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Enhancement in ballistic performance of composite armor through nano ceramic

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Abstract

In this study, industrial fiber and polymer mixtures were used for high-speed impact (ballistic) applications, where the effects of polymer (epoxy), polymeric mixture (epoxy + unsaturated polyester), synthetic rubber (polyurethane), Kevlar fiber, polyethylene fiber (ultra High molecular weight) and carbon fiber. Four successive systems of samples were prepared.the first system component made of (epoxy and 2 % graphene and 20 layer of fiber), then ballistic test was applied, the sample was successful in the test from a distance of 7 m. or more than, by using a pistol personally Glock, Caliber of 9 * 19 mm. The second system was consisting of (epoxy, 2 % graphene, 36 layers of fiber and one layer of hard rubber), it was succeeded in testing from a distance of 4 m or more than, by using a pistol personally Glock, Caliber of 9*19 mm. The third system made of mixture (80 % epoxy + 20% unsaturated polyester) and 44 layers of fiber and 2 % graphene as a composite with 20 layers of fiber outside the composite material, it was successful in testing by using a semi-automatic rifle (AK47) Caliber of 7.62*51 mm from a distance of 15 m or more than. The fourth system was prepared from alumina ceramic plate Al_2O_3 (from damaged laboratory furnace linings) with composite consisted of (a mixture (epoxy 80% + 20% unsaturated polyester) and 20 % silicon carbide).placed in a cloth bag together. It was successful in testing by using a semi-automatic rifle (AK47) Caliber of 7.62*51 mm from a distance of 15 m or more than.

Key words
Epoxy, kevlar, polyethylene, ballistic test.

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تعزيز في الأداء الباليستي للدروع المركبة من خلال النانو سيراميك

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الخلاصة

في هذه الدراسة، تم استخدام مخاليط البوليمرات والألياف الصناعية لتطبيقات الصدمة علية السرعة (الباليستية) حيث تم دراسة تاثير اضافة البوليمر (الايبوكسي)، الخليط البوليمري (الايبوكسي + البوليستر غير المشبع)، المطاط الصناعي (البولي يوريثين)، ألياف كيفلر، ألياف البولي إيثيلين (فائقة الوزن الجزيئي) وألياف الكربون. تم إعداد أربعة أنظمة متتالية من العينات. يتكون االنظام الأول من (الايبوكسي والجرافين 2 ٪ و20 طبقة من الألياف)، ثم تم تطبيق اختبار الباليستية، وكانت العينة ناجحة في الاختبار من مسافة 7 م أو أكثر من ذلك، باستخدام مسدس شخصيا من نوع غلوك عيار 9*19 ملم. ويتكون النظام الثاني من (إيبوكسي، 2٪ جرافين، 36 طبقة من الألياف وطبقة واحدة من المطاط الصلب الصناعي)، وقد نجح في الاختبار من مسافة 4 أمتار أو أكثر، باستخدام مسدس شخصي من نوع غلوك عيار 9*19 ملم. والنظام الثالث يتكون من خليط (80 ٪

من الإيبوكسي + 20 ٪ من البوليستر غير المشبع) و 44 طبقة من الألياف و 2 ٪ من الجرافين كمادة متراكبة و 20 طبقة من الألياف خارج العينة وضعت مع العينة في كيس من القماش، وقد نجحت في الاختبار باستخدام بندقية نصف آلية (AK47) عيار 7.62*51 ملم من مسافة 15 م أو أكثر. وتم إعداد النظام الرابع من طبقة من سيراميك الالومينا Al_2O_3 (من بطانات أفران المختبر التالفة) مع مركب يتكون من (خليط (إيبوكسي 80 ٪ + 20 ٪ بوليستر غير مشبع) و 20 ٪ من كربيد السيليكون). وضعت في كيس من القماش معا. ولقد نجحت في الاختبار باستخدام عيار بندقية نصف أوتوماتيكية (AK47) عيار 7.62*51 ملم من مسافة 15 م أو أكثر.

Introduction

Protection against high-velocity impact from objects such as projectiles is a major issue in manymilitary and also civilian applications. In many cases, hybrid armor systems consisting of a hardceramic strike face and a comparatively soft metal or composite backing are used for ballisticprotection in both vehicles and body armor. The role of the ceramic is to erode and blunt the hard tip of the projectile, while the role of the backing material is to absorb the residual energy of the eroded [1].

Projectile and the fragments of the fractured ceramic. One of the advantages of employing ceramicsin hybrid armor, compared to materials such as steel and aluminum, is that more lightweightsystems can be designed. The load on the vehicle or the soldier is reduced and the mobility is there by improved [1, 2].

Armor developments need a basic knowledge about the mechanisms that are acting under ballistic impact of the armor.. Knowledge about how the ceramics functions as stand-alone materials, and also how ceramic-based armor systems function, is important. Today, this topic is studied in several projects, and this report is written as a part of that work [1, 2].

The main aim of this report is to give an overview of the mechanisms that are involved in ballistic failure of ceramics and ceramic-based epoxyarmor.

