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Impact Strength of Glass/Kevlar Fiber Hybrid Composites with Various Stacking Sequences and Impact Energies

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Abstract: ***Hybrid composites have been considered as modern materials for many engineering applications, yet there is still a major concern on the influence of stacking sequence configuration in hybrid composite laminates especially under impact loading. Therefore, the focus of this paper is to determine the optimized stacking sequence of glass/Kevlar fiber hybrid composite laminates under impact loading. Hybrid composite laminates were fabricated using vacuum bagging method with four different stacking sequences known as H1, H2, H3 and H4. Low velocity drop weight impact test (ASTM D7136) was conducted using a hemispherical nose impactor diameter of 12 mm with a mass of 6 kg at impact energy levels of 10 J, 20 J, 30 J, and 40 J. From the results obtained, H3 specimen which has a stacking sequence of glass fiber in the exterior part with Kevlar fiber in the interior part was concluded as the optimized stacking sequence with better impact resistance properties. H3 specimen recorded a higher value in peak load, maximum initiation energy, high impact strength, high strength to weight ratio and high total energy absorbed to weight ratio. In addition, it was observed that H3 specimen has less damaged area compared to H1, H2, and H4 specimens. This study contributes knowledge on the impact resistance properties of hybrid composite laminates which will be much useful for material selection and product development.***

Keywords**:** ***Glass fiber, Hybrid composites, Impact, Kevlar fiber, Stacking sequence***

I. INTRODUCTION

In latter decades, fiber reinforced polymer (FRP) composites have transformed the world of engineering material and are broadly utilized in structural application areas such as aircrafts, spaces, automotive, sporting goods, marines and infrastructures due to their high specific strength and modulus properties [1]–[3]. The development of high performance FRP composites usually concerned with accomplishing high specific strength and modulus properties leaving one more important performance criterion that is the ability to absorb energy and resist impact loading. One such unpredictability related with the FRP composites is the evaluation of its impact behavior. The impact damage in composite laminates developed in an impact event may never be detected by visual inspection and several damage modes like matrix cracking, delamination and fiber breakage may occur [4][5].

The impact behavior of composite laminates had been a major factor in limiting their use and thus it emerges as an important phenomenon to be studied. To improve the impact performance of composite laminates, hybridization is one of the methods used [6],[7]. Hybrid composites can be utilized to meet various demand requirements in more economical way than conventional composites [8]–[10]. Nevertheless, there are an incredible numbers of outline parameters that strongly influence the impact behavior of hybrid composites. These parameters include stacking sequence of the hybrid composite, in which the stacking sequence of various fabrics plays a critical part in deciding the effect of impact behavior of hybrid composites [11][12]. Studies were conducted to investigate the effects of stacking sequence under impact loading as the stacking sequence plays a very important role on the impact resistance of laminates.

Muhi et al. [13] investigated on effects of stacking sequences of plain woven Kevlar layer on the impact resistance of GFRP under high velocity impact. It was concluded that when Kevlar layer moved from the impact side face sheet to fourth layer in GFRP, an increment of absorbed energy was observed due to increased toughness or stiffness. Meanwhile, Yadav et al. [14] reviewed the sandwiching effect of Kevlar reinforced interleave on fracture toughness and flexural modulus and likewise concluded the addition of Kevlar fibers increased the fracture toughness and flexural modulus due to high energy absorbance and high stiffness characteristics of Kevlar fibers.

Shaari et al. [15] analyzed the effects of sandwiching KFRP laminate on the impact resistance properties of GFRP. It resulted in a decrement of displacement at the peak load, slight reduction in stiffness, increased load carrying capabilities and resistance to deformation at the time of Kevlar fiber was added to glass fiber. Simultaneously, a study done by Bulut et al.

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[16] on the effects of different stacking sequences of hybrid composite laminates made up of carbon, Kevlar and glass fibers resulted that hybrid composite laminates with Kevlar fiber as impact side face sheet showed less fiber breakage and delamination.From the literatures, the impact properties with stacking sequence and impact energy levels of glass and Kevlar fibers have not been investigated extensively. In this article, two pure composites and four different hybrid composites having different stacking sequence are fabricated using vacuum bagging technique. The hybrids have a fixed ratio of glass and Kevlar fibers consisting of six layers of woven glass fibers and six layers of woven Kevlar fibers. These composites are investigated to determine the effects of various stacking sequences and impact energies on impact resistance properties and suggests the optimized stacking sequence on the assessment of impact response and energy absorption behavior of composite laminates under low velocity drop weight impact test. The different properties of hybrid composites can serve towards specific design requirements.

