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Effect of Fillers on Impact Resistance of Ultrahigh Molecular Weight Polyethylene [UHMWPE] reinforced Polyester Composites

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ABSTRACT

In this work, the Ultra High Molecular Weight Polyethylene [UHMWPE] fabric sample was coated using hand-lay technique with polyester resin and two types of fillers to improve the impact resistance property. The matrix comprises polyester resin with fillers like, Coconut shell powder and Boron carbide separately, in four different weight ratios [0%, 10%, 20% and 30%]. The influence of Coconut shell powder as well as Boron carbide on impact energy absorbing characteristics of the composites was studied. The impact resistance was found to be higher with the use of fillers. The Coconut shell powder provided better impact resistance about 45% higher than the Boron carbide. The average total energy absorbed by the Coconut shell powder sample ranged from 68 J to 69 J whereas the control sample absorb 47 J. Similarly the Boron carbide too provided better impact resistance by 19-36% compared with the control sample. The average total energy absorbed by the sample ranged from 56 J to 64 J. Results reveal that the increase in the percentage of Coconut shell powder filler did not significantly increase the impact resistance of UHMWPE whereas an increase in the percentage of Boron carbide improved the impact resistance, however higher percentages were found to reduce the impact resistance.

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KEYWORDS

UHMWPE, polyester resin, boron carbide, coconut shell powder, composite, impact resistance.

1. INTRODUCTION

The present situations of the countries in the world were forced to endow their defense system by modernizing the war equipments and gears. Militant attacks and local protests are also to be controlled. A huge budget is allocated for improvising the military gears to protect their soldiers in the war fair. In the protection of soldiers the body armours play a foremost role. Lightweight and high performance personal protective wears are the trend now as the demand for these protective suits among military and law enforcement personnel has grown, using various high-performance fibres like para-aramid (Kevlar®, Twaron®), ultra-high molecular polyethylene (Dyneema®, Spectra®) and high modulus polypropylene [Innegra®] [1–5]. These are used in body armours with the number of plies ranging from 20 to 50 as the density of these fibres is low even though they possess good strength and modulus [6]. According to the National Institute of Justice (NIJ) standard series, the depth of more than 4.4 cm due to the projectile on the armour creates blunt trauma and causes muscle tear to the wearer. The ballistic performance of a material is described as its capacity to absorb impact energy locally and uniformly distribute it throughout the entire surface quickly and effectively [7]. Fibres were numerously fractured and distorted during the absorption of ballistic energy [8]. The projectile's kinetic energy is absorbed by numerous layers of fabric, preventing the projectile from piercing the panel fully. Fabric layer interactions, yarn-to-yarn friction and projectile-yarn friction all have a role in the impact energy dissipation. When the number of fabric ply increases, the amount of energy communicated to the rear side of the panel decreases [9]. During ballistic impact, the fabric structure influences the energy absorption

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capabilities by spreading the energy across the entire fabric, resulting in generalized damage [10]. The final impact characteristics of composites are mainly depends on the characteristics of reinforcement material [11]. The body armour becomes heavy and less flexible with the number of fabric layers. Intensive research has been made to reduce the number of layers for wearer comfort without compromising the performance. To achieve the above, the high-performance fabric layers were coated to increase the impact resistance without increasing the weight much. Polyester, polyurethane and polypropylene were used as a coating or laminating materials. These composites have improved the ballistic performance of the fabrics to full fill the standard requirements with less number of layers. Polymeric composite materials with natural fillers/reinforcement have become increasingly popular in recent years, and several studies have been conducted on them since they provide numerous advantages over pure polymeric composites. Natural fillers/reinforcement has attracted a lot of interest in recent years due to the economic and environmental benefits of the composites generated [12]. Natural materials provide the following advantages: low cost, wide availability, lightweight, good thermal insulating properties, recyclable and reused source that does not harm the environment [13]. The Coconut shell powder added into the thermoset matrix material lowered the moulded product's production cost. India, Brazil, Indonesia, the Philippines, and Sri Lanka are the countries that produce coconuts. The chemical makeup of Coconut shell powder is Lignin (29.4%), Pentosans (27.7%), Cellulose (6.6%), Moisture (8%), Solvent extractives (4.2%), Uronic Anhydride (3.5%), and Ash (0.6%). [5]. Coconut shell powder filler is an iconic substance in the modern composite development technique due to its good strength and modular property. It also has outstanding sound insulation, non-toxic, and resists high temperatures with a low combustible property [14]. The usage of natural fillers in making of the composites for ballistic application is new approach and it was not tried before. The addition of resin with selected filler type, over high performance fabric will have the scope of improving the performance. Thus with the less number of layers (10 to 20 layers) it is possible to develop the protective gears to achieve the same performance of gears made with more number of layers (30 to 40 layers).

2. MATERIAL AND METHOD

2.1 Material

A plain woven UHMWPE fabric provided by Department of Textile Technology, Indian Institute of Technology, New Delhi., was used as reinforcement material in this experiment and the other details are given in Table 1. Polyester resin along with MEKP (Methyl Ethyl Ketone Peroxide) hardener, sourced from M/s Northern Polymers, New Delhi., was used to develop the matrix material of the composite. To uniformly apply the matrix material over the fabric, acetic acid is used as solvent. To analyse the influence of filler and its weight fraction in the matrix, coconut shell powder and boron carbide with a mesh size of 100 are used in this work expecting that these would increase the inter yarn friction so as to get higher impact resistance.

