Experimental Study of the Effect of Zinc Borate on Flame Retardancy of Carbon- Kevlar Hybrid Fibers Reinforced Composite Materials

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Abstract

This study aims to investigate possibility to increase the flame retardancy for composite materials by addition of a flame retardant material which represent the zinc borate as a coating layer of (4mm) thickness on the surface of composite material consist of araldite resin reinforced by hybrid fibers from carbon and kevlar fibers as a consecutive layers which be as a woven roving º) (0 º - 90. Then, this system (flame retardant material and composite material) was exposed to a direct flame which generated from oxyacetylene flame (up to 3000ºC) and gas flame (2000ºC) under different exposure distances (10,15, and 20mm), and study the range of resistance of flame retardant material layer to the flames and protected the substrate where we used the method of measuring the surface temperature opposite to the flame where we obtained the better results with large exposed distance and large percentage from protective layer which is zinc borate (30%) for both types of flames , as well as the flame resistance will be increased with decrease the flame temperature .

Keywords:Hybrid Composite Material, Flame Retardant Material, Zinc Borate.

دراسة عملية لتأثير بورات الخارصين على إعاقة اللّهب لمواد مركبة مقواة بألياف كاربون- كيفلار الهجينة

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الخلاصة

تهدف هذه الدراسة لبحث امكانية زيادة إعاقة اللّهب للمواد المركبة عن طريق إضافة مادة معيقة للّهب والتي تمثل بورات الخارصين بشكل طبقة طلاء بسمك (4mm) على سطح المادة المركبة المكونة من راتنج الإرلدايت المقوى بألياف هجينة من ألياف الكاربون وألياف كيفلار بشكل طبقات متتابعة والتي تكون بشكل ظفائر محاكة ثنائية الإتجاه (° 90 - ° 0) . بعدها عرض هذا النظام (المادة المعيقة للّهب و المادة المركبة) إلى لّهب مباشر متولد من شُعلة أوكسي أستيلينية بدرجة حرارة أكثر من (3000ºC) ولهب متولد من شُعلة غازية بدرجة حرارة(2000ºC) وبمسافات تعرض مختلفة (20mm,15mm,10mm) ودراسة مدى مقاومة طبقة المادة المعيقة للّهب لحرارة الشُعلتين ومدى حمايتها للمادة المركبة الواقعة تحتها حيث تم إعتماد طريقة قياس درجة حرارة السطح المقابل للشعلة في قياس درجة الحرارة المنتقلة خلال هذا النظام حيث تم الحصول على أفضل النتائج عندما تكون مسافة التعرض كبيرة و أكبر نسبة للطبقة الحامية والتي هي بورات الخارصين (نسبة 30%) ولكلا الشعلتين إضافة إلى ذلك تزداد المقاومة للّهب كلما قلت حرارة الشُعلة

Introduction

Fire safety is an integral part of precautions. Fire precautions have the objective to minimize the number of and damage from measuring hindering their initiation, limiting their propagation and if possible excluding flash-over. Preventing fires or delaying them makes escape possible over a longer period of time. As a result, life, health, and property are efficiently protected [1].

Since plastics are synthetic organic materials with carbon and often high hydrogen contents, they are combustible. For various applications in the building, electrical, transportation, mining, and other industries, plastics have to fulfill flame retardancy requirements laid down in mandatory regulation and voluntary specification. The objective in flame retarding polymers is to increase ignition resistance and reduce rate of flame spread [2].

One way to better protect combustible materials against initiating fires is the use of flame retardants , which are substances that can be chemically inserted into the polymer molecule or be physically blended in polymers after polymerization to suppress , reduce , delay or modify the propagation of a flame through a plastic materials. There are several classes of flame retardants; halogenated hydrocarbons (chlorine and bromine containing compounds and reactive flame retardants): inorganic flame retardants (boron compounds, antimony oxides, aluminum hydroxide, etc); phosphorus containing compounds; nitrogen containing flame retardants. Depending on their nature, flame retardants can act physically or chemically [3].

