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Study of Nano Powder for Improvement the Mechanical Properties of Armor

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Abstract

During this research nano alumina particles are used as reinforce material to improve characterization of armor. The work involves use of polyester resin as matrix. The properties obtained of resulted samples showed clearly improvement. Where values show linear increases in hardness from low value 77.3 gf/mm of pure polyester to high value 81.6 of polystyrene - 30 wt % nano alumina.

Values of thermal conductivity greatly influenced by amount of porosity and so on the density of the sample, where pure polyester has low value 0.0661 W/mk of thermal conductivity and polyester – 30 wt % nano aluminapossess conductivity 0.3411 W/mk.

Key Words: Nano alumina particles , polyester, armor

الخلاصة

خلال هذا البحث الدقائق النانوية من الالومينا استخدمت كمواد معززة لتحسين خواص الدروع . ينطوي العمل على استخدام راتنجات البوليستر كمصفوفات. وأظهرت الخصائص التي تم الحصول عليهامن العينات الى تحسن واضح ، تظهرالقيم زيادات خطية في الصلادة من 77.3 الى 81.6 gf/mm في البوليسترين الممزوج ب 30٪ بالوزن مع نانو الألومينا. قيم التوصيل الحراري تتأثر الى حد كبير بكمية المسامية و ذلك بالاعتماد على كثافة العينة، البوليستر الخالص له قيمة منخفضة من التوصيل الحراري 0.0661 W/mK والبوليستر − 30٪ بالوزن نانو الألومينا تمتلك موصلية 0.3411 W/mK.

الكلمات المفتاحية: الدقائق النانوية لالومينا ، البوليستر، الدروع

Introduction

Up to now a lot of research has been done in the field of protective textile. Body armor materials have traditionally been designed to protect the wearer against any kind of weapon threats [Effrosyni *et. al*.,2014]. The global terrorism threat at home and abroad means that police and army personnel, journalists reporting from war zones and civilian rescue workers have to wear body armor capable of stopping high velocity projectiles like bullets and bomb shrapnel [Effrosyni *et. al*.,2014].The development of body armor started since the 1960s when the ability of alumina ceramics to withstand bullet impacts was discovered by using advanced materials such as kevlar and glass fibers together with ceramic and carbon epoxy made modern armor much more sophisticated. The current armor can take multiple hits, provides good fire and smoke resistance and has low toxicity characteristics. However, modern armor generally relies on a ceramic layer to take almost all of the ballistic impact. The use of such materials compromises the weight and flexibility of armor in the field. Utilizing nanotechnology in the design of new materials which will ultimately enable the production of flexible light-weight body armor [Adam, 2008].

The primary objective of body armor research is to develop a low cost, lightweight, wearable garment system with ballistic impact resistance. Aramid and ultra-high molecular weight polyethylene have been introduced as base materials for ballistic protection. High performance fibers are characterized by low density, high strength, and high energy absorption [Young *et. al.*, 2003].

High-performance technical ceramics that are formed simultaneously under high pressure and temperature have been shown to achieve high mass efficiencies. Hot pressed boron carbide (typically B_4C) is used for personnel protection in the form of plate inserts, for aircraft protection as panels and seats, in ships, and in armored land vehicles as seats. For protection against more lethal threats, such as heavy machine gun and medium cannon threats, hot-pressed silicon carbide (SiC) is typically the material of choice. Hot-pressed silicon carbide is also used in armored vehicles as an applique, along with hot-pressed silicon nitride (Si_3N_4). Table (1) shows mechanical properties of various hot-pressed SiC and B_4C materials [Young *et. al.*, 2003].

Table (1): Mechanical properties of various hot- pressed SiC and B_4C materials [3].

