Enhancement the Armor Shielding Properties of CF/epoxy Composite by Addition Nanoparticles of Magnetic Iron Oxide

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Abstract. In the present investigation, we prepared two types of CF composites. The first prepared composite sample was CF/epoxy resin composite and the second was CF/epoxy resin / with a different weight ratio of magnetic iron oxide. Magnetic iron oxide was prepared by co-precipitation method, with particle sizes measured in range 25:35 nm. The resistance to penetration of high kinetic energy projectile of the prepared composite sample was measured and It was found that addition of 5% nano-particles of magnetic iron oxide to composite material sample decrease the residual velocity of projectile penetrating it by 9%.i.e increasing resistance of the sample to penetration of high kinetic energy projectile.it was found that the Resistance to penetration of sheet of composite material sampleC4 of weight=40.32kg to projectile 7.62×39 mm AP at distance 15m equivalent to resistance of steel sheet of weight =54.6 kg at distance 200m.Resistance to penetration of sheet of composite material sampleC4 to projectile 7.62×39 mm AP at distance 10m equivalent to the resistance of high-quality steel sheet(steel4340) of weight=47.85 kg at distance 25m.

1 Introduction

Carbon fiber CF considered as one of the most important fillers for polymeric matrix composite materials due to its unbelievable properties, such as high thermal stability, high specific strength and stiffness, performance to weight ratio, high conductivity, corrosion resistance and self-lubrication. Most significantly, use of CF allows a reduction in weight of the equipment's or vehicles due to its high strength to weight ratio. CF reinforced polymer composites used for aerospace efficacies, wind turbines applications in automotive energy systems, fuel cells, offshore– deep sea drilling platforms, compressed gas storage, turbo machinery and transportation, antistatic and electromagnetic shielding materials[1-3]. Liu and Kumar have studied the existing progress of carbon fiber structure, fabrication and properties including the introducing of nano-tubes in precursor fiber to improve the mechanical properties [4-6]. However, the essential mechanical characteristics of these composites such as toughness, longitudinal and transverse strength limited by the intrinsically poor interfacial adhesion between polymer materials and reinforcing CF surface. It is a long existing critical issue needed to be solving for ensuring the continued development of CF reinforced polymer composites for potential advanced composites applications [4-9].

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Motivated by this, many researchers focused on probing an understanding the physicochemical interaction at the fiber/matrix interface. For achieving strong interfacial bonding, the adequate level of Vander Waals and hydrogen bond forces between the matrix and CF are required during composite processing.

In addition, the fiber/matrix interfacial adhesion energy should be higher than the cohesion energy of the matrix. The modifications applied to CF structure made a big difference in improving the mechanical properties of high performance polymeric composites but the focus to control the fiber/matrix interfacial properties is still a major task [8-9].

CF, from a structure has crystallized graphitic basal planes with non-polar surface. The chemical inertness due to the existence of high temperature treatment step [carbonization/graphitization] during manufacturing, surface lipophobicity, and excessive smoothness and fewer adsorption properties of CF lead to weaker bonding with the matrix materials.

As remedy for CF inertness, modifications at fiber surface needed to execute strong fiber/matrix interfacial adhesion for effective stress transfer at the interface [10].

Epoxy resins are excellent and high-performance thermosetting resins, which display a unique combination of properties. Epoxy resins are one of the most versatile polymers with uses across an enormously wide variety of industries. They are composed of polymeric molecules that are converted to a solid by a chemical reaction. The ability to be transformed from a low-viscosity liquid (or thermoplastic state) into a tough, hard thermoset is the most valuable single property of epoxy resins. An epoxy system physically comprises two essential components: a resin and a curative. The curative causes the chemical reaction, which turns the epoxy resin into a solid, cross linked network of molecules. This polymer is called a thermoset polymer structure with high cohesive strength and adhesion properties because, when cured, it is relatively unaffected by heat and irreversibly rigid. However, the term epoxy can also be used to indicate an epoxy resin thermoplastic or cured state [11-14].

