, 1.5%, 2%, and 2.5%) and a particle size of (150  $\mu\text{m}$ ) were investigated by many variables, such as flame and bending resistance. In addition, through optical microscopy, the specimens of the polymer (unsaturated polyester) were measured in a pure state and with the addition of copper powder. Results revealed strong bending resistance of 338 MPa at the percentage of 0%. The added copper powder reduced the spaces within the polymer chains, thereby reflecting the high ability of the polymer to resist the applied stress. The homogeneity is high within the polymer and additives. The findings also indicate decreased bending resistance of 120 MPa at a percentage of 2%. The average burning time starts to show a strong impact at 0%, which then increases at 181Sec. The behavior then begins to increase when the weighed proportions are increased and then continued to increase at (1%) at 190 Sec. The maximum proportions also increased at a copper powder percentage of (2%) at 212 s. Results also indicate that the percentage for the time of burning ranged within negative and positive values. The negative values at minimum weight ratios of copper powder percentages of 0.5%–0.8% and positive values at great weight ratios of copper powder percentages of 1% and 2%.

**Keywords:** bending resistance, unsaturated polyester, polymer composites, flame retardant, copper powder.

### **Introduction:**

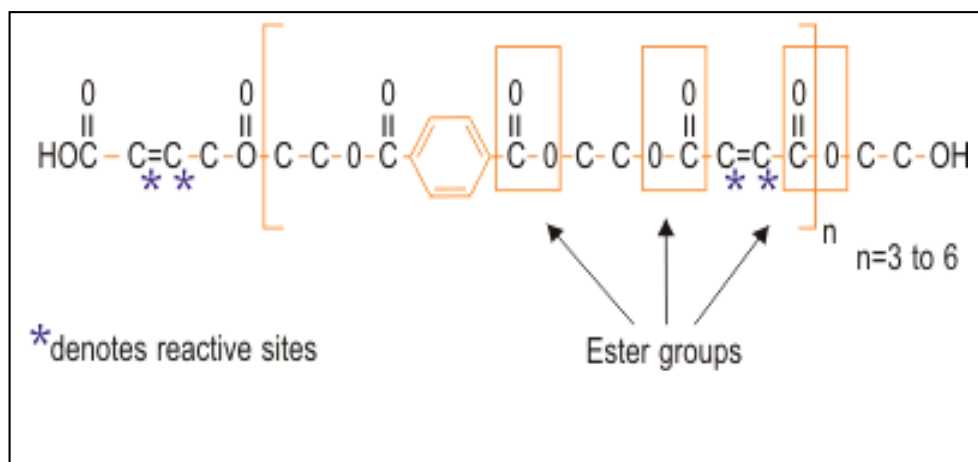
Unsaturated polyester resins are used in civil structural engineering applications, automotive paints, construction, piping, protective coatings, composites, storage tanks, and ship materials, which require fire resistance, ductility properties, and high strength [15,3-4]. Polyester is the most produced thermoplastic polymer and has many applications, such as textile fibers and bottles. The polyester used in textiles is generally polyethylene terephthalate with well-known properties of chemical inertness, lightness, good process ability, high-melting-point, high tenacity, and low cost [17]. The addition of fillers to polymer materials is a speedy and cheap technique to modify the characteristics of the base materials. For this purpose, particulate full of polymers are a subject of increasing interest in both science research with industry. Strength, rigidity, thermal and electrical conductivity, and dimensional stability, among other characteristics, can be tailored to the required values [14]. Also fiber reinforced polymer composite may include fillers, additives, and core materials. These factors modify and enhance the final product [2]. Fillers are solids added to polymers to improve their properties and decrease the cost, and they have the opposite effect of plasticizers with the decrease in the soft polymer, known as organic or inorganic material, added to the polymer either to increase the volume of the material plastic, which reduces the cost, or improve some mechanical properties [7,5]. Mechanical characteristics depend heavily on chemical characteristics and on the supermolecular structure and the stress-strain curve of the polymeric