1- The physical action occurs by:

a. Cooling: the additives cool the substrate to a temperature below the combustion temperature.
b. Formation of protective layer: a solid or gaseous protective layer, which excludes the oxygen necessary for the combustion process (e.g. phosphorus compounds).
c. Dilution: the inert gases from the additive dilute the fuel in the solid and gaseous phase (e.g. aluminum hydroxide).

2- The chemical action occurs by:

a. Reaction in gas phase : the radical mechanism of combustion is interrupted and exothermic reaction are stopped . System cools down (e.g. halogenated flame retardants).
b. Reaction in solid phase: by forming carbonaceous layer on the polymer surface (e.g. phosphorus compounds).

Flame Retardant Materials

Flame retardants are substances used in plastics, textiles, electronic circuitry and other materials to prevent fires. There are several types of flame retardants as mentioned above, one of these types is inorganic flame retardants. Few inorganic compounds are suitable for use as flame retardants in plastics, since such compounds must be effective in the range of decomposition temperature of the plastic, mainly (150ºC - 400ºC). Inorganic flame retardants don't evaporate under the influence of heat ; rather they decompose ; giving off non-flammable gases like water , carbon dioxide , sulphur dioxide , hydrogen chloride , etc. mostly endothermic reaction . in the gas phase , these act by diluting the mixture of flammable gases and by shielding the surface of the polymer against oxygen attack [4] .

The inorganic flame retardants act simultaneously on the surface of the solid phase by cooling the polymer via endothermic breakdown process and reducing the formation of pyrolysis products. In addition , as in the case of inorganic boron compounds , a glassy protective layer can form on the substrate , fending off the effect of oxygen and heat[5] .As example to inorganic flame retardants is zinc borate , aluminum hydroxide , magnesium hydroxide , and antimony oxides .

Zinc borate is used as a flame retardant and smoke suppressant for wide range of plastics, rubber, paper, and textiles. It can replace antimony oxide as synergist in plastics and rubber to enhance the activity of primary flame retardants by stepwise releasing the radicals in a wide variety of end – use products . It is also used in paints, adhesives, pigments and ceramic industries. **Table 1** shows the characterizations and properties of zinc borate.

Table (1): Characterizations and properties of zinc borate [3]

Property	Appearance	Melting Point °C	Density g/cm^3	PH	Mol Wt
Value	White Crystalline	980	3.64	7.6	434.62

Composite Materials

Composite material is a material consisting of two or more physically and (or) chemically distinct phase, suitably arranged or distributed. A composite material usually has characteristics that are not depicted by any of its components in isolation [6]. Generally, the composite material contains two elements:

1- Matrix material: it is the continuous phase; it may be metal, ceramic or polymer matrix. The polymer matrix is considered the best because of its mechanical and thermal properties, and also it can reinforced by a large fiber volume fraction compared with metal and ceramic matrix. In addition to the low cost and easy fabrication, as example for this materials araldite resin, polyester, and epoxy resin. Araldite resin belong to epoxy group which has excellent thermal and physical properties, and usually used in composite materials for different applications, where it distinct by excellent adhesive capability especially to fibers, also it retain constant dimensions after dryness [7].

2- Reinforcing material: The distributed phase is called reinforcement, many reinforcement materials are available in a variety of forms; continuous fibers; short fibers; whiskers, particles...etc. Reinforcements include organic fibers such as carbon and kevlar fibers, metallic fibers, ceramic fibers, and particles [8].
High strength, and high modulus carbon fibers are of about (7-8μm) in diameter and consist of small crystallites of turbostratic graphite, one of the allotropic forms of carbon[9].
Kevlar is an organic aramid fiber with (3100 MPa) tensile strength, and (131,000 MPa) elastic modulus. A density approximately one-half of aluminum, good toughness, in addition it is flame retardant [10].

