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Effect of Impactor Design on Unidirectional and Woven fiber Reinforced Composites

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Abstract

Since impact damage resistance is such an important property for composite materials, this research is devoted to study the effect of impactor design on the impact properties of epoxy composites reinforced with unidirectional glass, unidirectional carbon, woven glass and hybrid woven (glass + carbon) fibers . This research shows changing the impactor design have no effect on impact properties of woven reinforced composites while it has a significant effect on unidirectional fiber reinforced composites, impact damage behavior of woven composites is in the form of indentation and perforation while the behavior is matrix cracking and splits along the fiber direction and fracture for unidirectional fiber reinforced composites under impact loading and finally Glass fiber reinforced composites have a better impact properties than carbon reinforced composites.

Keywords : drop weight impact, impactor design, unidirectional fiber composites, and woven fiber composites.

1. Introduction

The advantages of composite materials are numerous and well documented. Composite materials are often used in environments in which they will suffer from impact damage. For example, damage can occur from a hammer being dropped on a composite pipe or from a bullet striking composite armor [1].

A 3D finite element model has been developed by B.M. Fadhil [2] for ballistic impact on ceramic targets with three different thicknesses (4, 7, 10mm) by three different nose projectiles (ogival, flat and hemispherical). It is found that the residual velocities and the amount of erosion that the projectile suffered are strongly affected by the shape of projectile head. Also the increasing the ceramic thickness leads to an increase the erosion rate and erosion amount, besides in increase in the absorbed energy [2].

Drop weight impact of fiber-reinforced composites has been studied by many researches. In research work of Sutherland and Guedes Soares [3] drop-weight impact tests have been carried out for low fiber-volume glass-polyester laminates for a range of diameter to thickness ratios. They also showed that an energy balance approach gives good correlation between impact force and incident energy. The impact response of woven carbon/epoxy and E-Glass / epoxy composite systems on vehicle body structures has been investigated by Arturas KERŠYS et. Al. [4] . For low-velocity impact, drop weight impact tests performed by EADS (European Aeronautic Defense and Space Company) Corporate Research Center Germany have been carried out. It is established that by increasing the impact energy elastic deformation of woven E-glass / epoxy composite systems is 1.5 times higher than carbon epoxy composite systems that defines the formation of smaller areas of damage.

O. Falc´o et. al. [5] present an experimental study of the effects of tow-drop gaps in variable Stiffness Panels under drop-weight impact events. Two different configurations, with and without ply-staggering, have been manufactured by Automated Fiber Placement and compared with their baseline counterpart without defects. Results indicate influence of gap defects is only relevant under small impact energy values. However, in the case of damage tolerance, the residual compressive strength after impact does not present significant differences to conventional straight fiber laminates. That indicated that the strength reduction was driven mainly by the damage caused by the impact event rather than by the influence of manufacturing-induced defects.

An attempt has been made by Naveen V Padaki et. al. to summarize the research progress on low velocity drop weight impact properties of textile reinforced composites. The paper mainly reports the impact test parameters and textile reinforcement along the matrix, interface effects, impact failure modes and major evaluation techniques for impact damage analyses such as ultrasonic scanning and retention of strength after impact [6]. Since impact damage resistance is such an important property for composite materials, this research will be devoted to study the effect of impactor design (cone, bullet and hemispherical) on the impact properties of epoxy composites reinforced with unidirectional glass, unidirectional carbon, woven glass, and hybrid woven (glass + carbon) fibers impact testing.

2. Experimental Part

The resin used for composites manufacturing was 105 Base epoxy (by DCP products), with 105 hardener. Lamination was carried out at 20–22°C with 1 week curing. Epoxy laminates composites (figure 1) were obtained by hand lay-up method, with planar dimensions 200 ×150 mm, which allows obtaining a laminate thickness of 5 mm. All the categories of samples tested are listed in Table 1.