material [13]. The mechanical characteristics of polymeric materials are important for almost each application in technology and industry, strain, strength, and rigidity are decisive characteristics in several applications [11]. The thermal and mechanical characteristics were studied for the polymer (polyester) reinforced with ceramic particles[16]: Impact and hardness increased nonlinearly with the increase in weight ratio, whereas the thermal conductivity increased with the increase in a weight ratio of ceramic fillers, reaching the greatest value of 0.319 w/m•°C for the combined material reinforced with alumina fillers at a maximum weight ratio of 20%. The impact of copper powder was studied on the mechanical characteristics of the polymer material, the results showed that the strength at breaks was affected slightly at a percentage of 0.8% and subsequently decreased together with an increasing weight ratio. This study aims to achieve a resistance of bending and fire-retardant properties to polymer (unsaturated polyester) reinforced with copper powder[8].

**Experimental Studied:**

**Material basis and fillers:**

The polymer (polyester) used in this study was supplied as a basic material by (Henkel A.S. ) company (Turkey). The polymer used in various industries is a brown viscous liquid with a strong and distinctive effect, with a density of about 1.5 g /cm<sup>3</sup>, viscosity of 1000 (p) at about 25 °C. The solid phase is diverted after the addition of ethyl ketone peroxide liquid, which is a transparent thick liquid and added percentage about of 2%.In this experimental work, we used as fillers (copper powder) with polymer material(polyester) [1]. The element copper is a chemical element with the symbol (Cu), and the atomic number for Cu is (29), density of 8.96 g / cm<sup>3</sup>, a melting point of 1084.62 °C, a boiling point of 2562 ° C, a melting temperature of 13.26 kJ / mol, and a molar thermal capacity of 24.440 J / (Mall • k) [10]. The element copper (Cu ) is smooth, flexible metal, high thermal and electrical conductivity. Cu was used as a building material, also as a good conductor for the electric and heat. Copper (Cu) ground by an electric grinding machine until it was turned into powder. Next, copper powder equal to or less than (250 μm) was treated by metal sieve, model (L3P) (ATM Corp., USA). Fig.(1) shows the graph of the chemical composition of unsaturated polyester, and Figure (2) shows the image of the copper powder.



Figure(1) Diagram of chemical structure for unsaturated polyester[9]



Figure (2) : Photograph copper powder.

**Preparation of models and shape (template)**

In this work, we used Hand layout method in the preparation of specimens polymer and fillings. Blending was initiated as a purpose of the percentages of the fillers (0.5, 0.8, 1, 1.5, 2, and 2.5)%. The material was mixed at laboratory temperature, and the mixture was stirred continuously and slowly. Mixing was continued for (6–9) min. until the mixture homogenized well. Then, the liquid mixture was poured from one side so that it flowed continuously and automatically for the another side of the form. Subsequently, the mixture was placed on the platform of a hand-operated mechanical vibrator and was shaken for (1–2) min. to remove air molecules.

Fig. (3) shows a picture of the polyester specimen with the added copper powder. An 11 cm × 1.5 cm × 4 mm rectangle was manufactured from transparent glass.

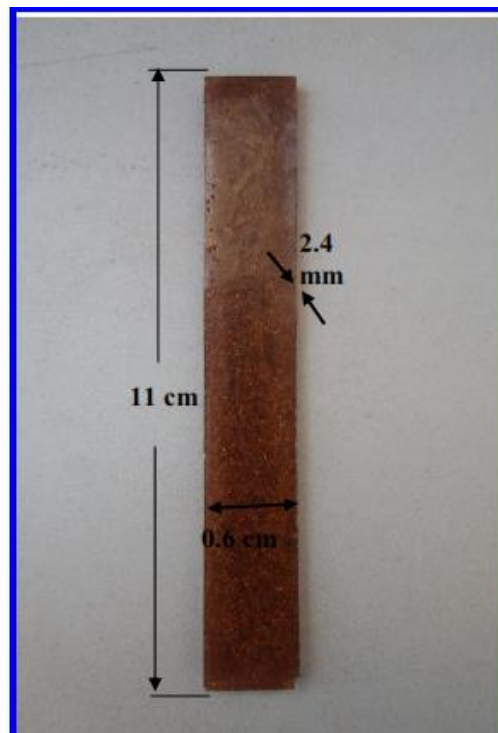


Figure (3) :Picture of the tensile specimen coupon dimensions centimeters.