Properties	B_4C	SiC	B_4C+SiC	TiB_2+SiC
Fracture toughness (MPa-m^1/2)	3.2	4.2	3.5	6.4
Hardness (GPa)	23.7	22.5	24	22.1

Transparent armor is a material or system of materials designed to be optically transparent. They are used to protect vehicle occupants from terrorist actions or other hostile conflicts. Transparent armor windows must also be compatible with night vision equipment. One potential solution to increase the ballistic performance of a window material is to increase its thickness. However, this solution is impractical in most applications, as it will increase the weight and impose space limitations in many vehicles. In addition, thick sections of transparent armor tend to experience greater optical distortion than thinner sections, reducing the transparency. New materials that are thinner, lightweight, and offer better ballistic performance are being sought. Existing transparent armor systems are typically comprised of many layers, separated by polymer interlayers. [Parimal *et. al.*, 2000].

R. Zaera and *et. al.*, studied a constitutive model to simulate the behavior of ceramic materials under impact loading is proposed in order to achieve a better representation of the damage process due to the material fragmentation. The model was implemented in a commercial finite element code [Fernandez-Fdz *et. al.*, 2011]. Philip M. Cunniff and et.al were estimated the ballistic impact potential of M5 fiber-based armor systems using an “armor materials by design” model for personnel armor; the model is based on a dimensional analysis of the mechanical properties of the fibers used to construct the armor system.The model indicates that M5 fiber-based armor has the potential to substantially decrease the weight of body armor while enhancing or maintaining impact performance [Philip *et. al.*, 2002].

D. W. Templeton and et.al were proposed Functionally graded materials (FGM) for niche army applications such as armor. Development of an FGM with a tailored ceramic-to-metal through-thickness gradient is one approach where an improved mass and space armor material for ballistic protection can conceivably be provided. This work investigates the ballistic efficiency of a postulated FGM ceramic-metallic armor system composed of aluminum nitride (AlN) and aluminum. The study had two primary objectives:

1) Development of a method to model an FGM, and
2) Examination of the computationally derived ballistic performance of the FGM armor system.

The FGM was modeled as a series of discrete (bonded) layers, with adjusted material parameters such as density and strength, to approximate a gradient structure. For a discrete six layers system with appropriately adjusted material parameters, results showed an increase of approximately 15% in the ballistic performance of the simulated FGM when compared to an equivalent target composed of AlN and aluminum [Douglas *et. al.*, 2007]. William A. Gooch and et.al, developed a ballistic applique that transitions from a ceramic cermet hard face to a metal back face which can be fabricated to near net shape during the densification process. These functionally gradient materials offer significant advantages in armor applications over conventional adhesive bonded ceramic-metal appliques. This paper will discuss the conceptional requirements, material development process and highlight the 14.5-mm ballistic testing conducted to date [William *et. al.*, 2001].

Design criteria:

The significant challenge is to balance the level of protection required for specific threat type against weight, comfort and flexibility and cost. Body armors must be worn to be effective in Weight, mobility, and comfort to ensuring their use properly distribute their weight over the body to minimize user fatigue, provide sufficient breathability for extended use and must not interfere with or restrict the user’s mobility.

Traditionally, soft body armors for ballistic protection were manufactured using layers of woven fabrics stitched together; now they include laminates stacked with nonwoven, unidirectional (UD) layers and combinations of woven/nonwoven laminates. Considering the UD laminates, fibers within each UD layer are aligned in a parallel arrangement and are reinforced with a compliant polymer resin or matrix such as Kraton that binds the fibers together. The UD layers are produced in very thin sheet forms and are stacked, for example, in an alternating 0°/90° cross-ply fashion as shown in Fig.(1).

Polyethylene films are added to protect the layers, and the final laminated shape is attained by applying heat and pressure. Commercial UD laminates used for ballistic protection include Honeywell’s Spectra Shield (ultrahigh molecular weight polyethylene (UHMWPE) fibers) and Gold Shield (Kevlar fibers) and DSM’s Dyneema (UHMWPE fibers).

In contrast, hard-textile or composite armors, such as helmets, are not flexible and are defined as those using a rigid resin material to bind the fibers together. Today’s textile-based armors, such as bullet-resistant vests and helmets, integrate many sophisticated polymer materials and textile processing technologies that are optimized across multiple dimensional scales [Paul, 2011].