To determine the mechanism of impact damage the experiment was performed when composite materials were deformed with different impactors design as shown in table 2 in an Instron Ceast 9350 impact tester instrumented drop-weight tower by an automatic anti-rebound impactor system (figure 2). Drop weight impact testing is a type of low velocity testing, and it is the most common test for composite materials. Drop weight impact tests are done to test the impact behavior on composite plates, which most closely resemble impact damage in the field [1].

3. Results and Discussion:

During the impactor design is changed the relationships of force-time, force-deformation, energy-time and energy-deformation were obtained from experimental data as follows:

3.1. Impact Force – Time behavior

Figure 3 shows the impact force – time results of the composites used in this study with different impactors shapes: cone, bullet and hemispherical. Impactor shape has significant effect on the force-time relationship, where it can be seen that time to failure of cone impactor is the same for all composites while for hemispherical and bullet impactors: failure time for unidirectional glass (UG) and unidirectional carbon (UC) composites is lower than cone impactor, this is due to the impact contact area which is large in the case of cone impactor (i.e. the contact pressure is less) and small in the case of hemispherical and bullet impactor (i.e. the contact pressure is more) .

It can be seen in figure 3 that in all impactors the minimum force is in the epoxy without any reinforcement and maximum force were in woven glass reinforced energy (WG) because they have good ability to absorb large share of impact stresses due to nature of fabric in two directions where plain woven textile laminates subjected to impact loading beyond threshould energy level show crack initiation within the ply which tries to propagate through the thickness, but has to cut through the fiber in the wrap direction wherein the resistance is offered due to high interlacement and the growth of crack is arrested. Hence, the delamination initiation and progression will be suppressed. In cone impactor, glass reinforced composites WG and UG have higher force values than WGC and UC this is due to the fact that Glass fibers, although have lower strength and stiffness, show better impact resistance than carbon fibers in the composites due to higher strain to failure. Carbon fibers, being most brittle show poor resistance to impact damage in composite form which has been validated in comparison to glass reinforced composites. UC composites showed low impact force and crack propagates rapidly in a very short time compared with others due to susceptibility to impact damage because of the brittle characteristics of the reinforced fibers in addition to non-isotropic behavior of the unidirectional fibers which are considered as a disadvantage in the composite's structure. WGC composites show a mixed behavior since it contains both glass and carbon fibers and have good ability to absorb good share of impact stresses due to nature of fabric in two directions.

3.2. Impact Force – Deformation behavior:

Figure 4 shows the impact force – deformation results of composites with different impactors shapes: cone, bullet and hemispherical, where it can be see the following: behavior of all composites during the impact (Fig. 4) showed most important peculiarity of these composite materials was decreasing stiffness when the displacement increased due to great specimen deflection.

For cone impactor: the area under the force-displacement curve showed the great part of impact energy absorbed with the composite of WG followed by UG, WGC and UC. Epoxy without any reinforcement was the lowest. WG composites had a special behavior, where both force and deformation is increase and decreases again due to the transformation of potential energy to kinetic energy. For UG, WGC and UC the force value increase and decrease with the continuous increase in the deformation until failure and show the initial processes of the sample perforation.

For bullet impactor: Epoxy without any reinforcement was the lowest. For WG and WGC both force and deformation is increase and decreases again due to the transformation of potential energy to kinetic energy. For UG and UC show a very low force and deformation values before failure and this is explained as the abrupt decrease of stiffness after matrix cracking and splits along fiber direction and fracture.

For hemispherical impactor: For WG and WGC both force and deformation is increase and decreases again due to the transformation of potential energy to kinetic energy. For UG the force value increase and decrease with the continuous increase in the deformation until failure and show the initial processes of the sample perforation. UC composites specimens show a very low force and deformation values before failure and this is explained as the abrupt decrease of stiffness after matrix cracking and splits along the (UC) fiber direction and fracture.

3.3. Impact Energy – Time behavior

Figure 5 shows the Energy – time relationships of the composites with different impactors shapes: cone, bullet and hemispherical.