**Devices:**

A universal measurement tensile machine device with the name (Zwick / Roell) and the type (BTI-FR2.5TN.D14) was used. The manufacturer of this device was (Germany), with an operating capacity of (100-129V / 4,4-3,7A).The maximum power of the device is (2.5 KN).The tensile modulus was calculated as the bending resistance for percentages of unsaturated polyester with copper powder. The tensile characteristics were according to the ASTM Standard D-638: Standard Test Method for Tensile Characteristics of Plastics [12]. The study sample thickness in this research is (2.4 mm) where are the ratios of each the samples. The tensile strength Q was calculated by the following equation:

$$Q = F / A \quad (\text{N/mm}^2) \quad \dots\dots\dots(1)$$

Where:

F = force (N) .

A =sample section area (mm<sup>2</sup>).

( Young's modulus ) Y = stress/strain  $\dots\dots\dots(2)$

Average Time of Burning (ATB) and Average Extent of Burning (AEB) for each sample measured in this work was done by a device measuring the Burning Rate, calculating the time required for combustion model to a distance of 75 mm from sample, also re-measurement three times for each sample was extracted average values.

**Mathematical calculation:**

The calculation of the Average Time of Burning, Average Extent of Burning are given by the following equations:

$$\text{Average Time of Burning (ATB)} = \frac{\sum (t - 30 \text{ s})}{\text{number of specimens}} \quad (1)$$

where: t : time(s), s: second.

$$\text{Average Extent of Burning (AEB)} = \frac{\sum (100 \text{ mm} - \text{unburned length})}{\text{number of specimens}} \quad (2)$$

The Rate of Burning (RB) using the following relation:

$$\text{Rate of Burning(RB)} = \frac{\text{Average Extent of Burning ( AEB) } \quad \text{cm}}{\text{Average Time of Burning ( ATB) } \quad \text{min.}} \quad (3)$$

**Results and Discussion:**

Figure (4) shows the relation between the bending resistance and the weight ratios for the polyester with the copper powder. This figure shows the bending resistance behavior starting with a strong effect (0%) value of 338 MPa. When the polymer is pure without any addition, the sample elasticity is high and has a lower hardness than the other samples that have added fillers. The bending resistance behavior of the measurement model declines with the increase in the ratio of weight of the fillers (0.8%) at a value of 126 MPa. Consequently, the behavior increases with the rise in the ratio of weight of the fillers (1.5%) at a value of 184 MPa. This result occurred because the polymer (unsaturated polyester) and fillers (copper powder) received most of the pressure (the distribution of the additive to the base material is inhomogeneous). Thus, given the distribution and pressures on all sides of the sample, no pressure is concentrated in one area. The result is failure

and less resistance, and the sample at this ratio is flexible and shows low hardness; thus, maximum stress is needed to achieve failure in bending resistance at this weight ratio of the polymer with fillers. A strong relationship may exist between the copper powder and the unsaturated polyester, creating a good surface. Thus, failure to exhibit bending resistance requires maximum stress.