Flame Retardancy Test

This test is used for thermal isolators which exposed to elevated temperatures exceed (3000ºC) as in the fires case. The heat of this test generated from thermal torch (oxyacetylene and gas). There are two methods to measure the temperature of material in this test [10]:

1- Surface temperature; in this method, a thermocouple puts on the opposite surface to the torch for calculate the amount of heat transmitted through flame retardant material and composite material. This method used in this study .
2- Depth of damage; after exposition, the material to the flame at specific time, we will measure the depth of penetration leaves on material surface.

Experimental Work

1- Materials: There are three types of materials employed in this study:

a. Flame retardant material, Zinc Borate 2335 ($2ZnO.3B_2O_3.5H_2O$) was used as a flame retardant, which supply from C-Tech corporation. Table 2 shows the chemical composition of zinc borate.

Table (2): Chemical composition of zinc borate

Compound	Zinc Oxide	Boric Anhydride	Water of Hydration	Impurities
Symbol	ZnO	B_2O_3	H_2O	-
Content(%)	37	47	14	2

b. Matrix material, Araldite resin (CY223) with density of (1.15-1.2 g/cm^3) which belong to epoxies group was used in this study. Figure (1) shows the chemical structure of Araldite resin.

c. Reinforcing fibers: Two types of fibers were used :

c.1- Carbon fibers, A woven roving fibers(0 º - 90 º) with density of (225 g/m^3).

c.2- Kevlar fibers, A woven roving fibers(0 º - 90 º) with density of (285 g/m^3).

These types of fibers used as consecutive layers in same matrix .

Figure (2) shows the chemical structure of kevlar fibers.

2- Preparation Test Specimens:

Specimens of flame retardancy test are a square shape, as shown in figure (3) with dimensions (100 ×100mm), and (10mm) thickness, which it consist of two layers:

a- Flame retardant material layer with (4mm) thickness represented by zinc borate.

b- Composite material layer with (6mm) thickness, it contains carbon and kevlar fibers which used as consecutive layers in araldite resin .

3- Flame Retardancy Test .

Two types of torch flame were used, oxy-acetylene and butane-propane flame. The system (contains flame retardant material and composite material) was exposed to these flames under different exposure distances (10, 15, and 20mm). Figure (4) shows the mechanism of flame retardancy test, surface temperature method used here to calculate the amount of heat transmitted through flame retardant material and composite material. Table (3) shows the temperatures of flames used in this study .

Table (3): Temperatures of flames

Gas	Symbol	Temperature,ºC
Oxyacetylene	C_2H_2	3000-3300
Butane-Propane	C_3H_8-C_4H_{10}	2000

Results and Discussion

From the results obtained by flame retardancy test, we can see :

Figure(5) represents the flame retardancy test for composite material with zinc borate as a surface layer at exposed distance (10mm) , the temperature of the opposite surface to the torch begins to increase with increasing the time of exposition to the flame . During this stage , zinc borate (10 %) has a water of hydration in its chemical structure , therefore , it released this water to extinguish the fire through cooling , in addition , zinc borate will formed glassy coating layer which protecting the substrate (composite material) and the fire spread will decrease[5] . This process of released water and formation of glassy coating layer will be increased as the zinc borate increased to (20 %, and 30 %).

Figure (6) shows the behavior of zinc borate with exposed distance (15mm). When the amount of flame retardant layer is (10 %), and with this exposed distance the time of break down of the retardant layer will be increased, because of decomposition of zinc borate and release the water, which dilute the ignition zone and the formation of protected layer will stay to longer time[4]. This state will be increased with increasing zinc borate content to (20 %, and 30 %).