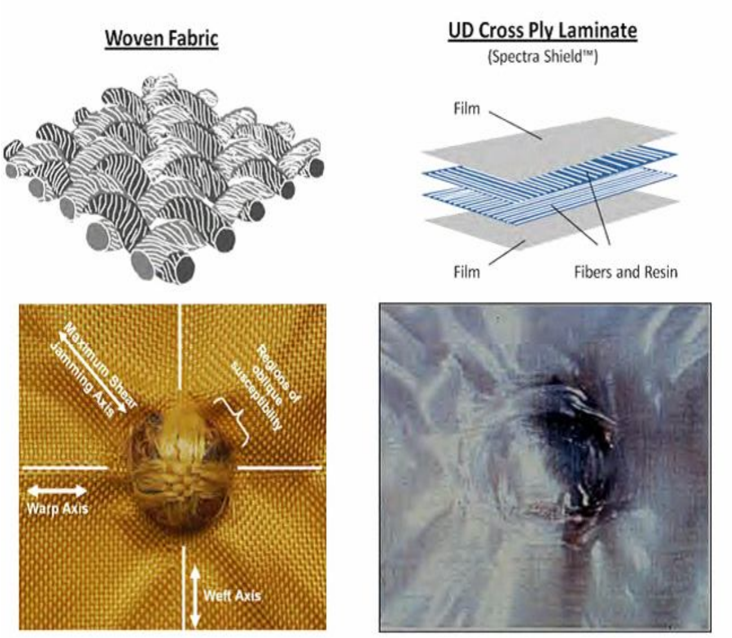

Fig. 1. Examples of woven and UD fabric lLaminateconstructions withballistic impact deformations shown [D. Fernandez-Fdz et.al., 2011].

Materials and Synthesis

The main two materials have been used in this work are unsaturated polyester resin and alumina nano powder,the characteristics of these materials illustrated in Table.(2).

Table (2) : characteristics of polyester resin and nano Al_2O_3

polyester resin		nano Al_2O_3	
Solid	65%	Density (g/cm^3)	3.9
Viscosity at 20℃	665 mpas	Melting point ^{o}C	2050
Acid value	▪ 30	Youngs modulus GPa	370
Density, g/cm^3	1.2	Vicker hardness GPa	20.97
Flash point ℃	34	Coefficient of thermal expansion $*10^{-6}$ µm/m^{o}c	8.20
Refractive index	1.542	Specific heat capacity J/g.^{o}c	0.88
Gel time, min	23	Thermal conductivity W/m.k	12
Appearance	Clear	Fracture toughness MPa m$^{-1/2}$	4

Proportion of mixing:

The mixing amount of alumina nano powder and polystyrene are shown in Table(3)

Table (3) mixing of alumina nano powder with polystyrene.

Sample	pure polystyrene [g]	nano Al_2O_3[g]
pure polyester	10.5504	0
polyester – 10 wt % nano alumina	9.4954	1.055
polyester – 20 wt % nano alumina	8.4403	2.1101
polyester – 30 wt % nano alumina	7.3853	3.1651

Each sample prepared by poured the constitutions into 50 mm diameter of the mould, then the samples obtained which are shown in Fig. 2, 3, 4 and 5 prepared for optical microscope, shore hardness, and thermal conductivity measuring.

Fig. 2. pure polystyrene

Fig .3. Polystyrene – 10 wt % nano alumina

Fig. 4. Polystyrene – 20 wt % nano alumina

Fig. 5. Polystyrene – 30 wt % nano alumina

Results and discussion:

All specimens have been examined microscopically by using Bel engineering optical microcope device made in Italy with 400X magnification. Fig.(6), illustrate microstructure of pure polystyrene specimen which show high percentage of porous,while the microstructure of polystyrene –10 wt % nano alumina possess low percentage of porous as shown in Fig.(7) This behavior is related to fill porous with nano alumina. The amount of porosity decrease as amount of nano alumina increase as clearly displayed in Fig.(8) and Fig.(9) for microstructure of polystyrene –20 wt % nano alumina and polystyrene - 30 wt % nano alumina respectively.