II. METHODS AND MATERIALS

A. Materials and Specimen Fabrication

The reinforcing fiber structures used in this study are glass and Kevlar woven fibers which were impregnated with epoxy resin as the binding agent. The glass fiber was a C-glass fiber, which has high chemical durability properties and supplied by Vistec Technology Sdn. Bhd. (Malaysia) in the form of plain-woven fabric. Meanwhile, the 2443 Kevlar-49 fiber was supplied by Fibre Glast Developments Corporation (USA) in the form of twill woven fabric. The matrix used was epoxy Miracast 1517. The epoxy resin was cured with the addition of the hardener with a ratio of 100:30. Both resin and hardener were supplied by Miracon Sdn. Bhd., Malaysia. Basically, six different types of composite laminates were fabricated using hand lay-up method followed by vacuum bagging process. The specimens were prepared in the form of square plates of 50 mm 50 mm with an average of (5.00 0.01) mm thickness. The hybrid composite laminates were prepared with four different stacking sequence configurations but similar ratio of glass to Kevlar fibers which is 50:50. Table I depicts the types of specimens fabricated with various composition and its density, while Fig. 1 illustrated various stacking sequences of hybrid composites used in this study.

Table-I: Composition and density of the glass and Kevlar fiber layers used for specimen fabrication

Specimen	Number of Fiber Layers		Stacking Sequence	Density (g/cm^3)
	Glass Fiber	Kevlar Fiber		
GFRP	22	-	22G	1.448
H1	10	10	4G-2K-2G-2K-2G-2K-2G-4K	1.117
H2	10	10	4K-2G-2K-2G-2K-2G-2K-4G	1.105
H3	10	10	5G-10K-5G	1.156
H4	10	10	5K-10G-5K	1.075
KFRP	-	16	16K	1.115

Note: Density data was taken from density tests conducted based on ASTM792. G denotes glass fiber while K denotes Kevlar fiber.

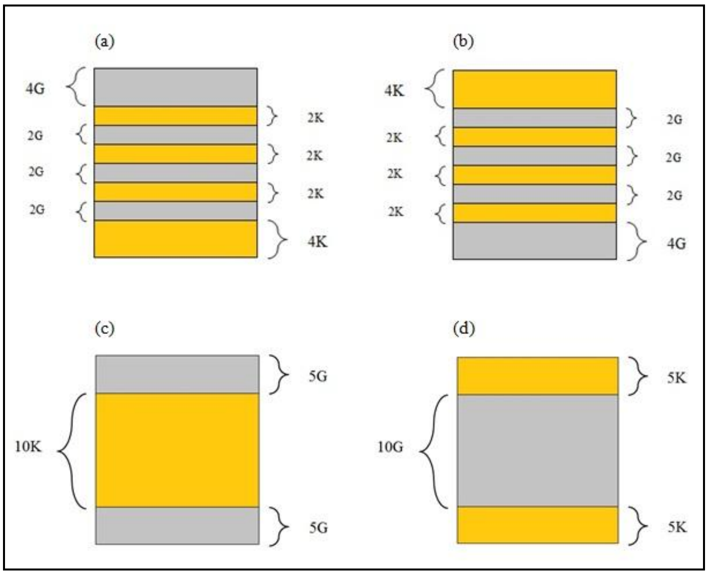


Fig. 1. Schematic view of stacking sequence for (a) H1 (b) H2 (c) H3 (d) H4 composite laminates

B. Low Velocity Impact Test

Low velocity impact test was performed using an Instron Dynatup 8250 Drop Weight Impact Tester (USA) which was equipped with a 12 mm diameter hemispherical tip impactor that has a mass of 6 kg. The drop height of the impactor was varied to achieve different ranges of impact energies. For this test, the specimens were impacted at 10 J, 20 J, 30 J, and 40 J. After the low velocity impact test was conducted, the fractured surface and damage extent induced by the impactor at various impact energy levels on the impacted and rear face of the FRP composite laminates were observed to examine the relationship between the damaged patterns and the absorbed impact energy level at different impact energies.