Many studies about the increasing the mechanical properties of CF/epoxy resin composite were applied, Mainly by the addition of nanoparticles materials as second filler to increase the bond between CF and epoxy resin such as carbon nano fiber or carbon nanotube. Carbon nanotubes (CNTs) have been widely used in enhancing composites for its excellent mechanical properties, large specific surface area, as well as good compatibility with polymer [8]. The method of introducing CNTs on the surface of fibers to enhancement the interfacial properties of composites has been a hot topic.

Jianwei Zhang, Su Jua, Dazhi Jiang, Hua-Xin Peng, enhanced Mechanical properties of carbon fiber (CF) reinforced epoxy composites with addition a small amount of multi-walled carbon nanotubes (MWCNTs). 1 wt % MWCNTs were well dispersed in the epoxy matrix and the CF prepregs were manufactured using the technique of fiber filament wind. The hybrid composites of MWCNT/CF/epoxy were fabricated by laying-up of fiber prepregs. Interlaminar shear strength (ILSS), tensile properties and microstructures of the composites were investigated. The results show that the addition of MWCNTs into the composites increased and enhancement the tensile properties and ILSS with much reduced disparity. Enhancing mechanisms behind these were elucidated [15].

In this research, we use the same concept to add nanoparticle filler but with a different point of view. In this investigation, the effect of the addition of nano particles of magnetic iron oxide into the resistance of CF/epoxy resin composite to penetration of high kinetic energy projectile was studied.

2 Experimental work

2.1 Materials

The carbon fiber used is PAN carbon fiber made from a polyacrylonitrile precursor has moderate strength; moderate modulus and carbon fiber yarn contain 3000 filaments obtained from Russia. The epoxy resin used in this study is a two component epoxy system consisting of (EPON 828) cured with polyamide (versamide 125) hardener. This two component system obtained from HEXION Company, France .epoxy processed in proportions of 1:1 by weight. Carbon fiber impregnated with phenol formaldehyde resin obtained from Russia. The nano-scale fine particles used are magnetic iron oxide [Fe3O4] prepared by precipitation method.

2.2 Nano-particles used of magnetic iron oxide [Fe_3O_4]

Super –paramagnetic magnetite (Fe_3O_4) were produced by a co-precipitation method from the aqueous solutions of $FeCl_2$ and $FeCl_3$ using a NaOH or NH_4OH solutions [17-18].By applying the following standard procedures. First, prepare 0.11M $FeCl_2$ and 0.2 M $FeCl_3$ in 1 liter distilled water and put the solution in a reactor and stirred vigorously. Then put NH_4OH solution in separating funnel then add ammonia solution drop by drop to iron chloride solutions with strong stirring till black precipitate formed then added an excess amount of NH_4OH solution and then agitate for 1 hour. After 1 hour we put the reactor in the water bath at 80^0C with strong stirring for 120 minutes. Then we stop stirring and lit the suspension particles to precipitate. After that we add distilled water to the reactor to wash particles and leave it till precipitate then we poured some water without the particles. We repeat the previous procedure several times till we washing iron oxide particles and still the iron oxide particles suspending in few drops of remaining water. Then we put the reactor in the furnace at 60^0C for 2 days to evaporate the liquid and achieved on the iron oxide particles. Finally, we weight the particles and put it in the suitable bottle.

2.3 Preparation of epoxy samples

Epoxy resin system consists of two parts A (EPON 828) and B hardener (versamide 125), part A was carefully weighed and a stoichiometric amount of part B was added, then stirring using magnetic stirrer for 30 min with low velocity to prevent air trapping. When addition nano-scale fine particles to composite material we added it first to part A of polymer and mixed together in the suitable beaker for 10 min for homogeneity [13].

2.4 Composite fabrication

Composite material based on CF/epoxy resin and was prepared by hand lay-up technique. Brush and roller were used to help the impregnation of fiber. The epoxy resin was prepared first as in the previous paragraph 2.2. The epoxy was brushed on the surface of CF. the epoxy-brushed fiber tape was carefully stacked up and aligned together layer above layer then compressed adding load 50 Kg over the upper surface and left at room temp for 24 hrs [11].

2.5 Determination of particle size of prepared magnetic iron oxide

The particle size of fumed silica and prepared magnetic iron oxide can be measured by several techniques as particle size analyzer (zeta sizer) or can be measured by High Resolution Transmission Electron Microscope. In our research, we used the last method for determination of particle size which was high resolution transmission electron microscope (TEM), type JEOL JEM 2010 FAS TEM, purchased from JAPAN. The used TEM specified by ultra-high resolution point-point reached to 194 nm and lattice resolution reached to 14nm.