Table 1. Specifications of UHMWPE fabric

Parameter	Details
Denier of the filament	1240
End per centimeter	8
Picks per centimeter	9
Warp Crimp	1.52%
Weft Crimp	1.15%
Grams per square meter	230 ±5

2.2 Method

2.2.1 Matrix Preparation

The weight fraction of material and resin was in the ratio of 60: 40. The boron carbide and coconut shell powder filler was added separately to resin in three different weight proportions wide 10%, 20% and 30% respectively. The details of weight fraction of reinforcement resin and filler has shown in the Table 2. MEKP hardener was mixed in the ratio of 1.5:100 with the resin in order to solidify the resin after application. Acetic acid was added about 10% of the total weight of the resin mixture to dilute it so that it can be applied over the fabric easily with brush. And also the reduction in viscosity of the resin will improve the distribution over the fabric.

Table 2. Weight fraction details of reinforcement, resin and filler

Percentage of filler	Average weight of the control sample (Grams)	Weight of resin (Grams)	Weight of the filler (Grams)	Average weight of the composite (Grams)
0%	5.14	3.43	0	8.57
10%	5.14	3.09	0.34	8.57
20%	5.14	2.74	0.68	8.57
30%	5.14	2.40	1.02	8.57

2.2.2 Composite Manufacturing

Hand lay-up method is used to laminate the UHMWPE fabric cut to the size 15 cm X 15 cm of weight 5.14 g. The hand lay-up method is an easy and effective method to coat the fabrics [15, 16]. Brush and a squeeze roller were used to spread the prepared resin all over the surface of the fabric uniformly by squeezing out the excess resin so as to prevent voids. Then the sample was reversed and the same procedure was followed to apply the resin. All the samples were prepared in a standard atmosphere to avoid variations. Care was taken to ensure uniform pressure between samples. The method is shown in the Figure 1. After coating the fabric was dried in the room temperature for 24 hrs. Using the same approach the resin was applied over the backside of the fabric also. To evaluate the fillers performance a control sample was prepared by laminating the fabric with polyester resin alone i.e without filler. Thus the composites have been developed for testing its impact energy absorption. The majority of application of textile composite are incorporated with woven fabrics and preforms [17].

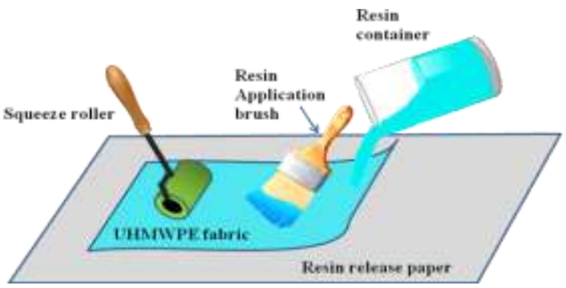


Figure 1. UHMWPE fabric lamination by hand layup method

2.2.3 Impact performance evaluation

The dynamic CEAST Fractovis Plus falling drop weight impact tester was used to assess the impact energy absorbed by the specimen as per ASTM D3763 standard. The composite specimens were fixed in the instrument's hollow circular jaw that's inner and outer diameters are 76mm and 108mm respectively. The samples were held tightly in the jaws by means of rubber grippers with a pneumatic pressure 7.18 kg-f.cm^{-2} to withstand the high impact loads. The impact over the composite sample was made by a 13 mm diameter hemispherical head impactor loaded with 19.97 kg weight dropped at a velocity of 4.5ms^{-1} to develop a impact energy of 201 J. The time, velocity, peak force and total energy were taken into consideration for assessing the specimen's performance [18].

2.2.4 Mechanism of impact load distribution in fabric

The impact load propagation on a plain woven fabric is shown in the Figure 2. The propagation of the load distribution takes place through the interlacement points (shown in red dots in the Figure 2) of warp and weft of the woven fabric, around the projectile impact point. The load distribution will be carried out effectively in fabrics that are having higher number of interlacement points at a closer proximity. Lesser the load distribution time increases the impact resistance of the fabric as the deformation or damage to the yarn will happen only after the failure or delay in the load distribution [19, 20]. The reason for the usage of plain woven fabric with a higher cover factor for the ballistic application is the same. The coating of fabric will reduce the slip in the interlacement points which will further reduce the load distribution time causing the fabric to be more impact resistance. The same has been explained by the work of Karahan et al [7].