III. RESULTS AND DISCUSSION

A. Effects of Different Nominal Impact Energies and Stacking Sequences on Impact Properties of Hybrid Composite Laminates

The transient responses in terms of load, energy, and deflection properties obtained from the low velocity drop weight impact test were recorded. The typical load versus deflection and load-energy versus time responses for all specimens were plotted at four different impact energy levels (10J, 20 J, 30 J, and 40 J) and shown in Fig. 2 and Fig. 3. The impact parameters obtained from the typical curves and other calculated parameters such as ductility index, impact strength, specific impact strength, and specific total energy absorbed were tabulated in Table II. From Fig. 2, the peak load increases with increasing impact energy for the impacted specimens. In comparison, KFRP specimens recorded higher peak load compared to GFRP specimens. Thus, it indicates that KFRP specimens were stiffest, and able to absorb and sustain more load. A similar conclusion was proposed by Zhi Sun et al. [17], whereby higher peak load indicates higher stiffness.

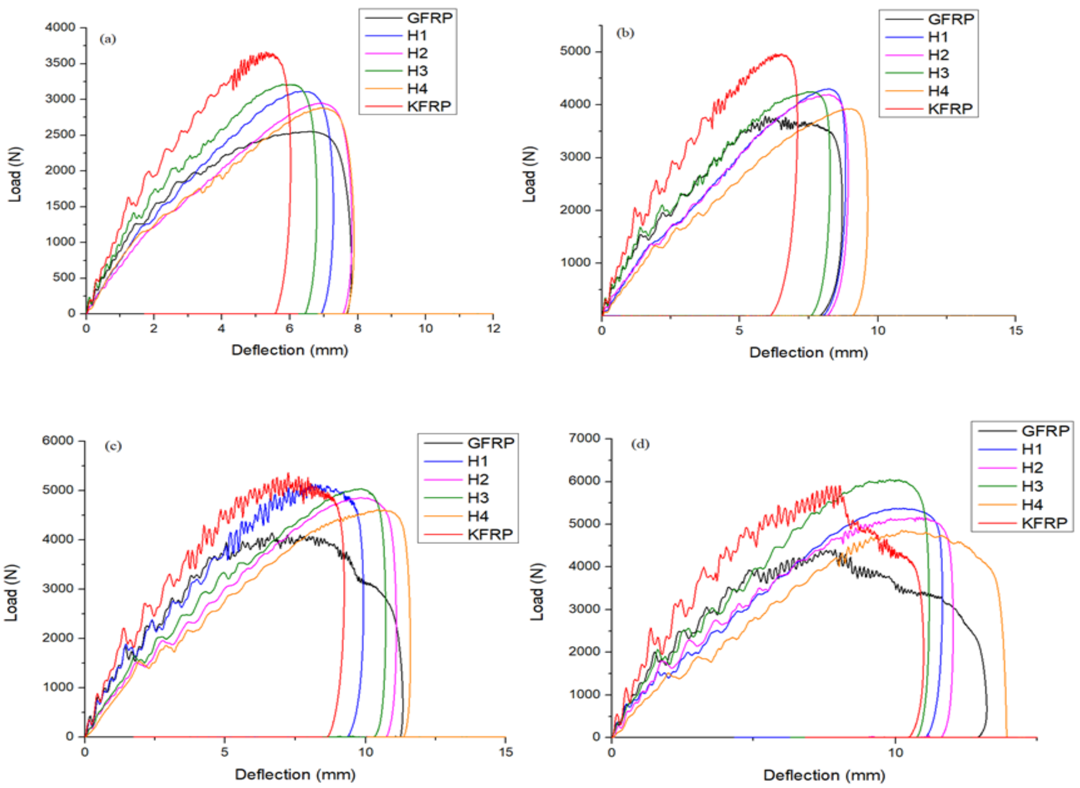


Fig. 2. Typical load versus deflection curves of composite laminates at (a) 10 J, (b) 20 J, (c) 30 J, and (d) 40 J impact energy levels

