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Fabrication and low velocity impact response to Ballistic Grade Fabrics

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Abstract: This paper presents the response of ballistic grade UHMWPE (Dyneema HB- 50, HB- 26) fabric materials to Low Velocity Impact loading in which impact tests were performed with the help of vertical drop-weight testing machine. These ballistic grade fabrics were characterized by a stacking sequence in [0/90]$_s$. In Experimental Results, impact parameters such as peak load, absorb energy force- energy- time history were evaluated and compared. Damage processes examined from the initiation of damage to final perforation.

Index Terms: Ballistic Grade Fabrics, Hard Ballistic (HB), Low Velocity Impact

I. INTRODUCTION

'Composite' as name implies that is mixture of two or more immiscible materials which is made by conventionally or unconventionally techniques[1-2]. A main concern which confines the practice of composites is their vulnerability to damage due to impact loading. The real-world circumstances like tool drops, runway debris, bird strikes, hail storms and ballistic loading induce substantial damage to the composite structures. However, low-velocity impact is measured potentially dangerous mainly due to the fact that the damage might be left unobserved, as the surface may seem to be undamaged [3-6]. The impact response of material is normally considered into low (large mass) velocity, intermediate velocity, high/ ballistic (small mass) velocity, and hyper velocity. Large mass impact, Low Velocity Impact (LVI), test condition arising from tool drops, which typically occur at a velocity below than 10 m/s. Intermediate impact test occur in 10 m/s to 50 m/s range, and its characteristic are of both low and high velocity impact whereas high velocity (Ballistic) impact comprises of small arm fire or explosive. When high velocity impact from 50 m/s to 100 m/s and hyper velocity impact ranging distance is greater than 2 to 5 km/s, the target material performs similar as fluid. Hirai et al. [7] investigated the effect of temperature on the low velocity impact response of vinyl ester- matrix composite reinforced with woven E- glass fabric and, showed that the extent of damage and the residual properties of the laminate vary with fiber surface treatment and impact test temperature, both. They also observed that the damage area increases with increasing temperature and impact energy. Markakiet et al. [8] studied the characterizations of impact response of alternate layers of Al alloy foam and Al_2O_3 (metallic foam/ ceramic laminates). They made also comparison between the penetration response of foam laminates and dense metal laminates of equivalent areal density. And, they suggested that the dense metal laminates are superseded by the foam laminates. With increasing impact velocity caused a change in the penetration mode from plugging to fragmentation. Silva et al. [9] performed low velocity impact test on laminate reinforced with polyethylene and Aramaic fibers and they found that laminates with lower bending stiffness allow higher radiation damping, reducing the impact force. Aslan et al. [10] studied the transient behavior of laminated composite plate subjected to dynamic loadings, under three different impact velocities (1m/s, 2m/s, 3m/s) and two different impactor masses (135g and 2600g). The resultant data had a great influence on the impact response of composite laminate with the variation of impact velocity and impact mass. Morais et al. [11] studied the influence of laminate thickness on the resistance to repeated low energy impacts of glass, carbon and aramid fabrics reinforced composites. The results obtained show that below a certain energy level, the cross-section areas of the laminate composite were the most relevant variable for the impact resistance. Gustine et al. [12] performed low velocity impact test on combination of kevlar/carbon fiber sandwich composites with the thermal shield (TS) as a good mechanical protection towards impact as well as a good impact revealing material and found different damage morphology mode during the impact test with or without TS particular at high impact energy. Ardakani et al. [13] studied the impact analysis of glass-fiber-reinforced aluminum (Glare) laminates for achieving high impact resistance, the use of silane coupling agent such as γ-GPS is necessary, which creates AlOOH fuzzes on Al surface and found that damaged area of glare laminates with poor interfacial adhesive bonding was much larger than that of with good bonding. Hosur et al. [14] investigated low-velocity impact response of carbon/epoxy laminates subjected to impact loading for cold–dry and cold–moist condition, both for a period of 3 and 6 months. For the samples subjected to cold–dry conditioning, in comparison to cold moist, the 3-month duration showed an improved response at all the energy levels. Whereas damage area of 3month condition was slightly higher than the case of 6-month samples for given impact energy. Stenzler et al. [15] studied impact mechanics of transparent multi-layered polymer composites for knowing the failure mode. The result shows that un-bonded multi-laminates fail globally, with large area damage, unlikely localized failure mode of bonded material. Samples without an interlayer (PMMA/PC) fracture catastrophically. Akin et al. [16] investigated on low velocity impact response for three different stacking sequences [0/90]2s, [-30/30]2s, [-45/45]2s, composite laminated plates and they found little effect of fiber orientation angle on impact experiments and but, one considerable damaging