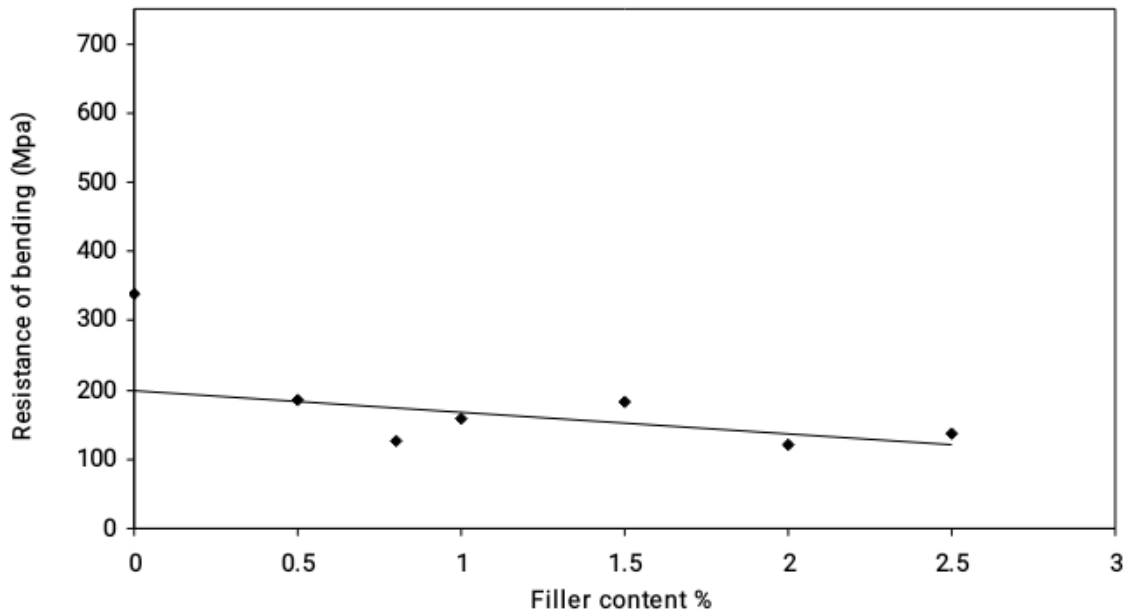
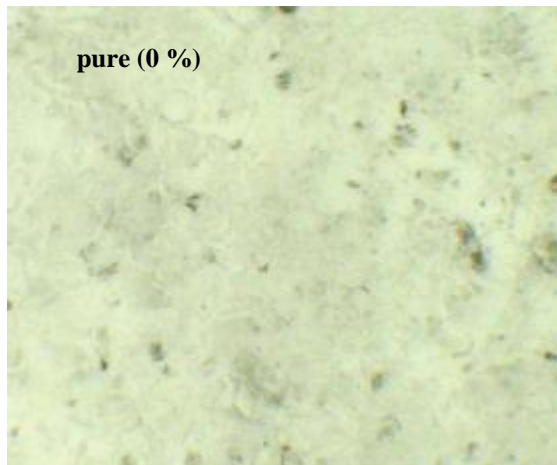
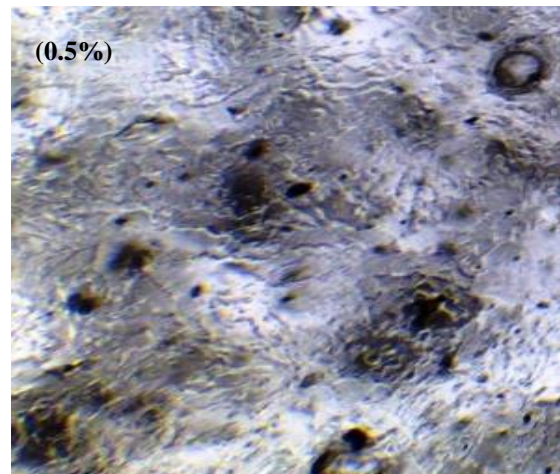


Figure (4): Resistance of bending for Polyester reinforced with Copper powder with different percentage of additives