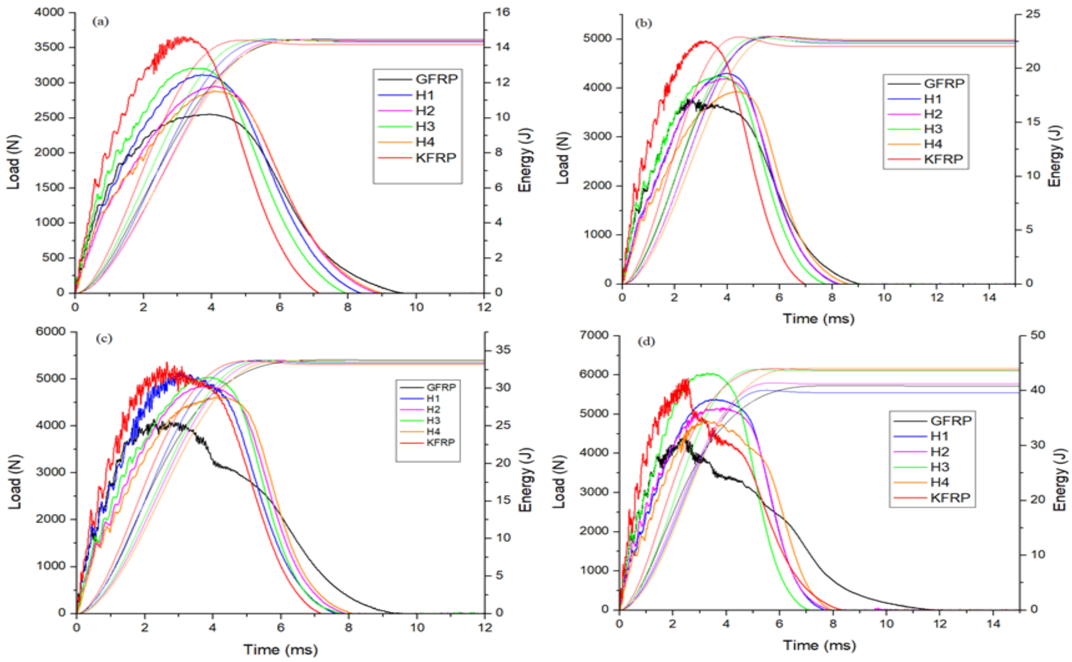


Fig. 3. Typical load-energy versus time curve of composite laminates at (a) 10 J, (b) 20 J, (c) 30 J, and (d) 40 J impact energy levels

Table-II: Impact parameters recorded for all composite laminates at various impact energy level

Specimens/Impact Energy	GFRP	H1	H2	H3	H4	KFRP
10 J						
Peak Load (kN)	2.794	3.127	2.973	3.249	2.863	3.5
Deflection at peak load (mm)	6.062	6.348	6.527	6.299	6.873	7.365
Initiation Energy (J)	11.625	11.805	11.77	11.952	11.748	12.118
Propagation Energy (J)	2.827	2.651	2.59	2.423	2.733	2.322
Ductility Index	0.243	0.2245	0.220	0.202	0.232	0.191
Impact Strength (kJ/m^2)	102.78	104.3791	104.3	105.67	103.87	107.14
Specific Impact Strength (kJ.m/kg)	0.0709	0.0936	0.09316	0.09563	0.08985	0.09967
Specific Total Energy Absorbed ($J.m^3/kg$)	0.009981	0.01296	0.01285	0.01301	0.01252	0.01343
20 J						
Peak Load (kN)	4.075	4.303	4.119	4.367	3.95	4.7627
Deflection at peak load (mm)	6.316	6.717	7.892	7.459	8.253	7.664
Initiation Energy (J)	18.49	19.08	18.54	19.27	18.218	20.39
Propagation Energy (J)	3.859	2.927	3.854	2.955	4.018	3.252
Ductility Index	0.208	0.15340	0.20787	0.153347	0.220551	0.1594
Impact Strength (kJ/m^2)	163.48	168.7042	163.9296	170.3842	161.0825	180.287
Specific Impact Strength (kJ.m/kg)	0.112906	0.1513	0.1467	0.15419	0.1393	0.1677
Specific Total Energy Absorbed ($J.m^3/kg$)	0.01543	0.019737	0.0200	0.02011	0.019235	0.0219
30 J						
Peak Load (kN)	4.137	4.829	4.814	5.055	4.428	5.328
Deflection at peak load (mm)	6.745	8.0912	9.784	9.33	9.871	7.243
Initiation Energy (J)	20.265	27.95	27.57	28.958	27.4	22.9
Propagation Energy (J)	13.498	5.693	5.683	4.677	6.33	10.453
Ductility Index	0.666075	0.203321	0.2061	0.161	0.23102	0.4564
Impact Strength (kJ/m^2)	179.1819	247.132	243.772	256.044	242.269	202.480
Specific Impact Strength (kJ.m/kg)	0.123744	0.2216	0.2182	0.2314	0.2095	0.1883
Specific Total Energy Absorbed ($J.m^3/kg$)	0.023317	0.0301	0.0297	0.0304	0.0291	0.0310
40 J						
Peak Load (kN)	4.324	5.357	4.908	5.678	4.86	5.494
Deflection at peak load (mm)	7.009	7.9867	8.7053	8.84	9.98	9.403
Initiation Energy (J)	22.023	30.693	28.881	33.69	28.21	29.486
Propagation Energy (J)	18.6207	11.8698	10.8611	8.7845	13.998	14.331
Ductility Index	0.845512	0.3867	0.3760	0.2607	0.4962	0.4860
Impact Strength (kJ/m^2)	194.726	271.385	255.364	297.88	249.431	260.715
Specific Impact Strength (kJ.m/kg)	0.1344	0.2433	0.2286	0.2695	0.2157	0.2425
Specific Total Energy Absorbed ($J.m^3/kg$)	0.028069	0.0381	0.0355	0.0384	0.0365	0.0407