For cone impactor: large impact contact area of this impactor results in making the energy-time curves of all composites are approximately end at the same time without being affected by the type of reinforciement. UG although have lower strength and stiffness, show better impact resistance than WGC and UC in the composites due to higher strain to failure which lead to a higher energy absorption. WG and WGC show a perforation failure while in UG and UC composites the energy keeps in increasing with time to the end of the test where fracture by matrix cracking and splits along the fiber direction and fracture. Epoxy has the lowest energy amount.

For bullet impactor: the shape of this impactor and the small contact impact area has an obvious effect on impact properties of the composites where WG and WGC show the higher absorbed energy with a perforation failure while in UG and UC composites fail in a very short time and the energy keeps in increasing with time to the end of the test where fracture by matrix cracking and splits along the fiber direction and fracture. Epoxy has the lowest energy amount.

For hemispherical impactor: the shape of this impactor and the increasing contact impact area has a special effect on impact properties of the composites where UG ,WG and WGC show the higher absorbed energy due to higher strain to failure which lead to a higher energy absorption with initial perforation failure for WG and WGC while in UG the failure is in the form of along the fiber direction. UC composites fail in a very short time with a very low energy and Epoxy has the lowest energy amount.

3.4. Impact Energy – Deformation behavior

Figure 6 shows the Energy – Deformation relationships of the composites when the composites deformed with different impactors shapes: cone, bullet and hemispherical.

This figure shows that WG composites with three impactors had a different behavior comparing with other composites where both energy and deformation is increase and decreases again due to the transformation of potential energy to kinetic energy. WGC composites showed an increasing energy when the displacement increased to fracture in all three impactor shapes.

UG has a higher energy and a larger deformation than other composites with cone and hemispherical impactors and with low enrgy – deformation values with bullet impactor due to the small impact contact area in bullet impactor (i.e. higher impact pressure) and large impact contact area in cone impactor (i.e. lower impact pressure) and varied contact area in hemispherical impactors.

UC composites showed low impact energy with bullet and hemispherical impactors, crack propagates rapidly with a very small deformation compared with others due to susceptibility to impact damage because of the brittle characteristics of the reinforced fibers in addition to non-isotropic behavior of the unidirectional fibers which are considered as a disadvantage in the composite's structure, With increasing impact energy the damage involves more matrix cracking and splits along the (UC) fibre direction. Cone impactor has no significant effect of on energy-deformation behavior 0f UC composite due to and large impact contact area in cone impactor (i.e. lower impact pressure). Epoxy without any reinforcement showed a very low absorbed energy with a very large deformation in all three impactors compared with the other composites.

3.5. Effect of Impactors design on Impact Properties of the Composites

Figure 7 shows a summary of the effect of impactors design on impact properties of the composites in this study, where it can be seen that changing the impactor design have no effect on impact properties of woven reinforced composites i.e. WG and WGC while it has a significant effect on unidirectional fiber reinforced composites i.e. UG and UC this is due to the fact that the nature of fabric in two directions where plain woven textile laminates subjected to impact loading beyond threshold energy level show crack initiation within the ply which tries to propagate through the thickness, but has to cut through the fiber in the wrap direction wherein the resistance is offered due to high interlacement and the growth of crack is arrested. Hence, the delamination initiation and progression will be suppressed.

3.6. Impact damage behavior of the Composites with changing the impactor design

Figure 8 shows the impact damage behavior of composites with changing the impactor design, where it can be seen that the damage behavior of woven composites is in the form of indentation and perforation while the behavior is matrix cracking and splits along the fiber direction and fracture for unidirectional fiber reinforced composites. Since epoxy has a brittle nature the crack starts and grow rapidly to a smooth brittle fracture.