We used Shore hardness type D (made in Germany) to measure the hardness with 4.5 gf spring force and the results indicated in the Table (4) shows that the hardness increases linearly from low value 77.3 gf/mm of pure polyester to high value 81.6 of polystyrene - 30 wt % nano alumina. This behaviormeans that there is an increase in the density and decrease amount of porosity as amount of nano alumina increased. Hot disk thermal constants analyzer 6.1 beta 37 (made in Sweden), have been used to calculate the thermal properties to the samples and the parameters which used are: measurement time (80 sec), heating power (22 mW) and sample temperature (18℃), the result illustrated in Table (5). The values of thermal conductivityof the sample greatly influenced by the amount of porosity and so on the density, where the thermal conductivity of pure polyester have low value 0.0661 w/mk. The increment of conductivity 0.3411 of polyester – 30 wt % nano alumia result as amount of porosity decreases during increasing the amount of nano alumina.

All temperature-time diagram of the examined samples show increment of temperature as the time increases. Fig.(10) shows, that the heat flow during pure polystyrene began from 0.35 k then increase to stable value 2 k from 44 to 64 s and from this point decrease to 1.9 k at 80 s, this behavior differs from that of polystyrene – 10 wt % nano alumina, where temperature began from zero and explosively increases with time until reach 3.7 k at 200 s as shown in the Fig.(11).

Temperature –Time graph of polystyrene – 20 wt % nano alumina as indicated in the Fig.(12), shows the same behavior of polystyrene–10 wt % nano alumina but temperature began from 1.4 k then increase to 4 k at 36 s, then increase to 4.5 k at 80 s.

Fig.(13), shows Temperature – Time of polystyrene – 30 wt % nano alumina, and during this diagram the heat flow started from zero until reach 1.5 k then sharply increase to 3.5 k at 100s and stable at this degree between 100-140 s and increase to 3.6 k at 200 s.