Besides, stiffer material deforms less with the ability to tolerate higher impact load [18]. Moreover, KFRP specimens recorded a higher value than GFRP in terms of deflection at peak load, initiation energy, and propagation energy at respective impact energies. Thus, the values indicated that Kevlar fiber has a better load carrying capabilities and resistance to deformation during impact in comparison with glass fiber, which points out the reason for Kevlar fiber to have a higher strain to failure in tension compared to glass fiber [15].

For impact energy at all levels, hybrid composite laminates (KGFRP) recorded a higher value than GFRP specimens, in terms of peak load, deflection at peak load, and initiation energy. Force acting on the specimens is dependent with the impact energy. This proved that the addition of Kevlar fibers to glass fibers increases the load carrying capability and resistance towards deformation during impact loading. In the fact that, when failure strain in glass fibers (brittle layer) reached in an interlaminar hybrid, the load was transferred to Kevlar fibers (ductile layer). A similar finding was reported by Jeremy et al. [19], where in their study carbon fiber (brittle layer) hybridized with Kevlar fiber (ductile layer) resulted in higher absorbed impact energy and peak load.

From the observation, H3 specimen recorded the highest peak load and maximum initiation energy compared to H1, H2, and H4 at all impact energy levels. This points out, that H3 specimen has a high load carrying capability as it can absorb more load and the high energy is required to initiate damage. The lowest peak load was recorded for H4 specimen in all impact energy levels. The H3 specimen which consist of Kevlar fiber in the interior while glass fiber in the exterior explains the reason for the value determined.

As, specimen H3 which consist of highest number of glass fiber in exterior delayed the penetration and enhanced the stiffness of the laminate. Similarly, Jang et al. [20] concluded in his research, by placing a brittle layer to receive the impactor enhances the stiffness of hybrid composite laminate rather than placing a ductile layer. Then, the impact load which then transferred to Kevlar fibers in an interlaminar hybrid, absorbs most of the load as Kevlar fiber is known for its high load carrying abilities. Moreover, the number of Kevlar layers in the interior was more in H3 specimen compared to other hybrid specimens. The ductility index of H3 specimen was observed to be the lowest among H1, H2, and H4 at means of all impact energies. It reveals, that H3 specimen is tougher or more energy required to initiate damage in the specimen rather than to propagate the damage [20]. The impact strength value calculated for hybrid specimens, revealed that the highest value recorded was for H3 specimen.

This means H3 specimen has more resistance towards damage during impact. Among the hybrid specimens, H3 specimen obtained the highest value of specific impact strength and specific energy absorbed. This denotes that H3 specimen are more effective absorbers and better resistance to damage with respect to its weight. A scatter graph was plotted to display the properties of specific impact strength versus specific total energy absorbed for FRP composite laminates at all impact energy levels. From Fig. 4, it was observed that a high strength to weight ratio and a high total energy absorbed to weight ratio were recorded for H3 specimen compared to other hybrid specimens, resulting in positive effect of H3 specimen stacking sequence