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effect was observed as full perforation, on the bottom of the composite material along with fiber direction.

2.Experimental

2.1. Materials and specimens

Two types of Dyneema fabric material, HB-50 and HB-26, having density 0.970 gm/ cm^3 and thickness of 0.270 mm [17] is fabricated as per current research. Then, specimen of size 55 mm^2 were prepared from fabricated fabric sheet by using diamond tip cutter under room condition and these circular fabric sheets were arranged in sequence [0/90]s of 5,6,7 layer and clamped between the fixture.

2.2. Low-velocity impact testing

The low-velocity impact test was performed using an instrumented impact test setup (Dyna tup Model 8210) as shown in Fig.1, equipped with data acquisition system.

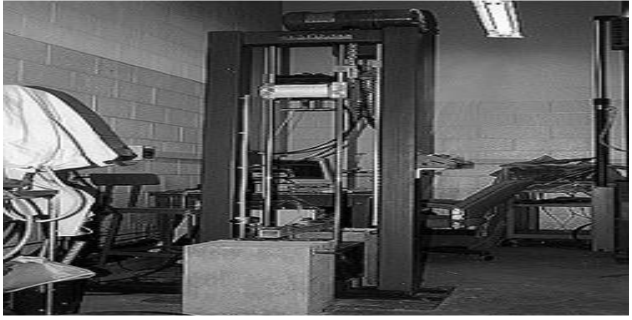

Fig. 1 Low velocity instrument falling weight impact testing machine.

The impact testing of samples was done on 12.5 mm diameter instrumented tup with a hemispherical end as shown in Fig.2.

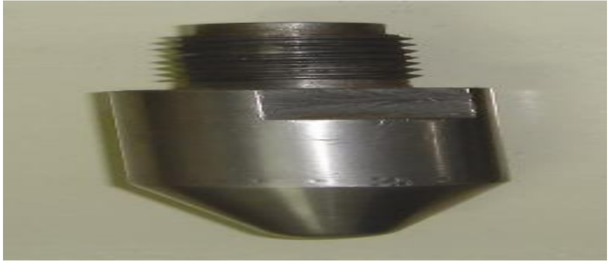

Fig. 2 Hemispherical tup.

The hemispherical shape was used for analysis of damage characteristics and, characteristics of hemispherical shape projectile are shown in Table 1.

Table 1: Characteristics of hemispherical shape projectile

Material	Net weight	Tip shape	Diameter
Steel 316	7.5kg	Hemispherical	12.5 mm

Two-piece griper clamps were designed as shown in Fig. 3(a & b) to avoid slippage which is a problem for the ballistic grade fabrics. Samples were positioned in fixed condition at the bottom of the impact testing machine in a circular sample holder shape of 55 mm diameter. However, the weight of cross-head was kept at 87 kg. Transient response of the laminates was measured and stored.