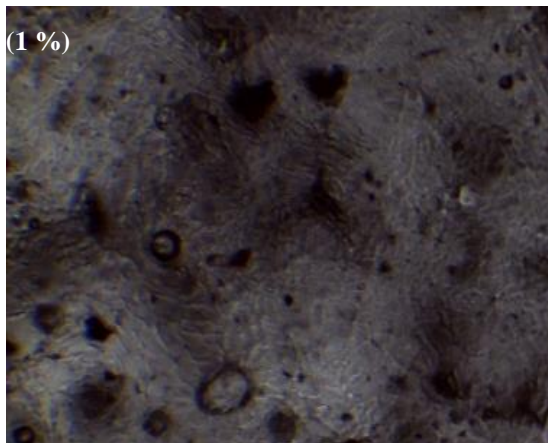
The samples of the pure base material (unsaturated polyester) and the samples with added copper powder were measured via optical microscopy. Figure(5) shows the photographs of samples for unsaturated polyester reinforced with copper powder and pure unsaturated polyester as acquired by optical microscopy (Leica DM500 and ICC50 H, Germany). The high zoom is (PLAN 40x/0.65( to test the surface samples. which was the testing of the samples surface (Morphology study), any study of unsaturated Polyester homogeneity with copper powder. What we notice from the pictures that there is homogeneity between the base material and the fillers at the ratio (0.5 at. %).where the sample at this percentage is highly elastic and low hardness because the fillings at this ratio have a low quantity, compared to the base material. We also note that, at the ratio (2.5 at.%) there is high homogeneity between the base material and fillings, and the sample is at this ratio of low elasticity and high hardness because the fillings at this ratio have a good quantity, compared to the base material, and the high hardness of the fillers.



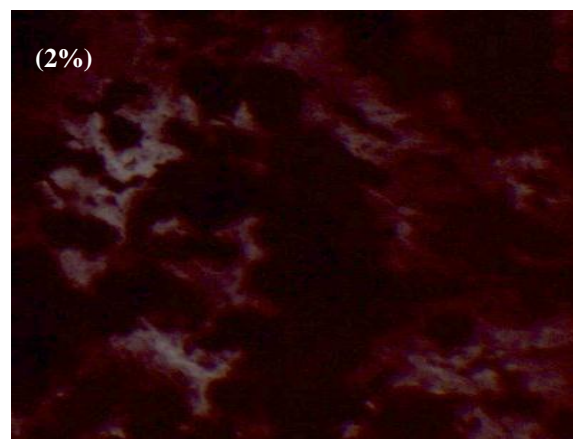
(5-a)



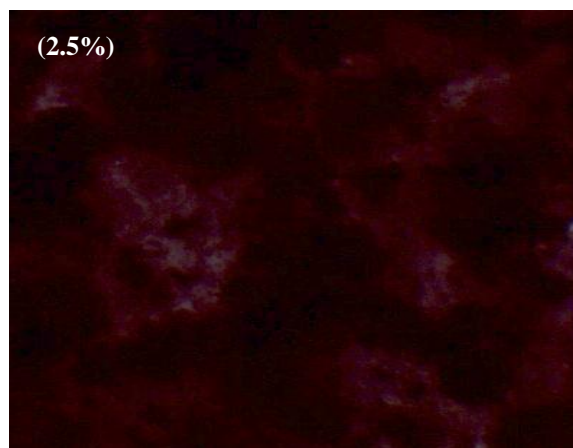
(5-b)



(5-c)



(5-d)



(5-e)

Figures (5-a -5-e) : Photographs of samples for unsaturated Polyester reinforced with Copper powder and the pure unsaturated Polyester as measured by optical microscopy.

In general, many polymers emit heat when they are burning, thereby reducing their usability, especially in places with a large amount of flame. The best way to address this concern is to use additives that increase the polymer's flame resistance. The behavior of ATB for unsaturated polyester reinforced with copper powder with different percentages of additives is shown in Figure (6). The behavior of ATB starts rapidly at 0% at about 3.1 min. and then begins to decrease and increase gradually with the increase in the percentages. The results show that the increase in the proportion of the copper powder negatively affects the resistance of flame, heat spread into the matrix of polymer, where we get a minimum value when the percentage (2.5 %) which is (2.24 min.), while the maximum value with the increase of the weight ratio about (3.32 min.) when the percentage (2%).