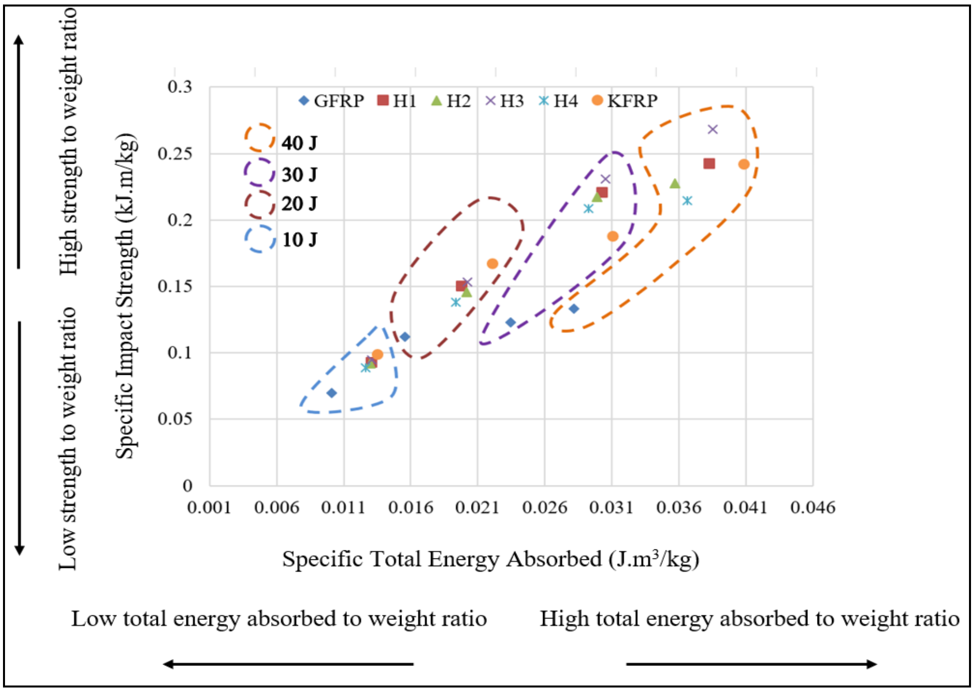


Fig. 4. Specific impact strength versus specific total energy absorbed of FRP composite laminates

B. Damage Assessment of FRP Composite Laminates

During an impact event, energy is absorbed in the form of an elastic deformation, little or no plastic deformation and through formation of new surfaces during a failure. Fig. 5 and Fig. 6 depict a visual observation of the impacted and non-impacted side of the damaged laminates for all FRP composites impacted at 10 J and 40 J. The selection of damage assessment of 10 J and 40 J was made to depict a clear picture on effects of various impact energies. From the observation, the damage area increases with impact energy. At an impact energy of 10 J less damage on the front face and back face was observed compared to 40 J, due to less impact load applied on the specimens. Furthermore, a larger damage area was observed in GFRP than KFRP, indicating Kevlar fibers tends to absorb more energy than glass fibers. The damage was more likely to spread in GFRP, but more localized in KFRP.