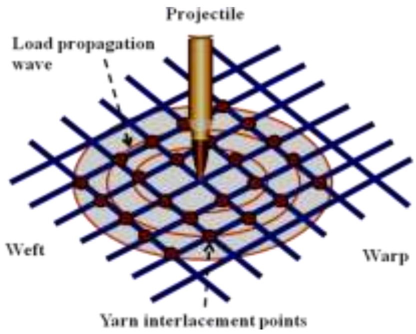


Figure 2. Mechanism of impact load distribution in fabric

3. RESULTS AND DISCUSSION

The composite panels were studied for impact assessment and the results are shown in Table 3. It is apparent that the coconut shell powder filler mixed polyester composites exhibits a increased level of impact energy absorption when compared with the control sample. This is due to the irregular surface of the filler particles (shown in figure 4) along with the polyester matrix reduces the slip in the filaments interlacement points and holds the filaments tightly together so as to improve its load bearing capacity by effective distribution of load between the filaments as discussed by Karahan [21]. The Scanning Electronic Microscopic images at 1000 and 5000 X magnification of the coconut shell powder are shown in the Figure 4. Therefore, the impact energy absorbing capacity of the composite increases to a significant level compared with the control sample. The average total energy absorbed by the composite ranges from 68 J to 69 J whereas the control sample able to absorb only 47 J. The Coconut shell powder filler added composite has improved the impact resistance value by 45 - 47% when compared with control sample. Next to that of coconut shell powder the boron carbide filler mixed polyester composites exhibited high-quality results when compared with control sample. As the boron carbide is known to be the strongest material, it was used in this work. Its reaction with polyester resin worked well and it also created a strong bond between filaments in order to withstand high impact energy. The Scanning Electronic Microscopic images at 25000 and 150000 X magnification of the Boron carbide are shown in the Figure 3. The average total energy absorbed by the sample ranges from 56 J to 64 J. Boron carbide has also improved the impact resistance by 19-36% compared with control sample.

From the SEM images it can be noticed that the coconut shell powder filler particle has the sharp edges with a compact agglomeration of scales which has the property of resisting the slip in the interlacement points of the fabric. Whereas the boron carbide particle, even though it is the strongest material it has the smooth blunted surfaces compared with coconut shell powder, hence it has the lower importance in resisting the slip at yarn interlacement points. In actual these particles will erode the projectile tip and make the deformation easier. The SEM images of the composites (shown in Figure 5) clearly show the particle adherence over the surface of the fabric was found clearly from. It shows the uniform distribution of the particles in the resin as well as fabric.

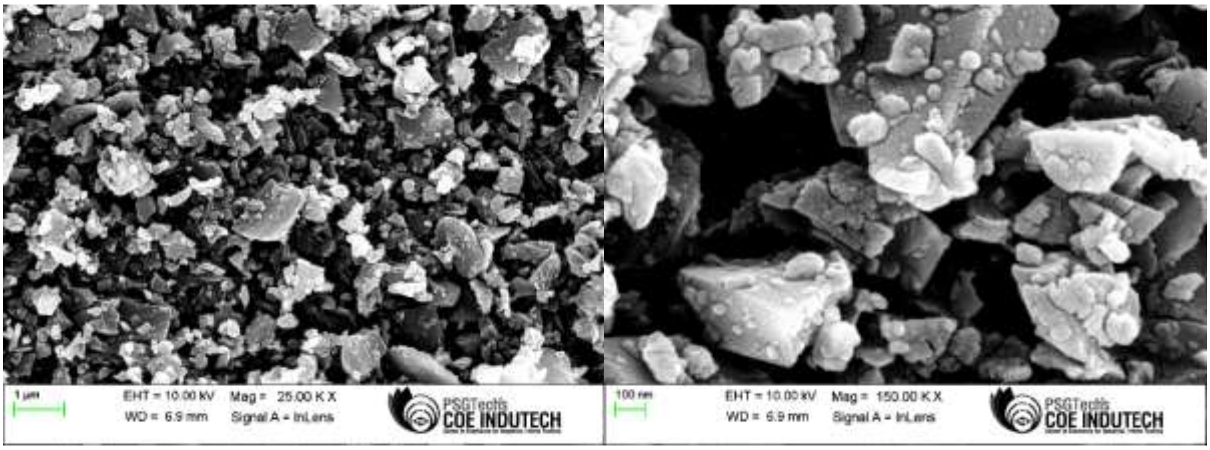


Figure 3. SEM images of boron carbide

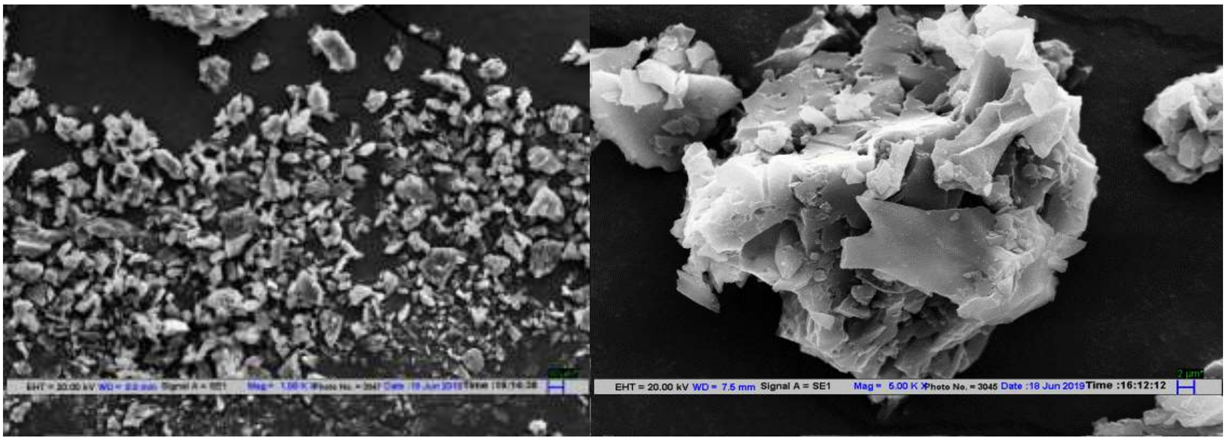
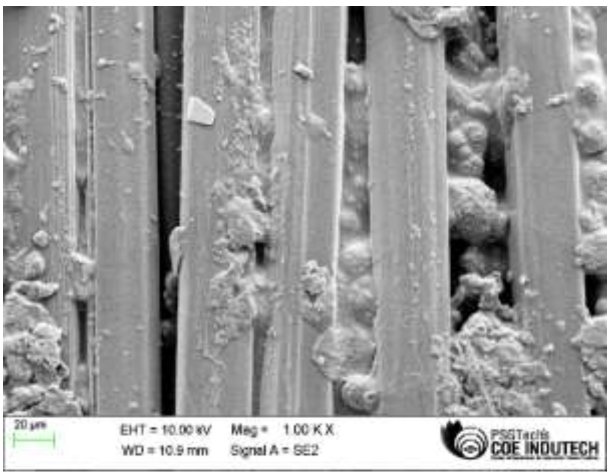