2.6 Penetration tests

Composite materials generally and CF composite especially are suitable for use in applications involving high velocity impact because they combine lightness with high strength. However, the impact of composite materials is a very complex process. As a consequence of this CF, matrix and interface properties are still optimized by trial and error using ballistic experiments. So the main objective of the experimental work was to study the penetration of 9mm and 7.62 * 39 mm projectiles into a set of laminated CF /epoxy composites targets and body armors using the experimental facilities of the shooting ranges, Weapons and Ammunition Researches Sector, Technical Research Center (T.R.C), Egypt. Ballistic tests were performed to determine the projectile impact and post-perforation velocities for the prepared targets from CF/epoxy composites with thickness 7mm and 35 mm. Projectile arrivals were detected using the muzzle velocity radar measuring system, Model 2605R. The Departure of the projectile was detected using the velocity measuring device, Model HPI B571 optical target system.

In this test, we tested the impact resistance of the prepared composite samples against small projectile as 9mm projectile and 7.62× 39 mm armor piercing (AP) projectile in order to explain the application of prepared composite as light armor. The composite samples were tested against 9mm projectile from 10m distance, while the another sample was tested against 7.62×39mm AP projectile from 10m distance [16].

2.6.1 Penetration setup

The penetration experiments were performed in the ballistic shooting range, which had provisions for the measurement of projectile impact and post-perforation velocities respectively, for prepared CF/epoxy composites targets. As shown in figure 1, the penetration setup mainly consists of: ballistic rifle, impact velocity and post perforation velocity frames with their respective electronic measuring instrument, and target mount.

By using the simulation program (AUTODYNE program) and calculations of absorbed energy and kinetic energy we compare the prepared sample with resistant of steel against the same projectile.

2.6.2 Setup of penetration test

To apply penetration test we should have penetration set up consist of the following parts:
A. Ballistic rifle used for penetration test

They are standard barrels, caliber 9 mm and caliber 7.62mm used for the particular purpose of the ballistic measurements of 9 × 19 and 7.62 × 39 bullets. The barrel was mounted horizontally during the whole tests. The 9 mm and 7.62 mm barrels were fixed on a rigid stand as shown in Figure 1, which in turn, was mounted on a concrete base by supporting studs. The barrel direction can change in elevation and traverse.

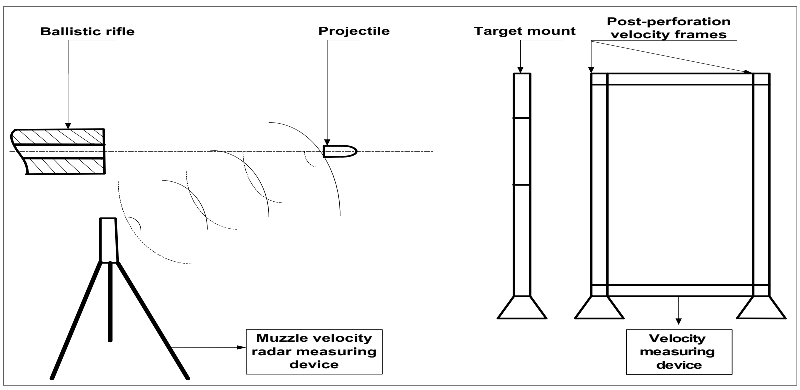

Figure 1. Scheme of ballistic set-up.

The test was carried out according to the following steps:
Penetration tests were performed in the shooting range according to the following steps:

1. The muzzle velocity measurement system, Model 2605R and the residual velocity measuring device, Model HPI B571 optical target system were first switched on. The computers were switched on and the software was activated.
2. All electronic instruments used were reset again to be ready for measurements
3. The prepared target was fixed in place.
4. The projectile giving a predetermined impact velocity was chosen and loaded into the barrel chamber. This was only allowed after evacuating the shooting range from personnel.
5. The safety door was closed and firing performed electrically from the control room. The displayed impact and residual velocities on their respective PC screens were recorded.
6. The breech was unlocked and empty cartridge case extracted.
7. The shooting point on the target was marked.
8. For firing another shot, the steps from 2-7 were repeat

2.7 Samples codes and compositions

The codes and composition of the prepared composite samples used in this research illustrated in table 1.