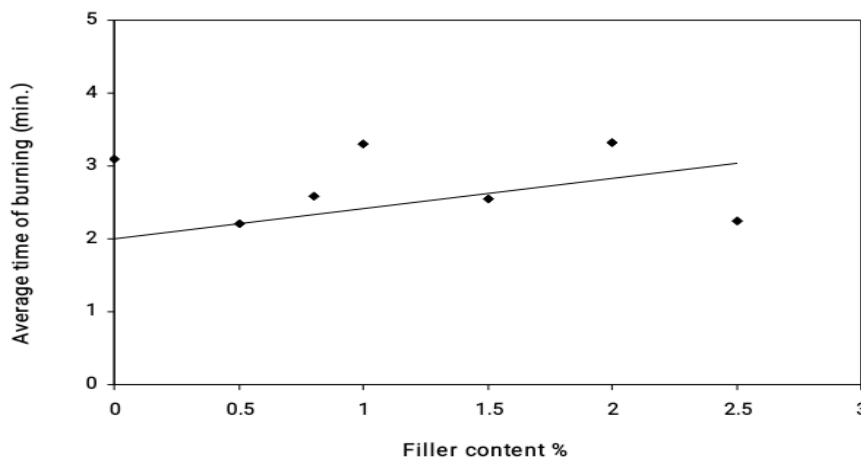


Figure (6): Average time of burning ( A.T.B.) for unsaturated Polyester reinforced with Copper powder with different percentage of additives .

Figure (7) shows the AEB with the percentages of copper powder addition for unsaturated polyester. The line graph shows that the AEB declined when a great amount of copper powder was added at a percentage of 2%. The behavior of AEB has a strong effect at a percentage of 0.5% at about 6 cm and then begins to decrease rapidly when the percentages to the composites are increased. This phenomenon reveals that increasing the proportion of the copper powder positively affects the resistance of flame, and heat spreads through the polymer matrix, where we obtain high value when the percentage (1 %), about (6.2 cm).

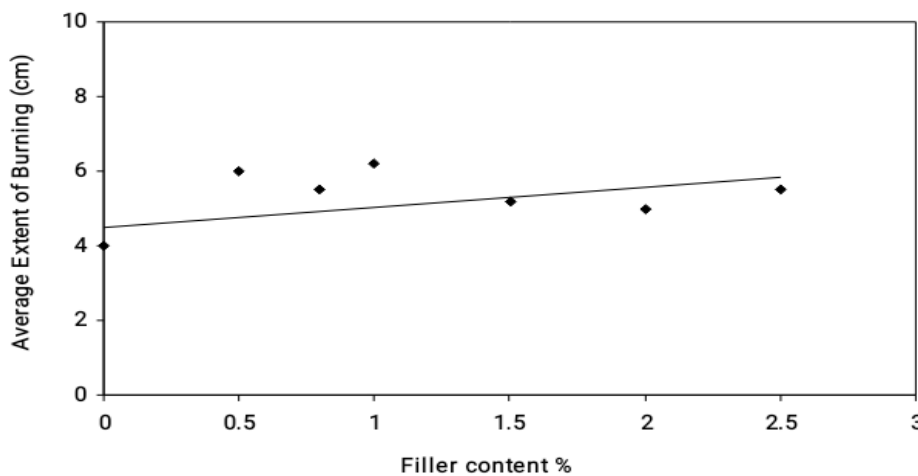


Figure (7): Average Extent of burning ( A.E.B.) for unsaturated Polyester reinforced with Copper powder with different percentage of additives .