Experimental

1. Materials used: there are many materials were used as a following:

- **Epoxy Resin (EP):**

Epoxy resin used in this work was Sikadur®-52 LP (IN), with its properties as follows:

1. Solvent-free
2. Suitable for both, dry and damp conditions
3. Usable at low temperatures
4. Shrinkage free hardening high mechanical and adhesive strengths.

- **Unsaturated Polyester(UPE):**

In this work we used unsaturated polyester (UPE) which have two components composed of a base resin and curing agent (hardener). They have an excellent appearance and can be used for wood working saps-topping sealers, sanding sealers and top coats, medium viscosity polyester system in the form of transparent liquid, which transforms into solid state after adding the hardener to it in a percentage of (2 %).

- **Hard rubber layer:**

In this layer Natural Rubber, Sulphur and zinc oxide with stearic acid are used as activator and MBT(2-Mercaptobenzothiazole), MBTS (Dibenzothiazole disulfide) as accelerator, the black carbon used in the type of (N115). From AL-Diwaniyah Tyers factory.

- **Graphene nano powder:**

Graphene was used in this work from the company (Sky spring Nanomaterials Inc. USA) and had the following characteristics:

1. Graphene Nano powder /nanoparticles 6-8 nm.
2. Exfoliated Graphene Nano powder, Platelets, Pristine.

3. Graphene Appearance: Black powder.
4. Graphene Thickness: 6-8 nm.
5. Graphene Average Particle Diameter: 15 micron.
6. Graphene Surface Area: 120-150 m^2/g.
7. Graphene Carbon: 99.5+%.
8. Graphene Electrical Conductivity (Siemens/meter): 10^7 (parallel to surface), 10^2 (perpendicular to surface).

- **Silicon carbide powder:**

SiC: the starting materials used for this work were a commercial a-SiC powder, produced by Struers company (impurity 99.5 %) (particle size <10mm).

- **Ultra High Molecular Weight Polyethylene Fiber (UHMWPE):**

This fiber was used in this work from the company (FIBER-LINE® LLC). Properties:

1. Excellent strength to weight ratio
2. High abrasion resistance
3. UV Stable
4. Chemically inert except for strong oxidizing acids
5. Resistant to fatigue & internal friction.

- **Kevlar fiber**

Kevlar fabric laminated fabrics was used in this job, from (Jisnor-tech industrial corporation).

- **Carbon fiber**

Sika Wrap® -300 C NW is a unidirectional, stitched, carbon fiber fabric (sheet) for the dry and wet application process was used in this work.

2. Sample preparation: Four samples were prepared, each one of them different from the other preparation system, the development of these systemswas gradually to obtaining the required results as following:

1. The sample was prepared by hand lay-up method, it consists of 20 layers of fiber (8 Kevlar, 4 carbons, 8 poly ethylene) [3, 4]. The matrix was made up of epoxy (Sika co.) and was supported by Nano graphene with a weight ratio of 2%. The dimensions of sample were 15*15 cm and 0.6 cm thick and 225 gm as a weight [5, 6].
2. Done improving the above system for testing ballistic where sample preparation in the same way and with the same template, it consists of 36 layers of fiber (16 Kevlar, 4 Carbon, 16 Poly Ethylene) and a layer of Artificial Hard Rubber [3, 4]. The 2 %wt. graphene supported epoxy (Sika co.) The sample dimensions were 15*15 cm in thickness of 1 cm and weight of 553 g.
3. It consists of 44 layers of fiber (18 Kevlar, 8 carbons, 18 UHMWPE) [3, 4]. The base material (matrix) consisted of a mixture of 80 % epoxy and 20 % unsaturated polystyrene [7] and 2% wt. of Nano graphene. The sample dimensions were 15 x 15 cm and 1.2 cm thick and 760 g.
4. A sample has been prepared with a different system than the above. A composite material of 80% epoxy and 20% unsaturated polyester as a matrix, it has been prepared without placing the fiber within the composite material, it was reinforced with 15% wt. of micro silicon carbide [5-7]. A ceramic plate of alumina (from the lining of damaged laboratory ovens) was used separately from the composite material [2].

The general sample consisted of two plates, the first one made from composite material and the second is alumina plate, each of which was coated with a layer of Kevlar in order to avoid fragmentation and thus be able to withstand multi hits. Then put in a cloth bag together. The dimensions of the composite material were 15*15 cm and thickness of 1 cm and weight (540) g. The layer of alumina dimensions 13*13 cm and the thickness of 1 cm and weight of 715 g.

3. Ballistic test

A field test of the armor plate was carried out to simulate the ballistics test, using an Ak-47 gun with a bullet 7.62*51 mm and handgun kind of (GLOCK 19) Austria with bullet 9*19 mm. The plate was fixed on the stand. The distance between the rifle nozzle and the shield plate was (4, 7, 10, 15 and 20) m depending on Specifications NIJ (0101.06), also the velocity measured by (M-1 shooting Chrony) is show in Fig.1. This test shows the ability of the armor plates to endure bullets from the weapon Ak-47 and handgun (GLOCK 19) [8].

Fig.1: M-1 shooting Chrony.