Figure 4. SEM images of coconut shell powder



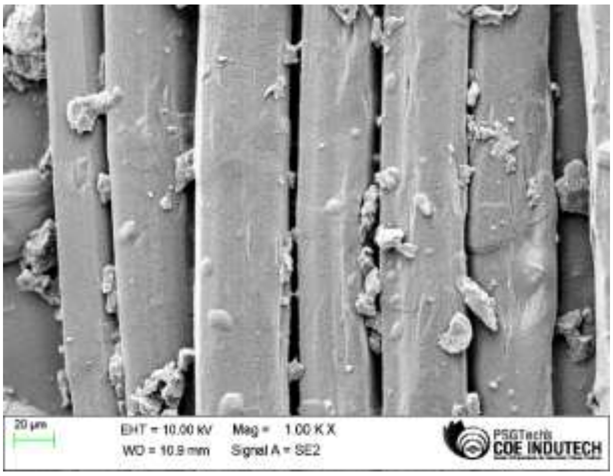


Figure 5. SEM image of boron filler composite

Figure 6. SEM image of coconut shell powder filler composite

Table 3. Impact test results of polyester resin coated UHMWPE fabric

Sample No.	Total impact energy absorbed by the sample (in Joules)						
	Coconut Shell Powder Filler				Boron Carbide Filler		
	0%	**10%**	**20%**	**30%**	**10%**	**20%**	**30%**
1	50	73	67	65	66	68	57
2	49	61	70	72	61	61	59
3	43	72	67	72	62	63	53
Average	**47**	**68**	**68**	**69**	**63**	**64**	**56**
SD	**3.8**	**6.7**	**1.7**	**4.0**	**2.6**	**3.6**	**3.1**

The above test results were deep-rooted by testing the 2 layered UHMWPE fabric composites coated with polyester resin separately which was prepared with coconut shell powder and boron carbide fillers. The two single layered composites were stitched together by means of an industrial sewing machine using a cotton yarn in diagonal ways to form diamond shaped binding, which is suitable for the ballistic applications. The orientation of the layers was done in two different ways, one is unidirectional and other one is bidirectional. The layer alignment and stitch pattern is shown in Figure 5. In preparation of the matrix material for this study the 10% filler content is used because it exhibited very good results in both coconut shell powder as well as boron carbide filler matrixes. When it was tested in the low velocity impact tester the results were found to be significantly improved when compared with single layered composites.

The Table 4. clearly depicts that the bidirectional sample have absorbed more impact energy than the unidirectional samples. Keeping the same yarn material of architecturally-modified fabric targets showed improved ballistic impact performance [22]. This is due to the tension variation between the warp and weft even though the fabric is balanced. During weaving as the warp is kept under high tension when compared to the weft, the elastic behaviour of the fabric will vary in warp and weft direction. In the bidirectional fabric, as the warp and weft direction is changed for the second layer the biased elastic behaviour will be balanced so it absorbs more impact energy than the unidirectional sample. In the coconut shell powder composites the bidirectional sample has 5% of increase in the energy absorption, whereas the boron carbide composite have 31% of increase in the impact energy absorption. The energy absorption curves for various filler percentages of the single layer composites were shown in the series of figures wide 6 to 12. The graph shows the relation between the impact forces resisted by the sample against the time duration. Each graph is constituted by the results of three samples at different colours. It can be clearly seen that the 0% filler composites have a very good elasticity but it breaks at normal load (shown in Figure 6). Whereas the 10%, 20% and 30% filler added composites have a gradual and linear increase in the elasticity and exhibits a high breaking load as they resisted the impact load for longer time duration (shown from Figure 7 to Figure 12). The same was confirmed by the energy absorption curves of 10% percentage filler added double layer composites (shown in Figure 13). Both the graph results established that coconut shell powder filler composites showed excellent results when compared with the boron carbide fillers.

The profile of the composites after the impact test confirms the above mentioned statement. The Figure 14 shows the after test composites profile clearly. The profiles which are having the less doom height with a linear slope and a clear hole indicates that it has absorbed less impact energy as the impact load distribution have not done effectively. Similarly the composites that's profile are having a larger doom height with a curvilinear slope and a yarn pull indicates that it has absorbed more impact energy due to the effective impact load distribution. The similar kind of result analysis was also discussed by Majumdar et al [23].