4. Conclusions:

1. Changing the impactor design has no effect on impact properties of woven reinforced composites.
2. WG and WGC while it has a significant effect on unidirectional fiber reinforced composites i.e. UG and UC this is due to the fact that the nature of fabric in two directions where plain woven textile laminates subjected to impact loading beyond threshold energy level show crack initiation within the ply which tries to propagate through the thickness, but has to cut through the fiber in the wrap direction wherein the resistance is offered due to high interlacement and the growth of crack is arrested. Hence, the delamination initiation and progression will be suppressed.
3. Impact damage behavior of woven composites is in the form of indentation and perforation in woven fiber reinforced composites while the behavior is matrix cracking and splits along the fiber direction and fracture for unidirectional fiber reinforced composites under impact loading.
4. Glass fiber reinforced composites have better impact properties than carbon reinforced composites.

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تأثير تصميم الصادم على مواد متراكبة مقواة بالياف احادية الاتجاه ونسيجية

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المستخلص :

تعتبر خاصية التلف بالصدمة من الخواص المهمة جدا للمواد المتراكبة لذلك يركز هذا البحث على دراسة تأثير تصميم الصادم على خواص الصدمة لمواد متراكبة ذات اساس من الايبوكسي مقواة بالياف احادية الاتجاه من الزجاج والكاربون ، الياف نسيجية من الزجاج والياف نسيجية هجينية من الزجاج والكاربون . اظهرت النتائج ان تغيير تصميم الصادم ليس له تأثير على المواد المتراكبة المقواة بالالياف النسيجية بينما كان له تأثير كبير على المواد المتراكبة المقواة بالياف احادية الاتجاه ، كان نمط الفشل خلال فحص الصدمة في المواد المتراكبة المقواة بالالياف النسيجية بهيأة ثقب واختراق وفي المواد المتراكبة المقواة بالالياف الاحادية الاتجاه بكسر المادة الاساس والانفصال على طول الالياف وكانت مقاومة المواد المتراكبة المقواة بالالياف الزجاجية افضل بكثير من تلك المقواة بالياف الكاربون .

الكلمات المفتاحية : الصدمة بالوزن الهابط ، تصميم الصادم ، المواد المتراكبة المقواة بالالياف احادية الاتجاه و المواد المتراكبة المقواة بالالياف النسيجية .

Table 1: Prepared Samples for the study.

No.	Matrix	Composites Symbol	Weight fraction of Matrix wt_m%	Fibers	Weight fraction of fibers Wt_f%
1	Epoxy	**Epoxy**	**100**	**-**	**0**
2		**WGC**	**80**	**Woven Carbon+Glass**	**20**
3		**WG**	**80**	**Woven Glass**	**20**
4		**UC**	**80**	**Unidirectional Carbon**	**20**
5		**UG**	**80**	**Unidirectional Glass**	**20**

Table 2 : Impactors design for the study.

values of masses and heights	Impactor Design		
	Bullet	Cone	Hemispherical
Impactor mass (kg) Impact height (mm)			

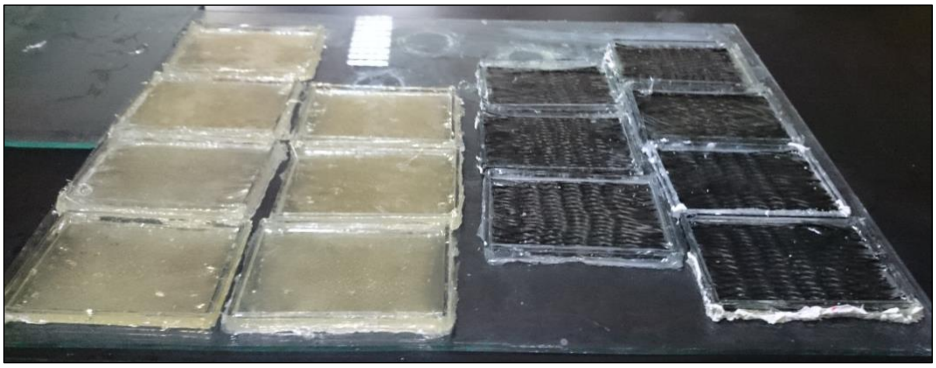
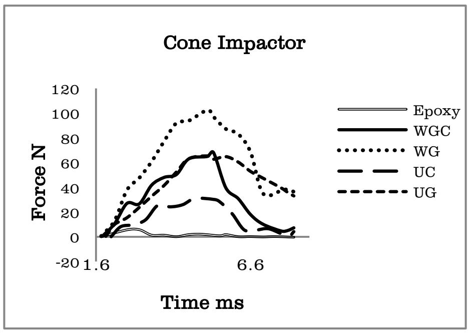
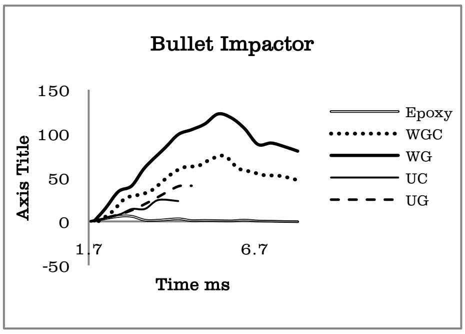
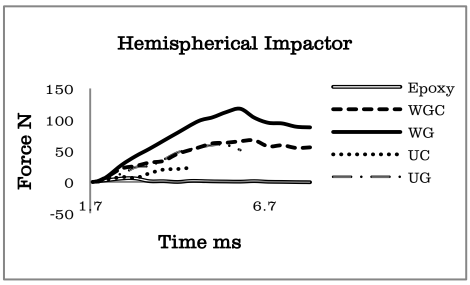