As a result, when the exposed distance to flame increased to (20mm), the time necessary to break down of flame retardant layer will increase and the combustion gaseous will reduced and there will be a less plastic to burn due to water of hydration and protected glassy coating layer[5], and this protection will improves with increasing flame retardant percentage to (20 %, and 30 %). All that will rise the time of break down for zinc borate layer and substrate composite material as shown in Figure(7) which represents flame retardancy test for zinc borate layer with exposed distance(20mm) . From all figure we obtained the better results with large exposed distance and large percentage from protective layer which is zinc borate (30%) for both types of flames , as well as the flame resistance will increase with decrease the flame temperature as illustrated in the diagrams between surface temperature and time of flame exposition .

Conclusions

From this study, we concluded that:
1- Increasing the flame retardancy as the zinc borate content increased .
2- The resistance to flame spread will increased with increasing of exposed distance , due to decreased of the heat transmitted to flame retardant material which will rise the stand of glassy coating layer against flame .
3- The flame retardancy is increased as the flame temperature is decreased.

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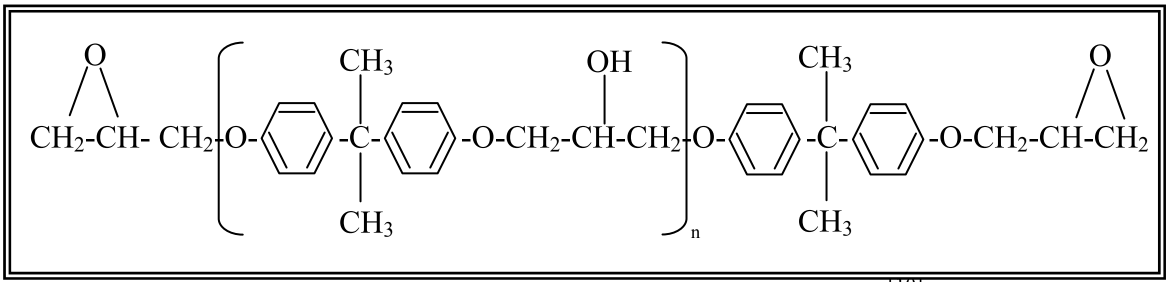

Figure (1): Chemical structure of Araldite resin[10].

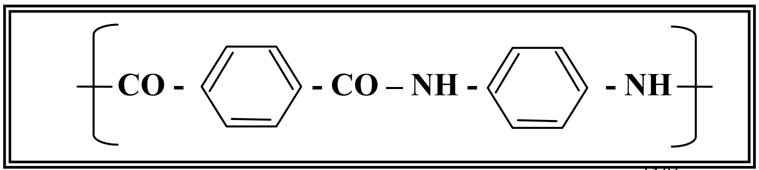

Figure (2): Chemical structure of kevlar fibers[10].