Table 1. Details of composition of each formulation.

Formulation	Composition
C1	[CF+ epoxy resin]composite with thickness 7 mm
C2	[CF+ epoxy resin+ 2.5% iron oxide] composite with thickness 7 mm
C3	[CF+ epoxy resin+ 5% iron oxide] composite with thickness 7 mm
C4	[CF+ epoxy resin+ 5% % iron oxide] composite with thickness 35 mm

3 Result and discussion

3.1 Particle size determinations of magnetic iron oxide particles

The particle size of prepared magnetic iron oxide can be determined from the figure 2, which show the TEM picture for the prepared magnetic iron oxide. The particle size of prepared magnetic iron oxide was in the range of 25:35 nm.

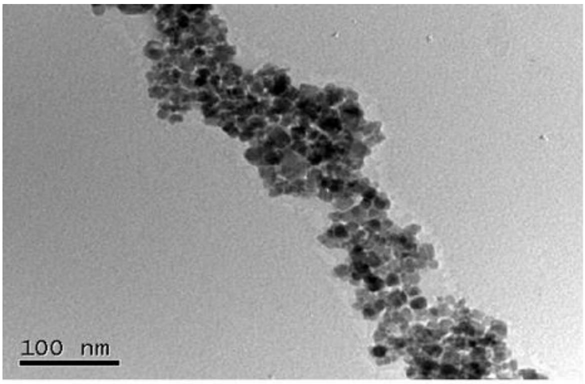

Figure 2. Particle size of magnetic iron oxide.

3.2 Resistance of prepared composite material to penetration of high kinetic energy projectile

In this part, the resistance of prepared composite material samples to penetration against high kinetic energy projectile in order to use in armor applications will be discussed. The resistance to penetration is expressed by measuring the residual velocity and energy absorbed by the sample during penetration of projectile.

3.2.1 Resistance of prepared composite samples to penetration of 9mm projectile

In this test, three composite material samples were prepared and subjected to 9mm projectile from distance 10m. The samples are C1, C2, and C3. The effect of the addition of nano-particles of magnetic iron oxide to composite material on the resistance to penetration shown in table 2.

Table 2. Resistance test result for composite material samples C1, C2andC3.

Sample code	Sample thickness [mm]	Sample density [gm/cm^3]	Impact velocity V_i [m/s]	Residual velocity V_r [m/s]	Velocity Drop ΔV [m/s]	Velocity Drop Percentag
C1	7	1.154	251.24	197.5	53.74	21
C2	7	1.12	251.7	188	63.7	25.4
C3	7	1.12	251.5	180	71.5	28.5

From Table 2, we can see that the drop in velocity due to penetration of 9mm projectile for composite sample C3 is higher than that of composite samples C2and C1 respectively. It also shows that the residual velocity of the projectile due to penetrateC3 is less than that of sample C1 by 9%.
This mean that addition of 5% nano-particles to composite material sample decrease the residual velocity of the projectile penetrating it by 9%.i.e increasing resistance of the sample to penetration of high kinetic energy projectile.

3.2.2 Resistance of prepared composite samples to penetration of 7.62×39mm AP projectile

In this test, composite material sample based on CF/epoxy resin/ 5% magnetic iron oxide was tested. The sample C4 with a thickness of 35mm was subjected to 7.62×39mm AP projectile from distance 10m.the result shown in table 3.

Table 3. Resistance test result for composite material sample C4.

Sample code	Sample thickness [mm]	Sample density [gm/cm^3]	Impact velocity V_i [m/s]	Residual velocity V_r [m/s]	Velocity Drop ΔV [m/s]	Velocity Drop Percentage %	Absorbed energy [J]
C4	35	1.12	750	290	460	61	1889.68

From table 3, it can be seen that sample C4 absorbed energy equal to 1889.68 J from the kinetic energy of the projectile at 10m which equals to 2222.5 J. From previous work which has been done in the department of weapons and ammunition M.T.C., the velocity of projectile versus distance was plotted. This plot is shown in figure 3 [16]. From this figure, the velocity at which the kinetic energy of projectile equal absorbed energy by sample C4 at distance 10m can be detected. From the figure, we found that velocity which gives the same energy was at 15m.i.e. the composite sampleR11 stopped projectile at distance 15m.