Figure (8) shows the impact of fillers (copper powder) percentages on the polymer (unsaturated polyester) with the RB. A significant decrease is observed in the copper powder weight of less than 0.5%, but then increases when copper powder is added to unsaturated polyester at a percentage of 0.5%. The RB of the prepared composite with a certain added percentage of copper powder continuously decreased as the weight percentage of the additives increased, thus indicating an inversely proportional relationship. At the percentage of 2%, the RB is low (1.5 cm/min) because of the increasing amount of residual copper powder at the surface. The burning material isolates the polymer matrix from the atmosphere. This condition is an important factor in increasing the RB of the unsaturated polyester [6]. Figure (9) shows the changes in the percentages of the burning time as a function of the percentages of copper powder addition and the calculated weight fraction of impure and pure copper powder. It shows that the percentage of the burning time is inversely proportional to the filler content. Also, the results indicate that the percentage for the time of burning ranged within negative values at minimum weight ratios of (0.5–0.8)% and positive values at great weight ratios of (1 and 2)%, i.e., the percentage of continuous burning reduced with the increase in the additive weight percentages.

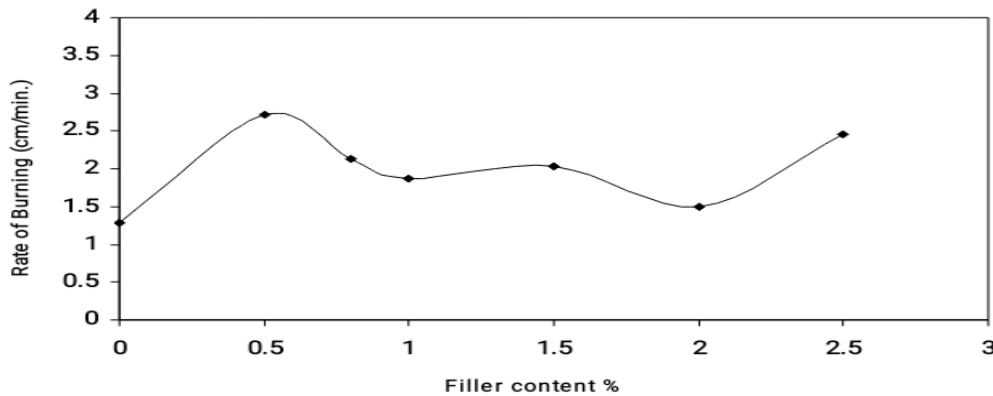


Figure (8) : Rate of burning (R.T.) for unsaturated Polyester reinforced with Copper powder with different percentage of additives .

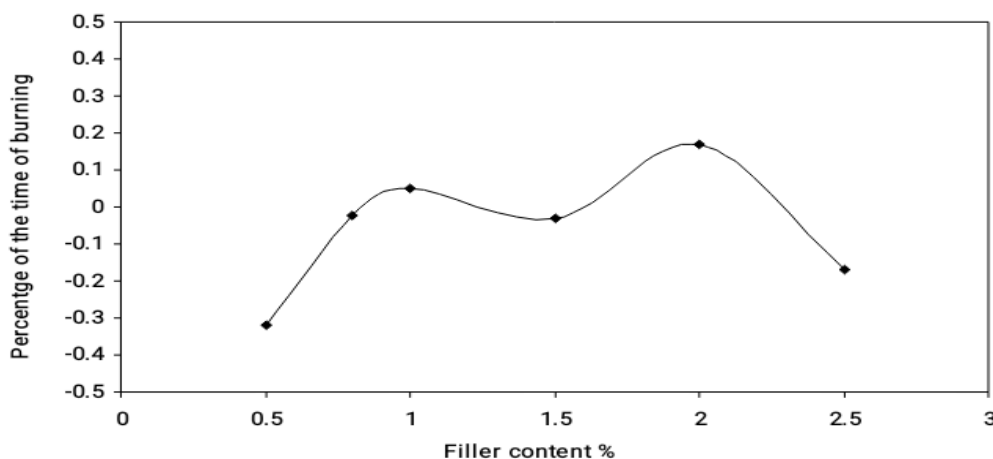


Figure (9) percentage of time of burning for unsaturated Polyester reinforced with Copper powder with different percentage of additives .