Table 4. Impact test results of polyester coated 2 layered UHMWPE fabric

Sample	Fabric Alignment	Impact energy observed (in Joules)
Coconut Shell Powder Filler composite	**Unidirectional**	174
	Bidirectional	182
Boron Carbide Filler composite	**Unidirectional**	102
	Bidirectional	134

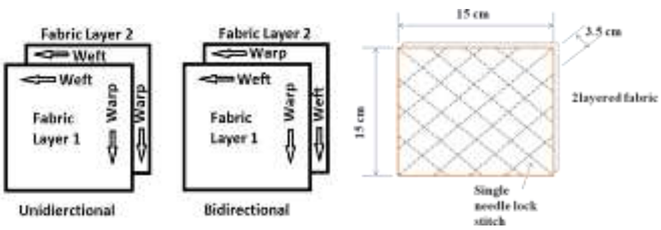


Figure 7. Layer alignment and Stitch pattern

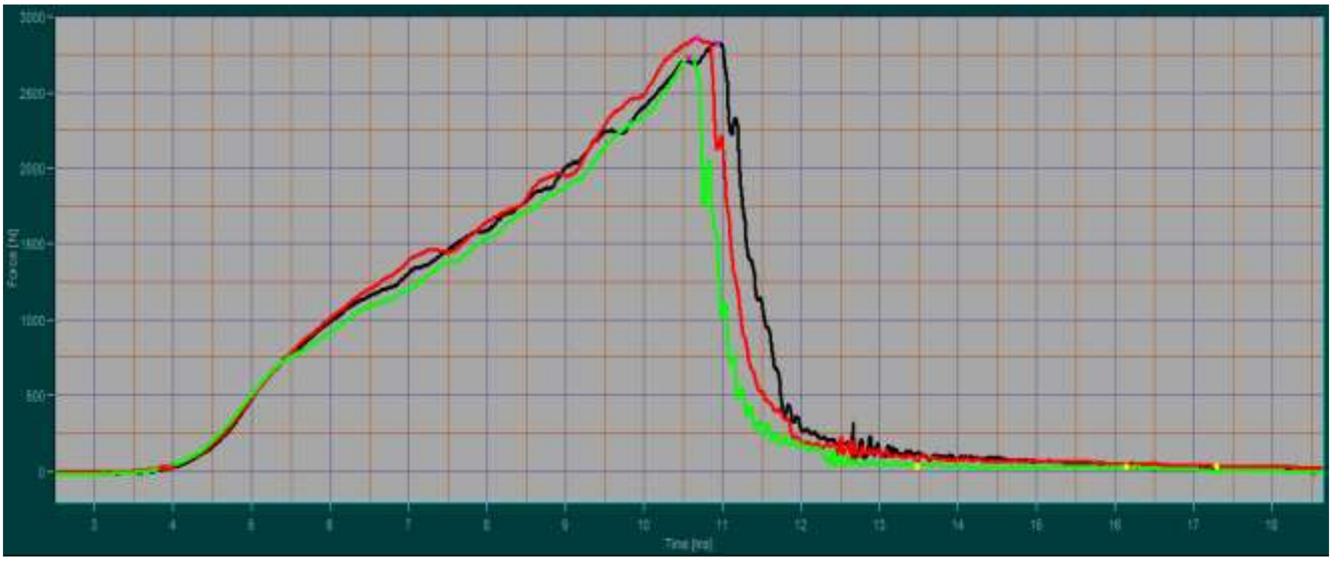


Figure 6. Energy absorption curve for 0 % of filler added with resin

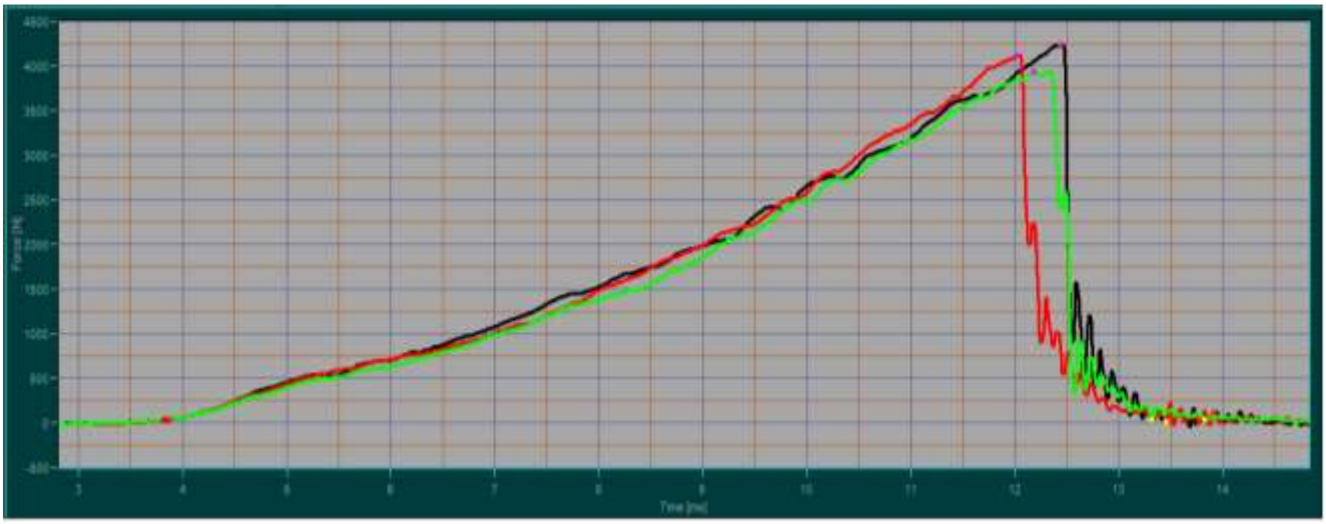


Figure 7. Energy absorption curve for 10 % of boron carbide filler added with resin