Fig. 3 (a) Bottom Plate fixture

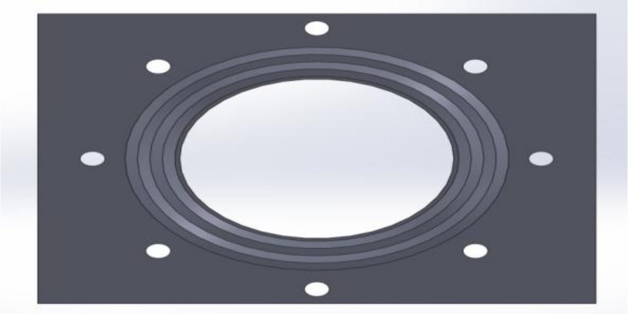

Fig. 3 (b) Top Plate fixture

All tests were performed on more than the 10 specimens. Impact parameters were measured as load, energy, velocity and displacement, with the functions of time. For each type of laminates, three samples were subjected to ~3.45 m/sec impact velocity and ~521 joules impact energy. Different energy levels were obtained by varying the drop-height. The drop weight impact tests were performed as per ASTMD7136 standard [18]. From the transient response data, force–time, and energy- time response curves were experimentally studied. Furthermore, Impact parameters like peak load, absorbed energy, were also compared.

3. Result & Discussion

3.1 Characteristics of HB-26 and HB-50

It is evident from the energy-time histories curve, Fig. 4(a-h) and Fig.4(i-p), that HB-26 composite panels absorbed lesser energy due to impact as compared to HB-50 composite panels. The energy-time plot of HB-26 in the Fig.4(a-h) clearly indicates that as the layers increases, the frictional forces between the impactor and composite panels increases thereby displaying more energy absorbed. However, in the case of HB-50, the energy absorption capacity was found to be increased. This was occurred due to fact that carbon present in HB-26 displayed weaker performance in impact loading as compared to HB-50.