Results and discussion

Four samples were prepared for this, every one of them had special system as show in a Table 1, this test was according to (NIJ Standard-0101.06) [8]. The plates were tested in real field using (AK 47) and handgun kind of (GLOCK 19) Austria with distances in between (4, 7, 10, 15, 20) m. The results showed that all plates had the ability on penetrate the impact except one, the plate failed with 4 m but after increasing the distance to 7 m and more the plate had a clear success. The results of used samples which are shown in Table1 demonstrate the vest development. The armor put against the handgun bullets of 9*19 mm from a distance of 7 m and more. As shown in Fig. 2.

Table 1: The system of armor samples.

Armor system	Weight of sample (g)	caliber of bullet	penetration
2% graphene +epoxy resin +20 layer of fibers (8K,4C,8PE)	500	9*19 mm	Complete penetration from 1 around
2% graphene +epoxy resin +36 layer of fibers (16K,4C,16PE) +hard rubber	1064	9*19 mm	No Complete penetration from All around
{2%graphene+(Polymer blend (20%polyester+80%epoxy)) +44 layer of fibers}+20 layer fiber of Kevlar(outside a sample)	1484(composite)+ 176(external fiber)	7.62*51mm	No Complete penetration
Plate Al_2o_3 +4 layer fiber of Kevlar + composite (15%wt. SIC +Polymer blend (20%polyester+80%epoxy))	1823(Al_2o_3)+ 1093(composite)	7.62*51mm	No Complete penetration

Fig.2: Ballistic test by handgun bullets of 9*19 mm from a distance of 7 m.

In the second system, the first sample was developed by increasing the fiber layers and one layer of hard synthetic rubber was added. Armor was obtained against handgun caliber bullets of 9*19 mm from very close distances, it was completely safe. This is due to the increase in the number of layers that worked to absorb and dissipate the energy of the lead until it stopped with the help of ceramic material saturated by the fiber with the binder (Matrix). Each fiber layer traversed by the bullet works to prevent the movement of the bullet and this is the basis of the work of fiber layers and ceramic material in all samples as shown in Figs. 3 and 4.

Fig.3: The ballistic test by handgun bullets of 9*19 mm from a distance of 4 m.

Fig.4: The ballistic test by handgun bullets of 9*19 mm from a distance of 10 m.

In the third system, the second sample was developed by increasing the number of fiber layers, the type of matrix material was a blend composite of (80% epoxy + 20% unsaturated polyester) to achieve a higher impact strength.

This blend increases the flexibility which makes the sample absorb the momentum of the bullet [7]. The idea of adding fiber layers outside the sample to allow it to move freely and not restricted by the base material and thus increase the dispersion of energy and increase resistance to the bullet and this is what has already happened to be the total weight of the sample plus the external fiber equals (1660) g. After the casting process was completed and the solidity was obtained, the sample was tested by AK47 ofcaliber 7.62*51 mm, the sample was penetrated but after putting 20 layers of Kevlar fiber after the sample, all were placed in a cloth bag the bullet was stopped. In fact, four layers were able to stop the bullet, but at the critical limit and to increase safety and reduce the energy associated with the bullet, which cause deformities in the back face, was placed twenty layers of fiber as shown in Figs. 5 and 6 [3, 4].

Fig.5: The sample before test.

Fig.6: Ballistic test by AK47 with bullets of7.62*51 mm.

In the fourth sample, fibers were replaced with a plate of alumina was used for economic benefit. Nano graphene were replaced by micro silicon carbide with 15 % weight for the same purpose [2, 9]. This weight ratio of ceramic powder was used based on the results of impact test, when studying the behavior of micro silicon carbide in this test, it was found that when increasing the weight ratio of its, the strength of the sample increases [9, 10]. Only four layers of Kevlar fiber were used, one layer was applied to each face of the alumina plate and the composite material to ensure that it was not broken from the first strike to withstand multiple shots [2, 5].

The two plates were placed in a cloth bag to be one body but separated from each other, each of these plates was used to perform a particular function for alumina plates that break and deform the tip of the pointed bullet due to the hardness and rigidity of this material.

If improved by pressing on the warm will give better results.

As for the overlapping material plates, it has a good resilience that can absorb and dissipate energy from the bullet and their weight was equal (2916) g as shown in Fig.7.

Fig.7: The ballistic test by AK47 with bullets of 7.62*51 mm.

Conclusion

1. In ballistic test the sample made of mixture (80% epoxy + 20% unsaturated polyester) and 44 layers of fiber and 2% graphene as a composite with 20 layers of fiber outside the composite material, then placed in a cloth bag together. It was successful in testing by using a semi-automatic rifle (AK47) Caliber of 7.62*51 mm from a distance of 15 m and more, and its weight was 1660 g.
2. Ceramic plate Al_2O_3 (from damaged laboratory furnace linings) with composite consisted of (a mixture (epoxy 80% + 20% unsaturated polyester) and 15% silicon carbide). Placed in a cloth bag together. It was successful in testing by using a semi-automatic rifle (AK47) Caliber of 7.62*51 mm from a distance of 15 m and its weight 2916 g.

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