Figure 8. Energy absorption curve for 20 % of boron carbide filler added with resin

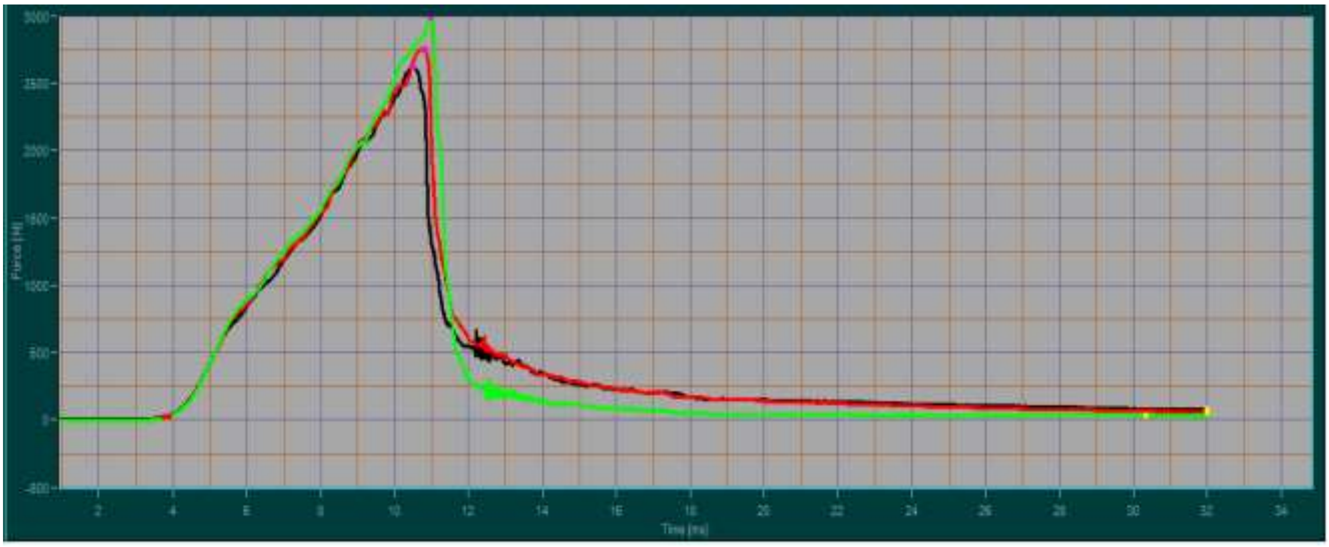


Figure 9. Energy absorption curve for 30 % of coconut shell powder filler added with resin

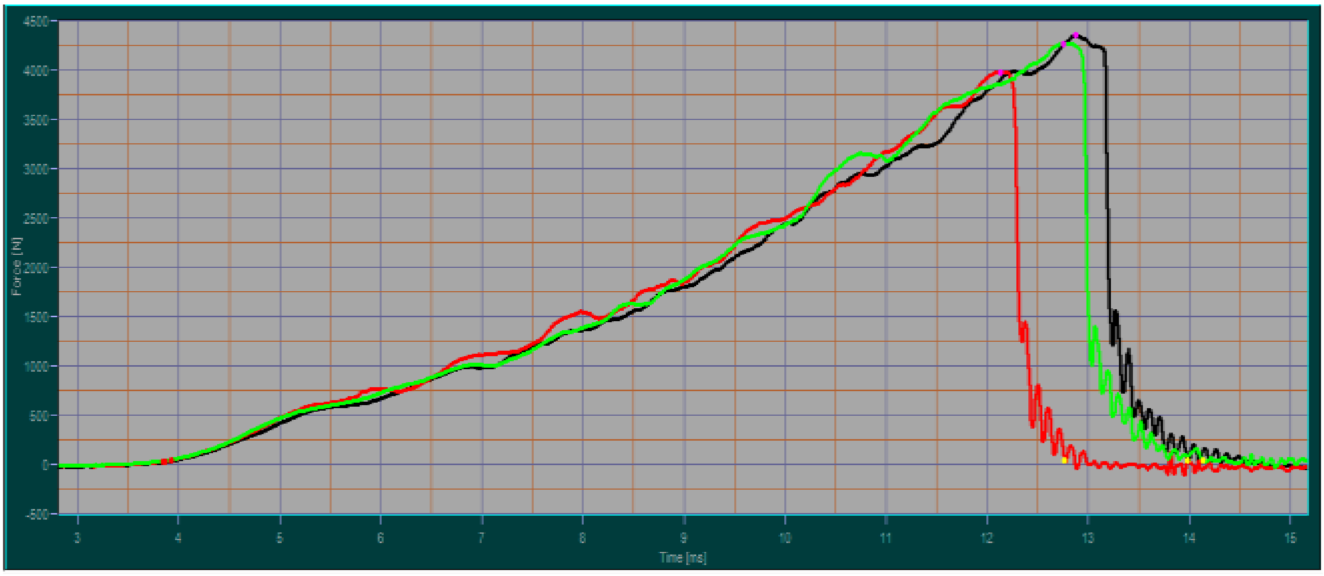


Figure 10. Energy absorption curve for 10 % of coconut shell powder filler added with resin