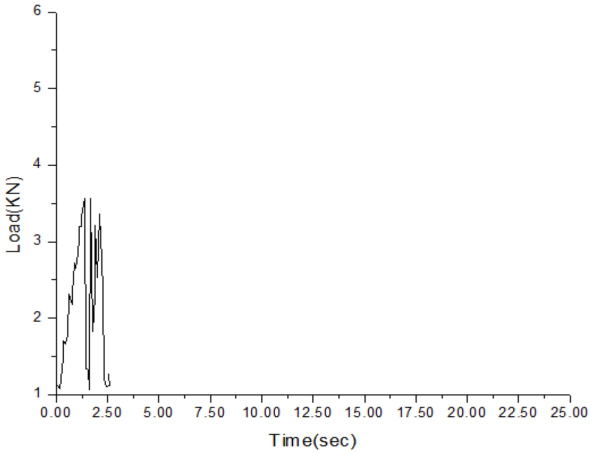

FIG 4-(a) 5 LAYER HB-26, LOAD VERSES TIME

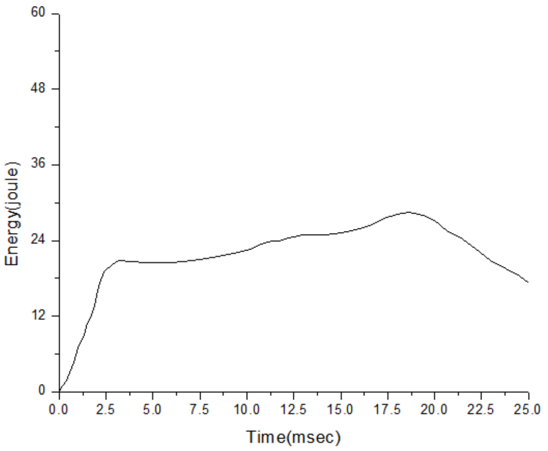

FIG.4(b) 5 LAYER HB -26, ENERGY VERSES TIME

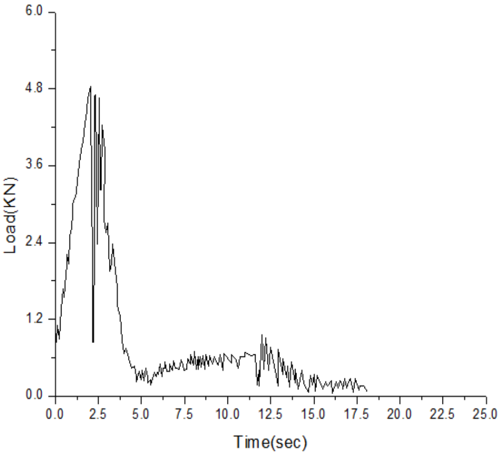

FIG 4(c) 6 LAYER HB-26, LOAD VERSES TIME

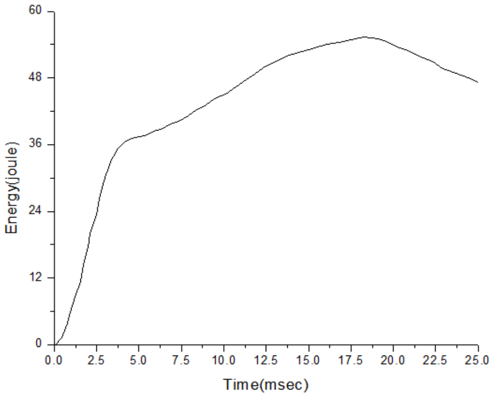

FIG 4(d) 6 LAYER HB-26, ENERGY VERSES TIME .