Fig 1: samples and molds of the work.

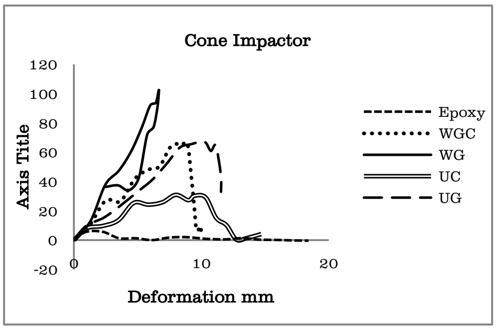
Figure 2 : Impact tester machine.

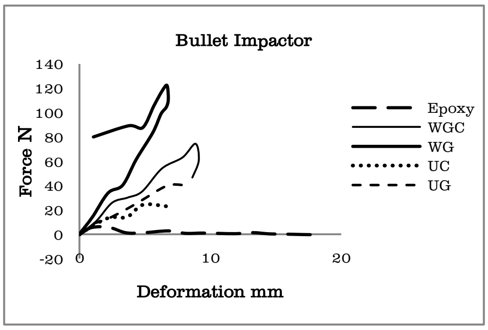


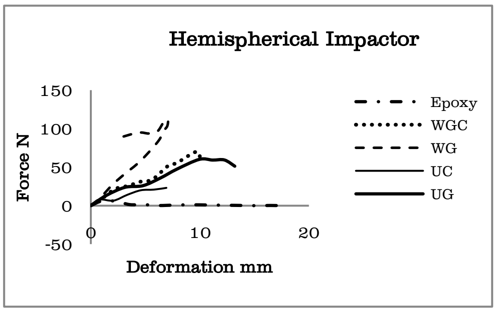




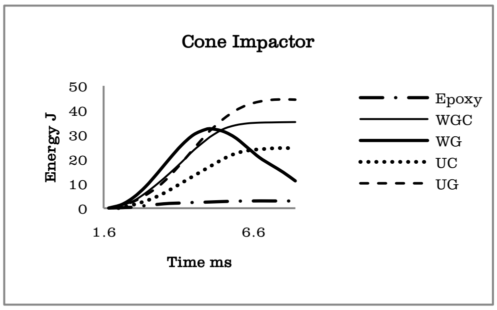
Figures 3 : Force – time relationship of the composites with different impactors shapes.