**Conclusion:**

Copper powder fillers with unsaturated polyester as metal filler was used in this research. The results indicate decreased bending resistance of approximately 120 MPa at a percentage of 2%. The ATB starts to show a strong impact at 0% and increases at 181 s. The behavior then increases when the proportions are increased to 1% and 190 s. The increase in the proportion of the copper powder negatively affects the resistance of flame, in addition, spread of heat through the polymer matrix, where a minimum value is achieved at a percentage of 2.5% at 212 s. The maximum value is reached at about 3.32 min at a percentage of 2%. The results indicate that the percentage to the time of burning ranges within the negative values at minimum weight ratios of the copper powder of (0.5%–0.8%) and positive values at great weight ratios of the added copper powder of (1% and 2%).

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## خواص مقاومة الانحناء والاحتراق للبولي استر غير المشبع والمدعم بمسحوق النحاس

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### الملخص

تم دراسة تأثير إضافة مسحوق النحاس على خواص مقاومة الانحناء والاحتراق للبولي استر غير المشبع حيث تم إضافة مسحوق النحاس كحشوات مألثة وبنسب وزنية (0.5%، 0.8%، 1%، 1.5%، 2%، 2.5%) وعند حجم دقائق للحشوات مساو أو أقل من (150 µm) لبوليمر البولي استر غير المشبع ذو المنشأ التركي للحصول على مادة متراكبة، ولمعرفة إمكانية المضاف (مسحوق النحاس) كحشوات مألثة ودورها في تغيير مقاومة الانحناء وزيادة أو تقليل من الفترة الزمنية لمقاومة الاحتراق وانتشارها في المصفوفة البوليمرية. تم في هذه الدراسة العملية قياس عدة متغيرات منها مقاومة الانحناء للمادة المتراكبة والفترة الزمنية للاحتراقية إضافة إلى إيجاد النسبة المئوية لزمان الاحتراق، وأيضا تم قياس العينات للمادة الأساس (البولي استر غير المشبع) بصورة نقيه وعند إضافة الحشوات (مسحوق النحاس) بواسطة المجهر الضوئي (Optical Microscope) لمعرفة مدى تجانس وترابط البوليمر مع الحشوات عند إضافة النسب الوزنية. أي القيام بدراسة التركيب الدقيق للعينات. أظهرت النتائج أن أقصى مقاومة انحناء للمادة البوليمرية المقواة (بمسحوق النحاس) هي (338Mpa) عند النسبة الوزنية (0%)، حيث إن مسحوق النحاس المضاف إلى البوليمر يعمل على تقليل الفراغات بين السلاسل البوليمرية مما يعكس إمكانية البوليمر العالية بتحمل الإجهاد المسلط عليه وتكون درجة التجانس عالية بين كل من البوليمر والحشوات المضافة و بعدها تنخفض قيم مقاومة الانحناء عند زيادة نسب المضاف إلى أن تصل إلى أقل قيمة لها عند النسبة الوزنية (2%) وهي (120Mpa). كما أن سلوك المادة البوليمرية المتراكبة لمعدل زمن الاحتراق يبدأ بتأثير قوي عند النسبة (0%) إذ تصل قيمته إلى (181 Sec) وبعدها يبدأ السلوك بالازدياد عند زيادة النسب الوزنية للمضاف إذ تصل قيمته إلى (190 Sec) عند النسبة (1%)، إلى أن يصل إلى أقصى قيمة عند النسبة (2%) إذ تصل قيمته إلى (212 Sec)، وأوضحت النتائج أيضًا بأن النسبة المئوية لزمان الاحتراق تتراوح بين القيم السالبة عند النسب الوزنية المنخفضة من المضاف وهي (0.5% - 0.8%) وتكون موجبة عند النسب الوزنية وهي (1%، 2%).

**الكلمات المفتاحية:** مقاومة الانحناء، البولي استر غير المشبع، البوليمرات المتراكبة، مقاومة الاحتراق، مسحوق النحاس.