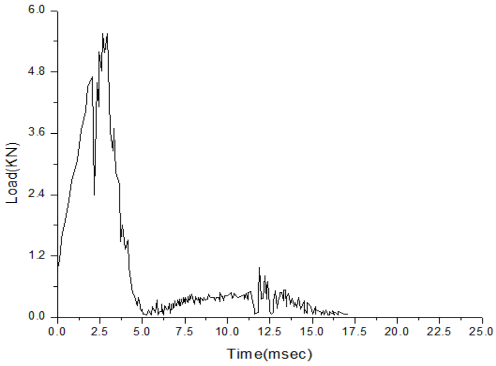

FIG 4(e) 7 LAYER HB-26, LOAD VERSES TIME

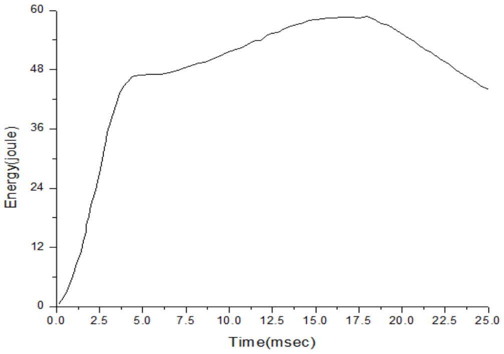

FIG 4(f) 7 LAYER HB-26, ENERGY VERSES TIME

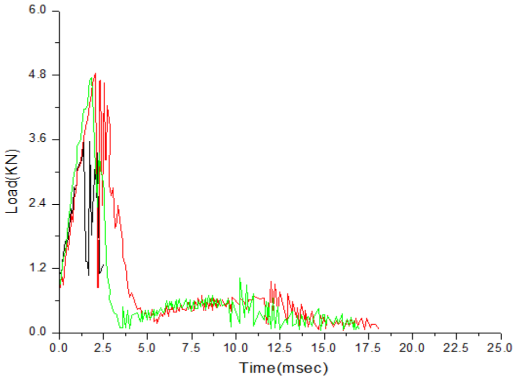

FIG 4(g) 5,6,7 LAYER HB 26 LOAD VERSES TIME

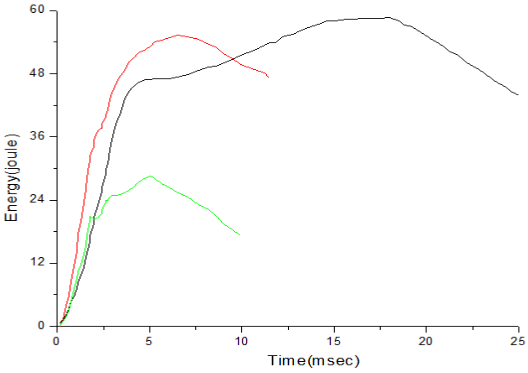

FIG 4(h) 5.6,7 LAYER HB 26, ENERGY VERSES TIME

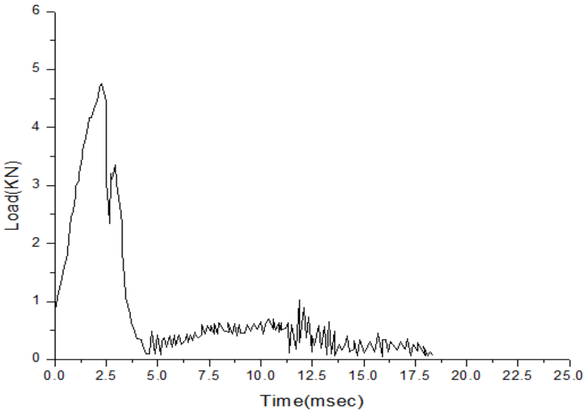

FIG 4(i) 5 LAYER HB-50, LOAD VERSES TIME

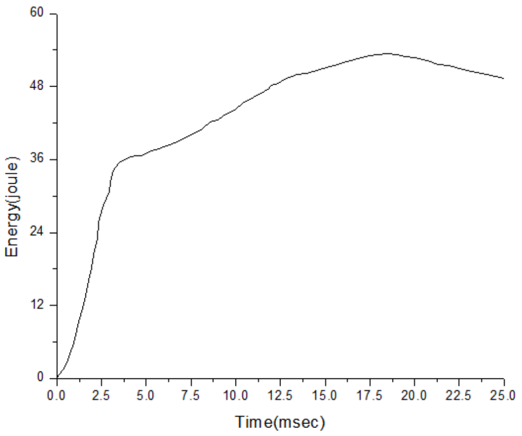

FIG 4(j) 5 LAYER HB-50, ENERGY VERSES TIME.

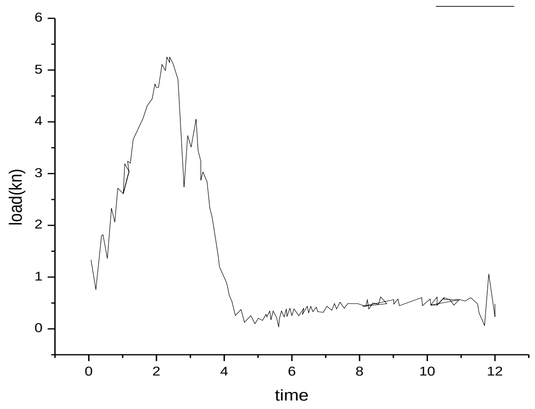

FIG4 (k) 6 LAYER HB-50, LOAD VERSES TIME.

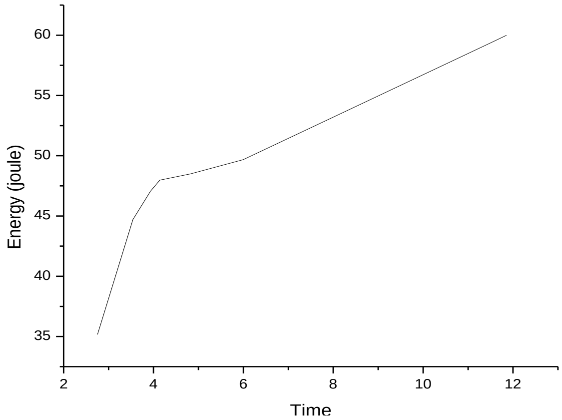

FIG 4(l) 6 LAYER HB-50, ENERGY VERSES TIME

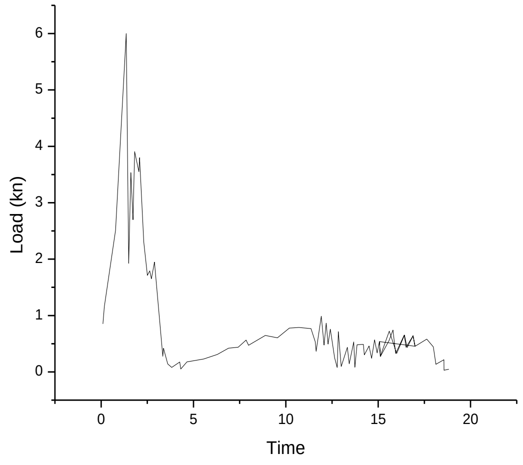

FIG4(m) 7 LAYER HB-50, LOAD VERSES TIME.