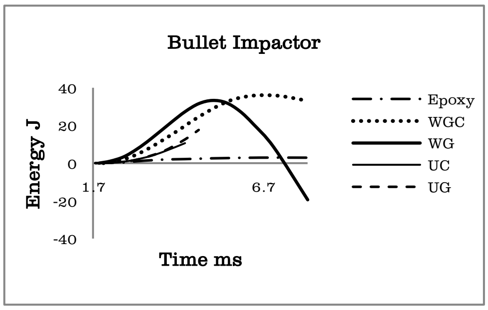


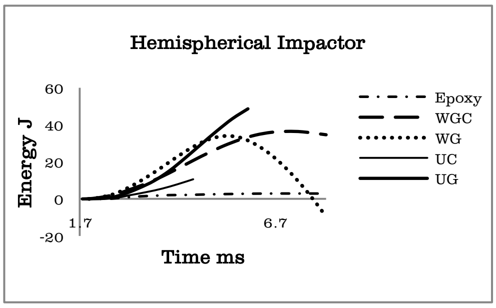




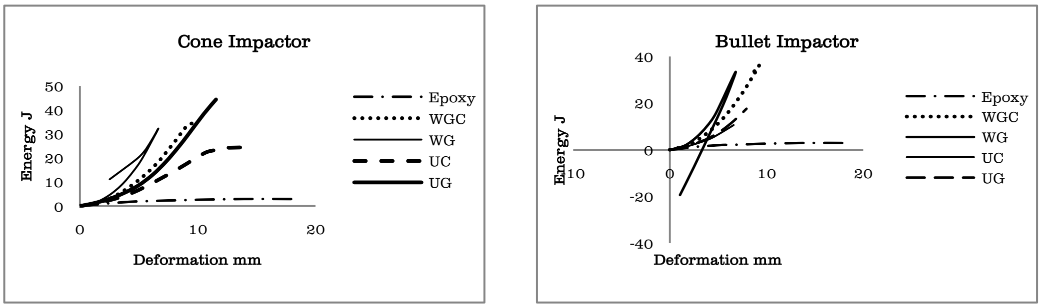
Figures 4: Force – Deformation relationship of composites with different impactors shapes.

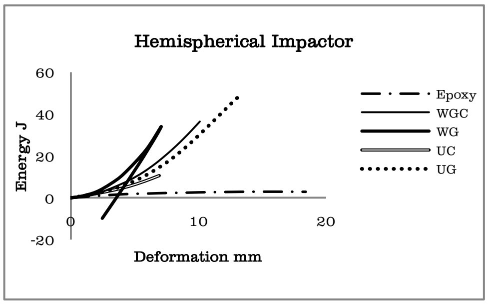






Figures 5 : Energy – Time relationship of the composites different impactors shapes.





Figures 6 : Energy – Deformation relationship of the composites with different impactors shapes.