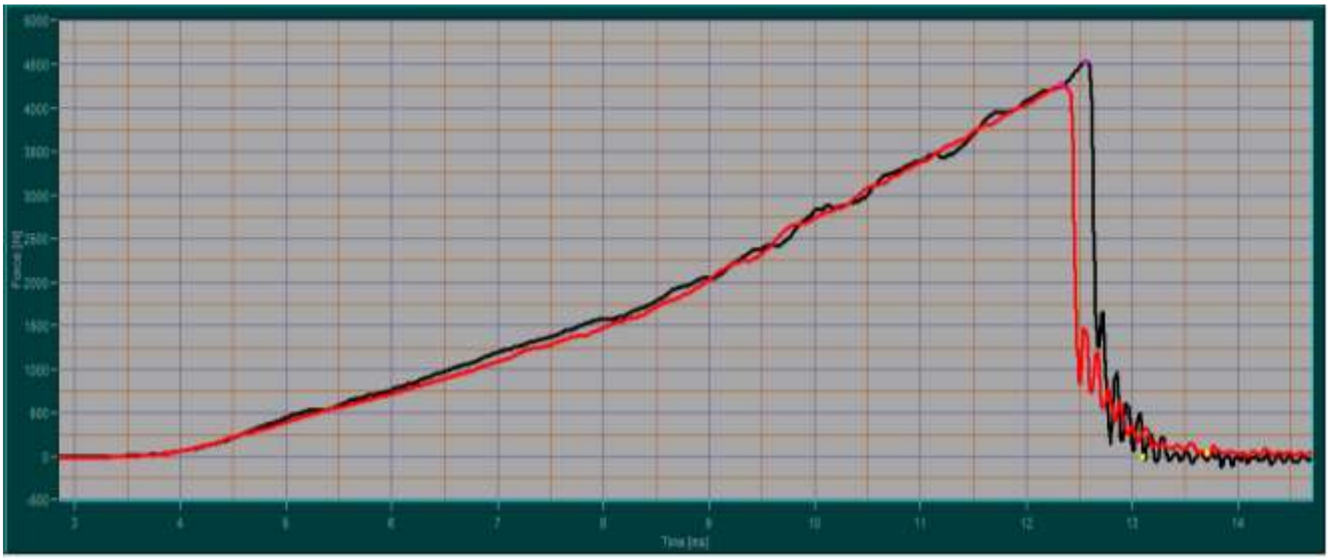


Figure 11. Energy absorption curve for 20 % of coconut shell powder filler added with resin

Figure 12. Energy absorption curve for 30 % of coconut shell powder filler added with resin

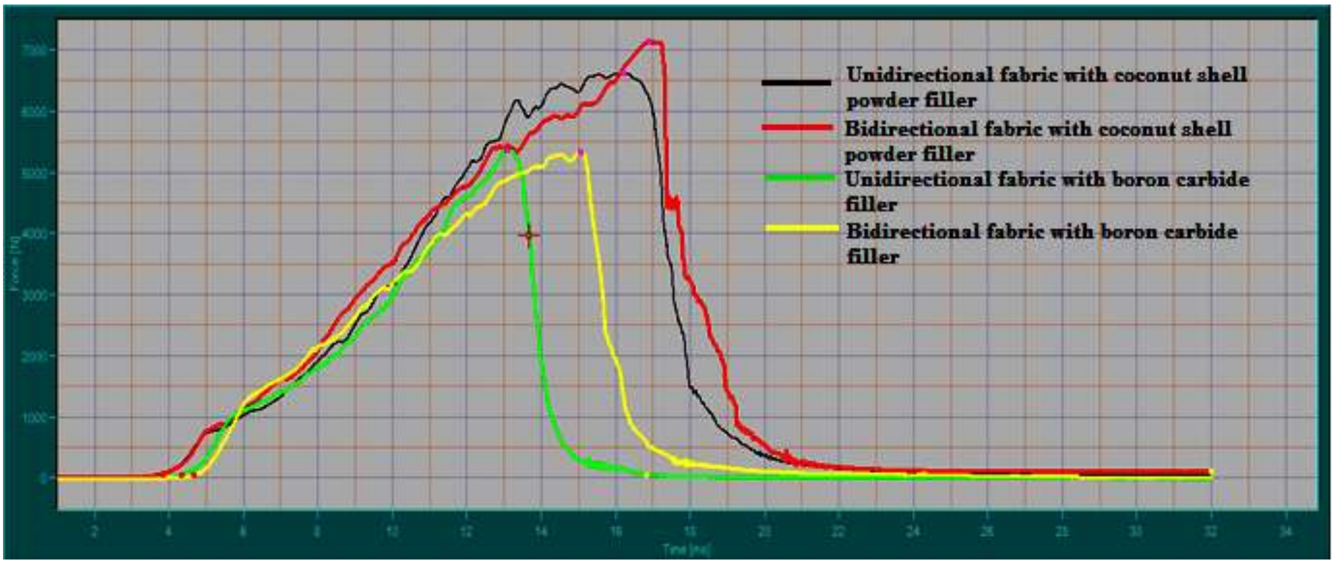


Figure 13. Energy absorption curve for 10 % of boron carbide and coconut shell powder filler added with resin

The control sample i.e the composite without filler have seen with smaller doom height with linear slope and the images validates the increase in doom height along with the change in the curvilinear slope with respect to the increase in filler percentage can be observed in coconut shell powder filler composites. But in the case of boron carbide filler composites the impact energy absorbing capacity was found to be increasing up to 20% of filler add-on after that the energy absorbing capacity was found to be reduced due to the increase in yarn slip caused by the matrix lubrication. On the basis of the above results the two layered composites profile also studied. The bidirectional layered samples are seen with the clear doom shape which again reveals that the high doom height with curvilinear slope shows the high absorbing capacity of the impact energy when compared with the unidirectional two layered composites.