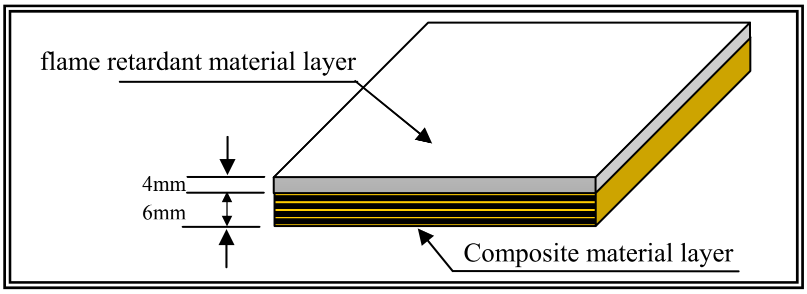

Figure (3): Specimen of thermal erosion test

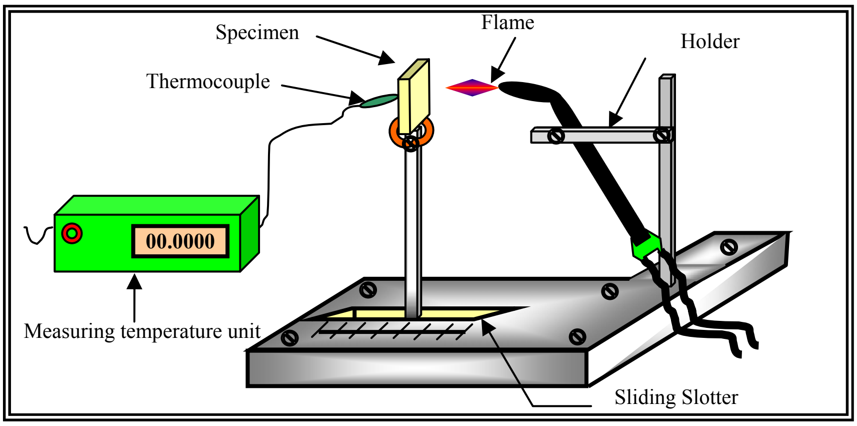

Figure (4): Mechanism of Flame Retardancy Test

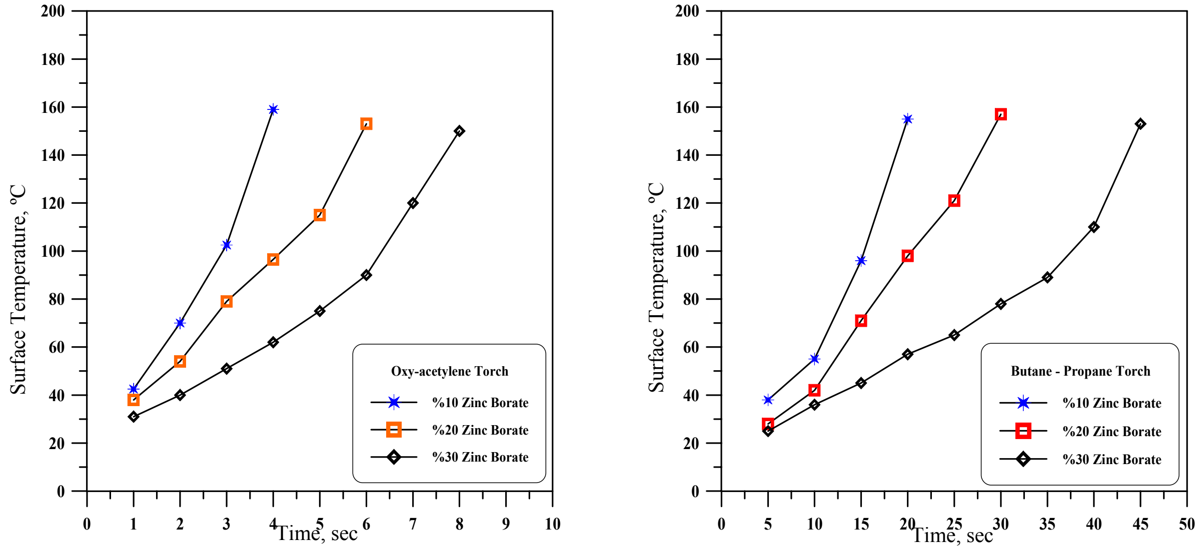

Figure (5): Flame Retardancy Results for Zinc Borate Layer with Exposed Distance (10mm)