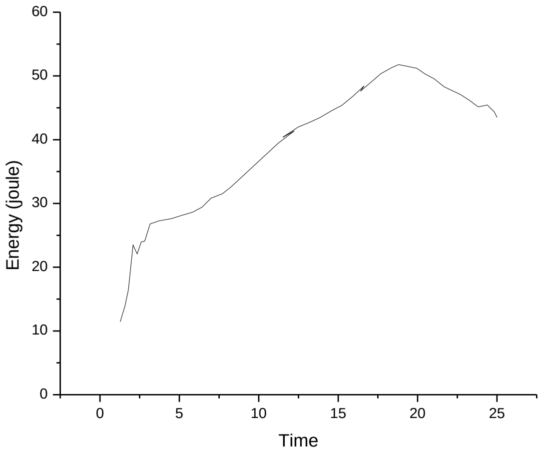

FIG 4(n) 7 LAYER HB-50, ENERGY VERSES TIME

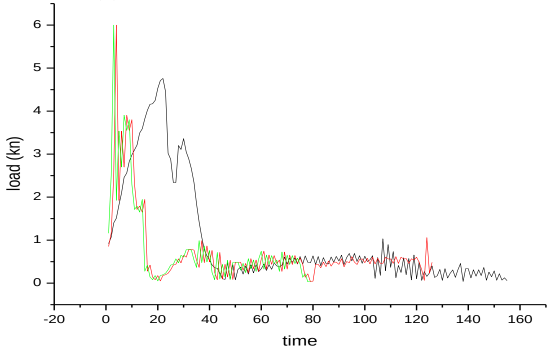

FIG 4(o) 5,6,7 Layer HB-50, LOAD VERSES TIME

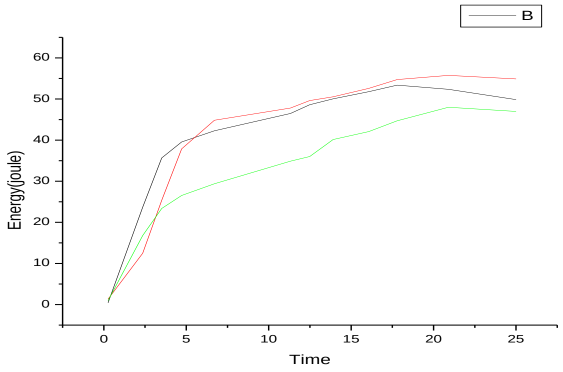

FIG4 (p) 5,6,7 Layer HB-50, ENERGY VERSES TIME

Fig. 5 (a) shows a graph plotted between maximum load and number of layers (5L, 6L and 7L) of HB - 50 and HB – 26. The graph shows that HB–50 needs maximum load to fracture the specimen of 7 layer than HB–26. A graph is plotted between energy absorbed and number of layers in Fig. 5 (b). it clearly shows that HB – 50 absorbs 20% more energy than HB–26 at 7 layers. So according to ballistic point of view HB-50 is better than HB–26. Although, both material HB-26 and HB-50 showed linearity in initial phase of impact testing. This linearity behavior showing the shear plugging which is the major energy absorbing mechanism depending upon the layer of target [19].

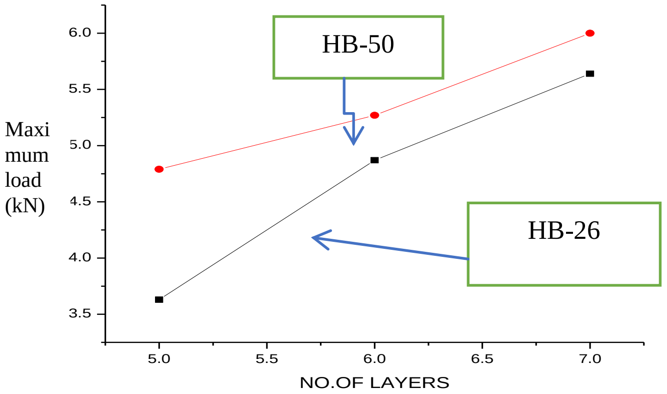

FIG - 5(a) MAXIMUM LOAD VERSES NO.OF LAYERS.