4. CONCLUSION

In this research work the influence of fillers on the impact energy absorption of UHMWPE fabric reinforced polyester resin composites were studied. Coconut shell powder filler have high impact energy absorbing capacity compared with boron carbide filler composites. The boron carbide filler composites were comparable with coconut shell powder up to 20 % add on, after that decline trend was observed. Coconut shell powder filler increases impact resistance by 45 to 47%. Boron carbide filler composites improved the impact resistance by 19 to 36%. In double layer composite the boron carbide and coconut shell powder composites increases the impact load resistance by more than 200% compared with single layer composites. Bidirectional composite showed better results compared with unidirectional composites. Coconut shell powder and boron carbide filler coated fabrics can be effectively used in manufacturing ballistic gears with less weight.

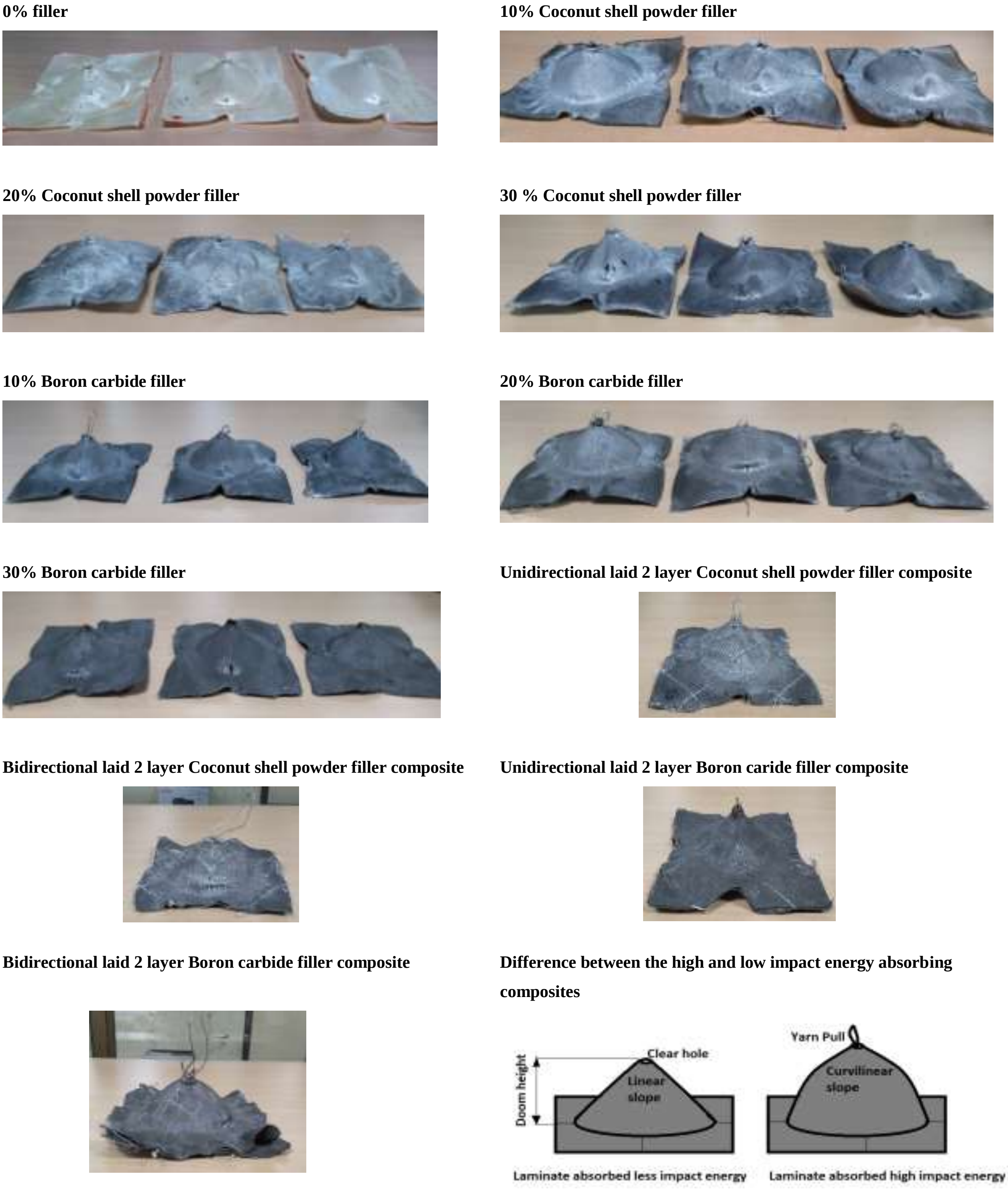


Figure 14. Images of the deformation of the composites after the impact test

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