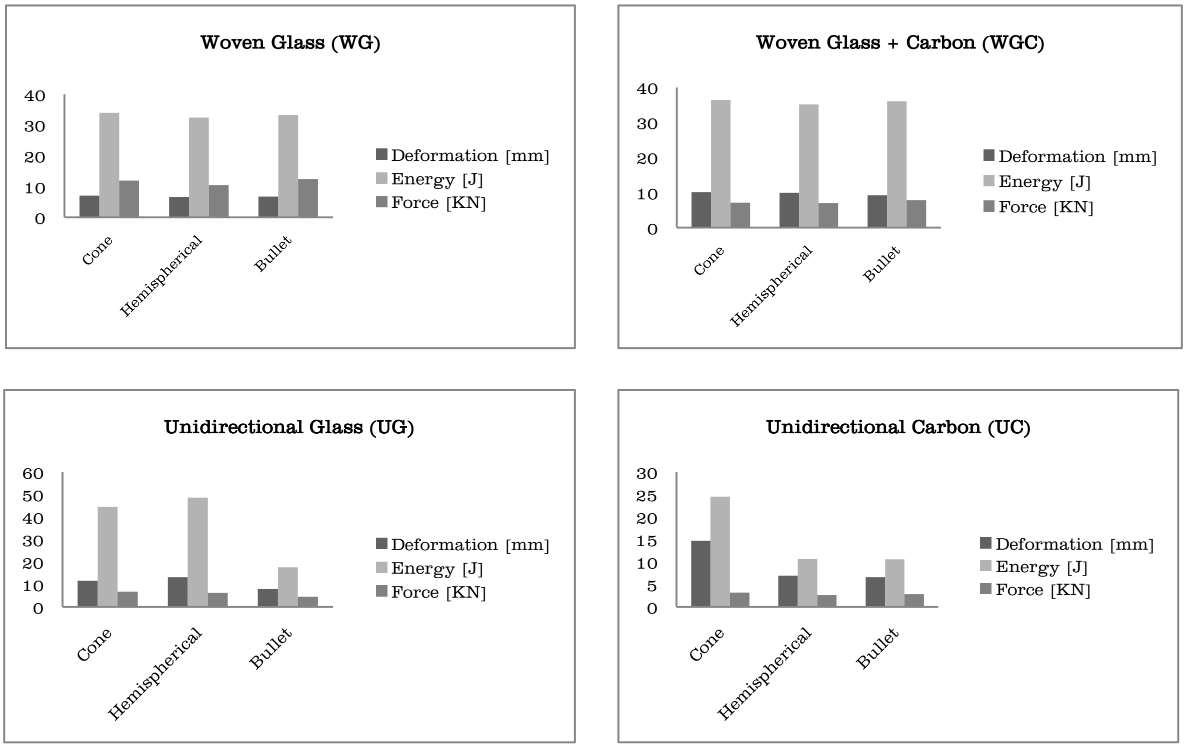


Figure 7 : Effect of impactors design on impact properties of the composites in this study.

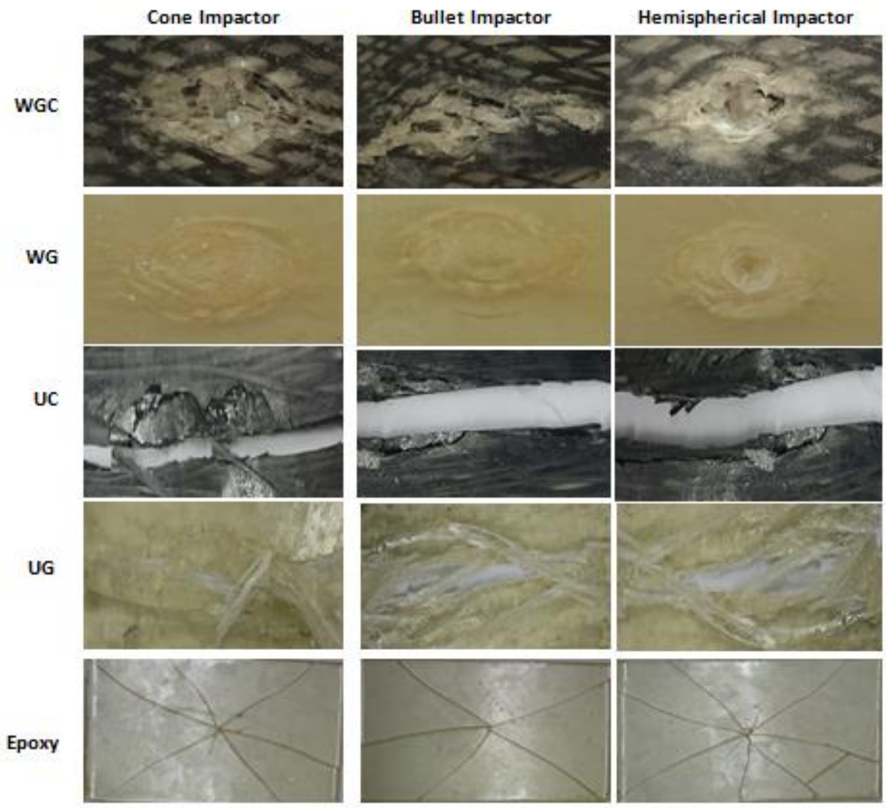


Figure 8 : shows the impact damage behavior of: WGC, WG, UG and UC composites with changing the impactor design.