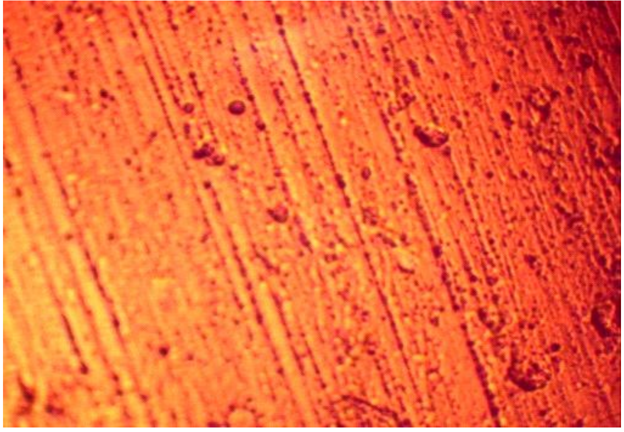

Fig. 6. The microstructure of pure polystyrene

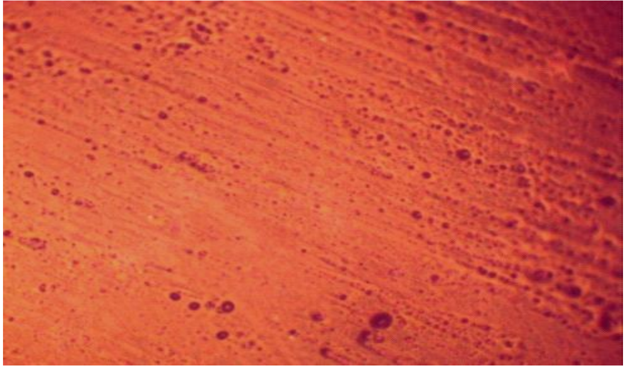

Fig. 7. The microstructure of polystyrene – 10 wt % nano alumina

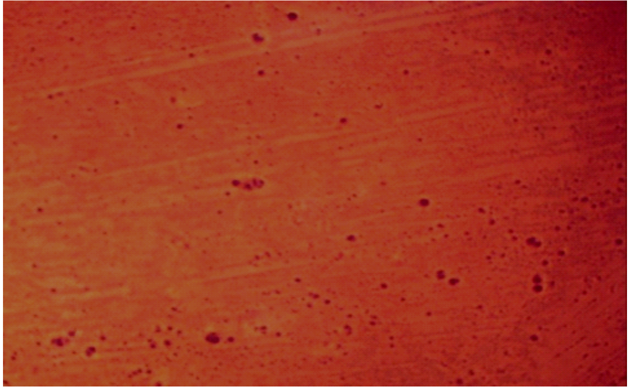

Fig. 8. The microstructure of polystyrene – 20 wt % nano alumina

Fig. 9. The microstructure of polystyrene – 30 wt % nano alumina

Table (4): Shore-D hardness

Sample	1st value gf/mm	2nd value gf/mm	3rd value gf/mm	Average gf/mm
pure polyester	79	77	76	77.3
polyester – 10 wt % nano alumina	78	76	77	78.3
polyester – 20 wt % nano alumina	80	83	76	79.6
polyester – 30 wt % nano alumina	83	80	82	81.6

Table (5): Thermal Conductivity

Sample	Thermal conductivity W/mK
pure polyester	0.1479
polyester – 10 wt % nano alumina	0.0661
polyester – 20 wt % nano alumina	0.3411
``polyester – 30 wt % nano alumina	0.2533