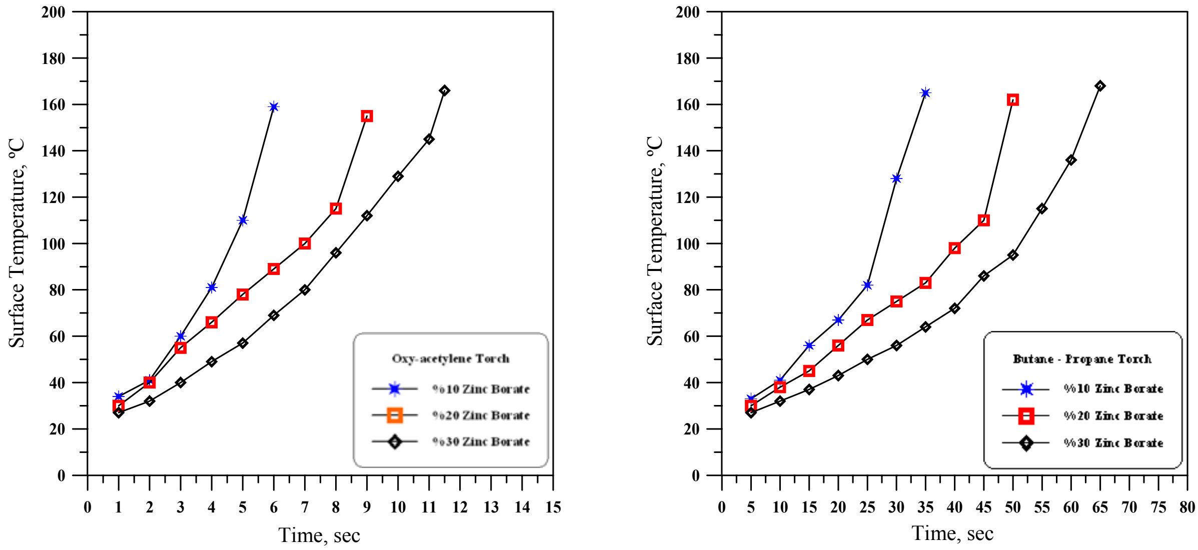

Figure (6): Flame Retardancy Results for Zinc Borate Layer with Exposed Distance (15mm)

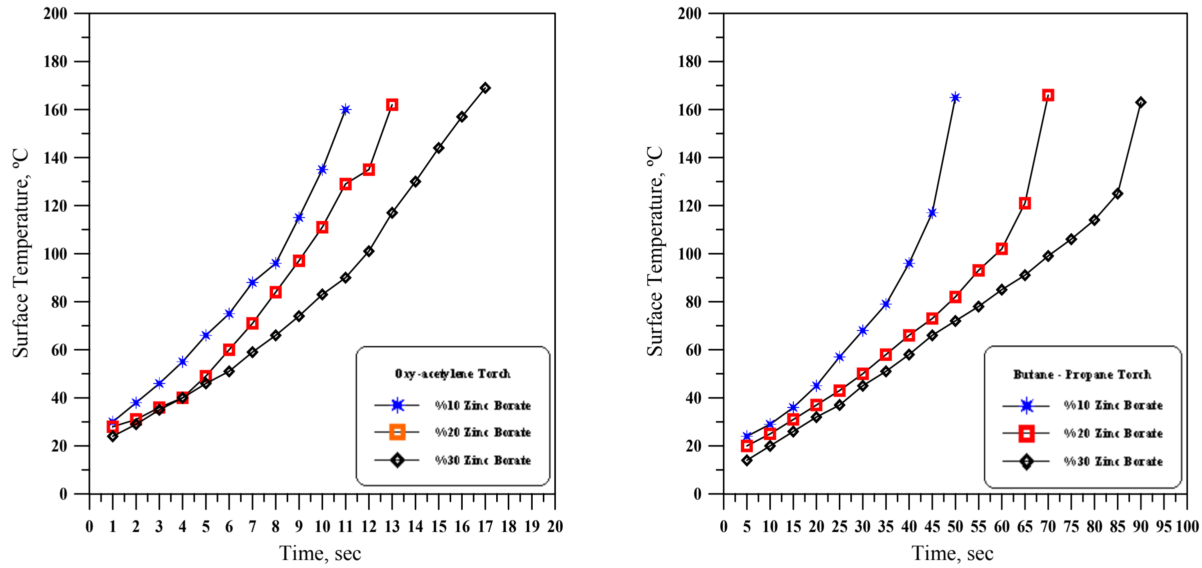

Figure (7): Flame Retardancy Results for Zinc Borate Layer with Exposed Distance (20mm)