Calculations

From figure 3 at 15m velocity = 691.5 m/s

Kinetic energy of projectile at 25m [K.E] = $0.5 \times m \times V^2$

$= 0.5 \times 7.9 \times 10^{-3} \times (691.5)^2 = 1880.595$ J

Absorbed energy by sample C4 = 1889 J

But, energy absorbed by sample C4=kinetic energy of the projectile at 15m.

So, C4 can stop the projectile 7.62×39mm AP at distance 25m.

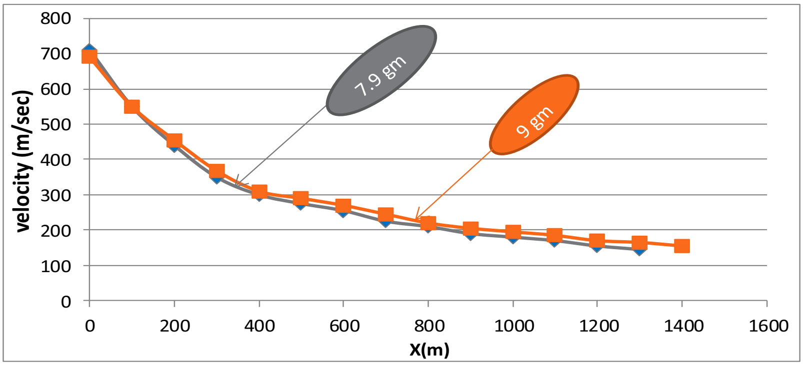

Figure 3. Velocity of 7.62×39mm AP projectile versus distance.

3.2.3 Comparison between steel and composite sample C4 to resistance of penetration

The projectile used for this comparison was 7.62×39mm armor piercing (AP). The results show that the prepared composite sample C4 can stop the projectile at distance equal 15m. However, 7mm thickness of steel can stop this projectile at a distance equal to 200m, as stated in the literature. So, the prepared composite sample gives better results than steel. In addition to the big difference of weight of the sheet of the composite of dimensions 1mx1mx35mm which is (40 kg) compared to the weight of the sheet of steel of dimension 1mx1mx7mm which is (54.6 kg) should be taken into consideration.

3.2.4 Comparison between high quality steel (4340) and composite sample C4 to resistance of penetration

The projectile used for this comparison was 7.62×39mm armor piercing (AP). The results show that the prepared composite sample C4 can stop the projectile at a distance equals to 15m. However, 6.1mm thickness of steel 4340 can stop the projectile at a distance equals to 25m, as calculated by using AUTODYNE program, and also absorbed the same amount of energy as absorbed by composite sample C4 at a distance equals to 10m. So, the resistance of the prepared composite sample to projectile penetration equals the resistance of 6.1mm of high quality steel for the same projectile. Also, the weight of a sheet of the composite of dimensions 1mx1mx35mm is 40.32 kg; however the weight of a sheet of steel of dimension 1mx1mx6.1mm is 47.6 kg.

4 Conclusion

The composite material based on CF/epoxy resin and CF/epoxy resin/nano particles of magnetic iron oxide were preparing by hand layup technique. It was found that the prepared magnetic iron oxide has particle size in range 25:35 nm. The addition of 5% nano-particles of magnetic iron oxide to CF/epoxy resin composite material improve the resistance of composite to penetration of high kinetic energy projectile expressed by a decrease of residual velocity of the projectile by 9%. Resistance to penetration of sheet of composite material sampleC4 of weight=40.32kg to projectile 7.62×39 mm AP at distance 15m equivalent to the resistance of steel sheet of weight =54.6 kg at distance 200m. Resistance to penetration of sheet of composite material sampleC4 of weight=40.32 kg to projectile 7.62×39 mm AP at distance 10m equivalent to the resistance of high quality steel sheet(steel4340) of weight=47.85 kg at distance 25m.

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