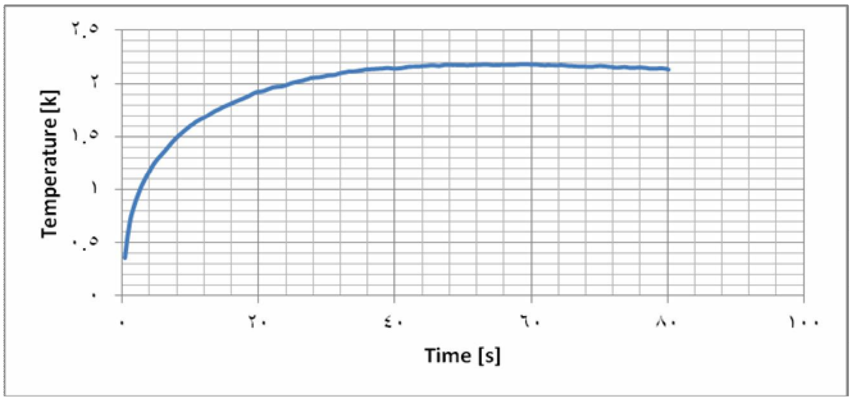

Fig. 10. Temperature – Time graph of pure polystyrene

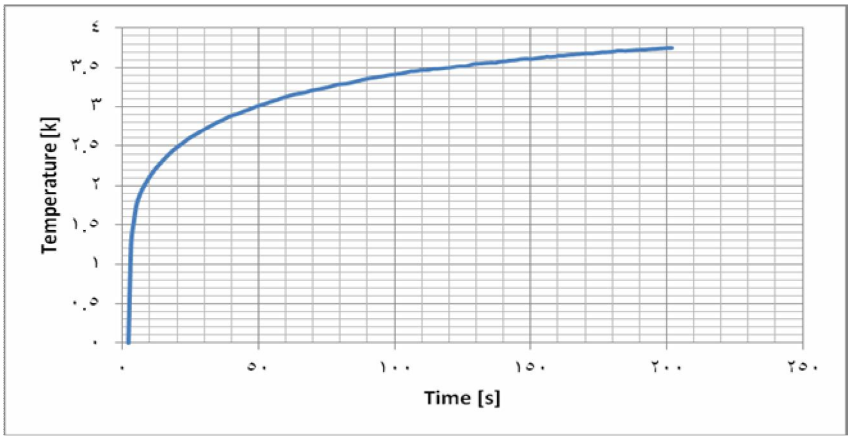

Fig. 11. Temperature – Time graph of polystyrene – 10 wt % nano alumina

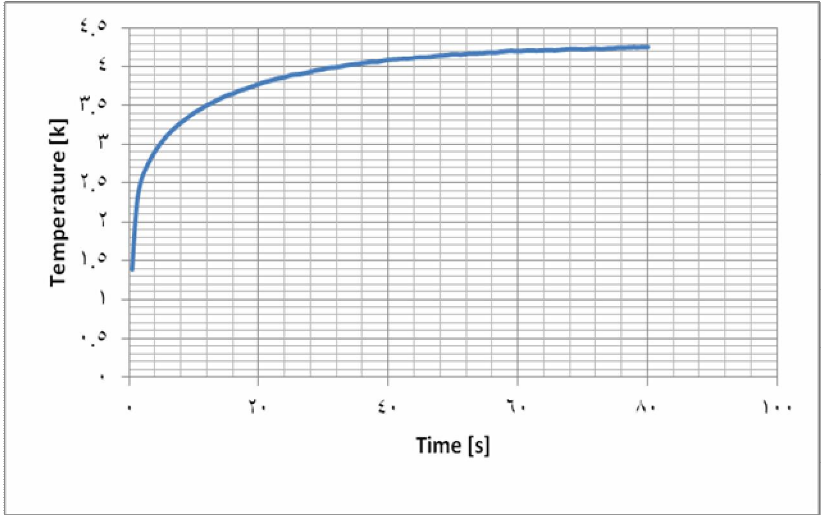

Fig. 12. Temperature – Time graph of polystyrene – 20 wt % nano alumina

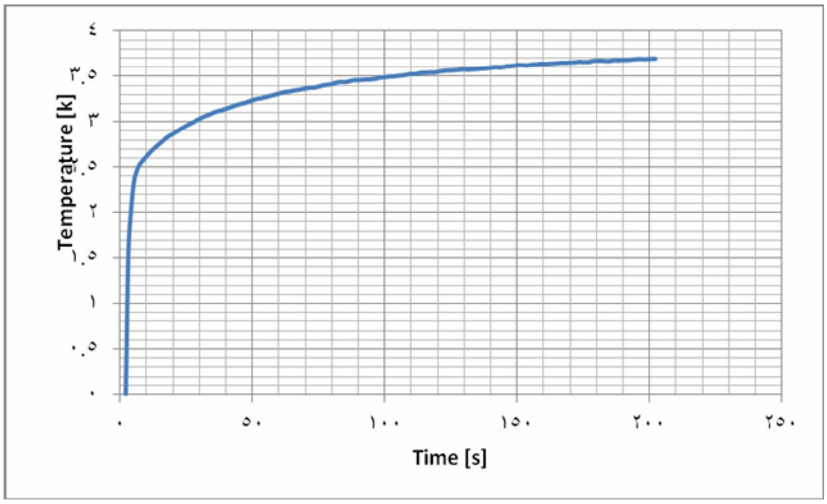

Fig. 13. Temperature – Time graph of polystyrene – 30 wt % nano alumina

Conclusions:

The values of hardness and thermal conductivity increases linearly from low value of pure polyester to high value of polystyrene - 30 wt% nano alumina. Pure polyester have 77.3 shore D hardness and 0.0661 W/mk of thermal conductivity. Polystyrene - 30 wt % nano alumina have shore D hardness 81.6 and 0.3411 W/mk of conductivity

This behavior greatly influenced by the amount of porosity and so on the density of the sample. The amount of porosity which is decreased as the amount of nano alumina increase. Pure polystyrene specimen has high percentage of porous while polystyrene – 30 wt % nano aluminapossess very low percentage of porous.

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