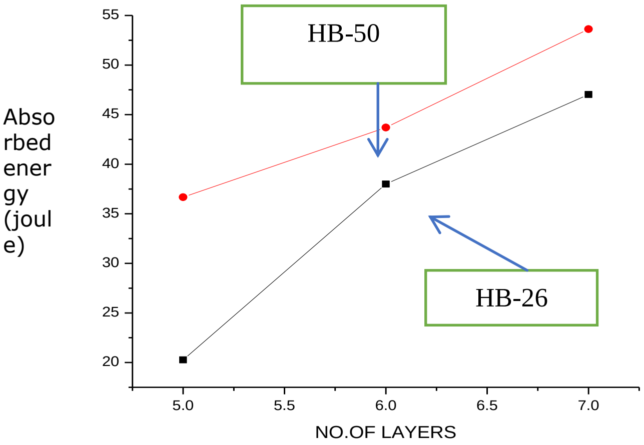

FIG - 5(b) ENERGY ABSORBED VERSES NO .OF LAYERS

Total energy absorbed was observed 20.77J, 38.0 J, 47.03 J for respective layers 5 layer (5L), 6 layers (6L) and 7 layers (7L) after applying the maximum impact load of 3.63 kN and 4.87 kN and 5.64 kN, respectively.

However, this energy observed data was determined in different impact duration of 3.172 msec., 5.063 msec and 18.190 msec for fabric layers of 5L, 6L and 7L, respectively with constant initial kinetic energy with 521.68 Nm.

Total energy absorbed was observed 36.68J, 53.63J, 27.52 J for respective layers 5L, 6L and 7L after applying the maximum impact load of 4.79 kN and 5.27 kN and 6.00 kN, respectively. However, this energy observed data was determined in different impact duration of 3.904 msec,4.490 msec, 11.590 msec for fabric layers of 5L, 6L and 7L, respectively for constant initial kinetic energy with 521.68 Nm. The fracture initiation phase starts from zero to the first peak of the impact force. The fracture propagation phase starts at the end of the fracture initiation phase to the point where the impact force drops back to zero. The impact response of HB-26 and HB-50 are almost similar, while HB-50 shows the very larger ultimate load and lower contact time values is occurred due to higher stiffness and strength. These test results data suggest that HB-50 possess better impact resistance in low velocity impact incident (LVI) [20]. Impact damage was seen, as shown in Fig.6 (a-d), visually from front and back surfaces. Since the local damage is larger, the effect of compressive forces on these fabric panels result in quick degradation of strength due to interlaminar failure of multilayers fabric composites and in turn compressive effect propagates within the materials making it vulnerable to further failure.

Fig. 6(a) Impacted specimen of HB-26 for 5L.

Fig. 6(b) Impacted specimen of HB-26 for 6L.

Fig. 6 (C) Impacted specimen of HB-50 for 5L.

Fig. 6(d) Impacted specimen of HB-50 for 6L.

For similar trends of load vs layers, and energy vs layers curves of composites HB-26 and HB-50, both, ensuring the material linearity damage property during test [21]. This shearing type of fracture mode which occurred under impact compressive loading is due to high stresses resulting in higher energy absorbed [22].

4. Conclusions

Comparison of the contact force- time and energy time curves of the ballistic fabric of different grade absorb the impact energy differently. Due to high impact energy fracture are initiated and propagated. The initial part of the curve is approximately linear and when the impact force reaches at its highest point it suddenly drops which indicate the first crack in the specimen. The ballistic grade fabric still can absorb more energy. Thus, the impact force again increases to that point and drop again indicating the second crack developed. This process continues until the specimen is completely failed. The total energy absorption of ballistic Fabric HB- 50 is superior to HB- 26.

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