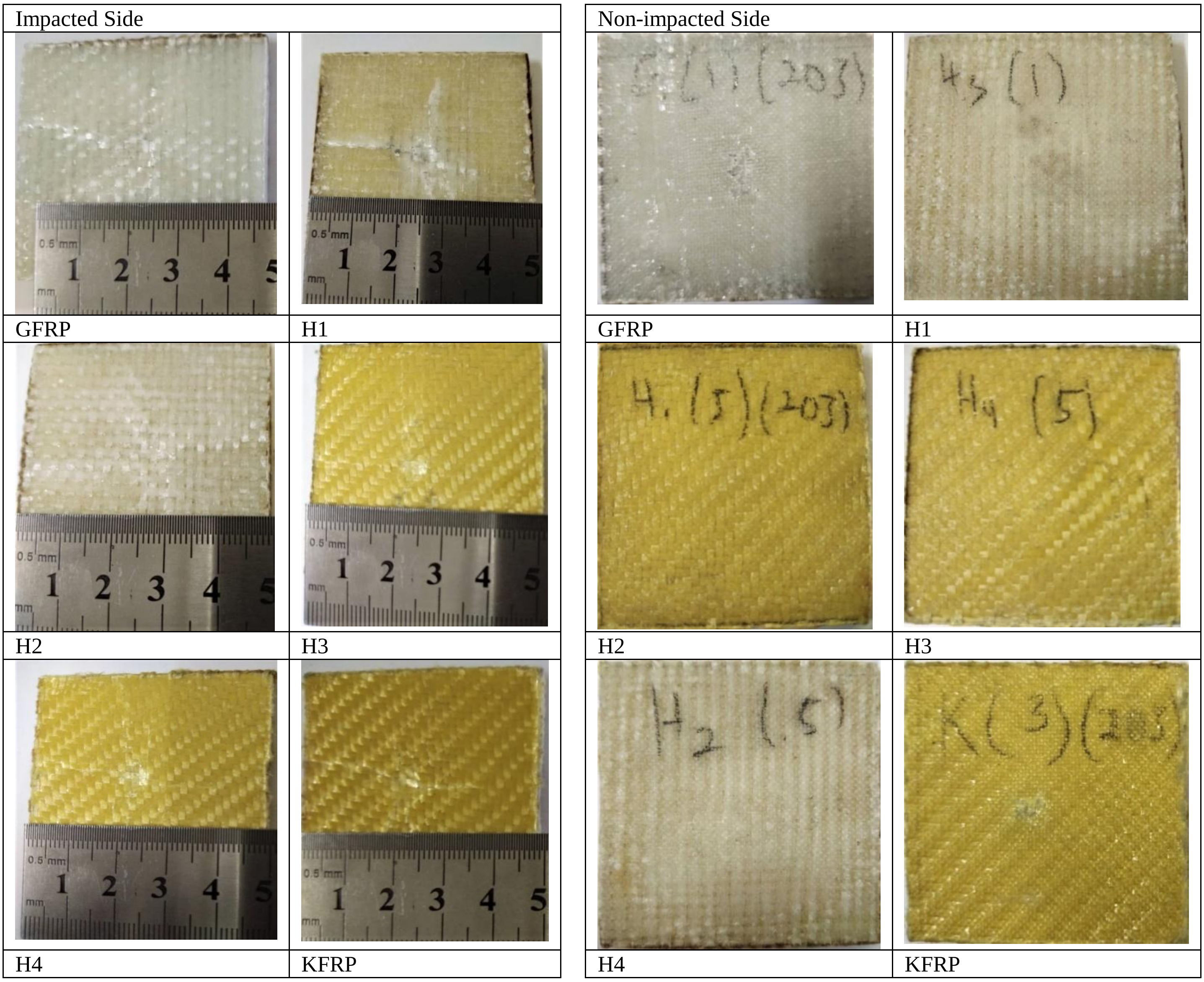
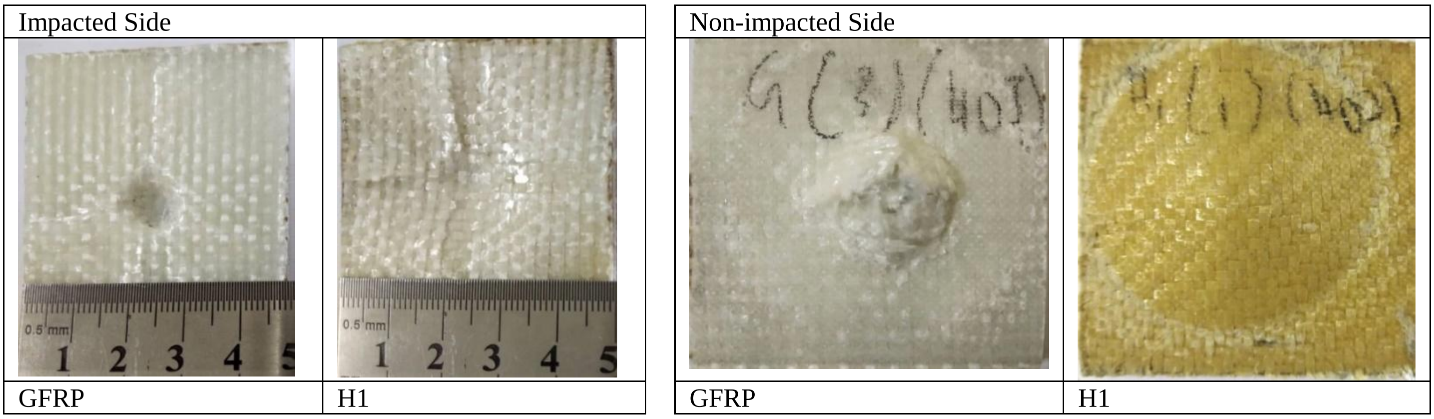


Fig. 5. Visual observation of impacted and non-impacted side of FRP composite laminates impacted at 10 J



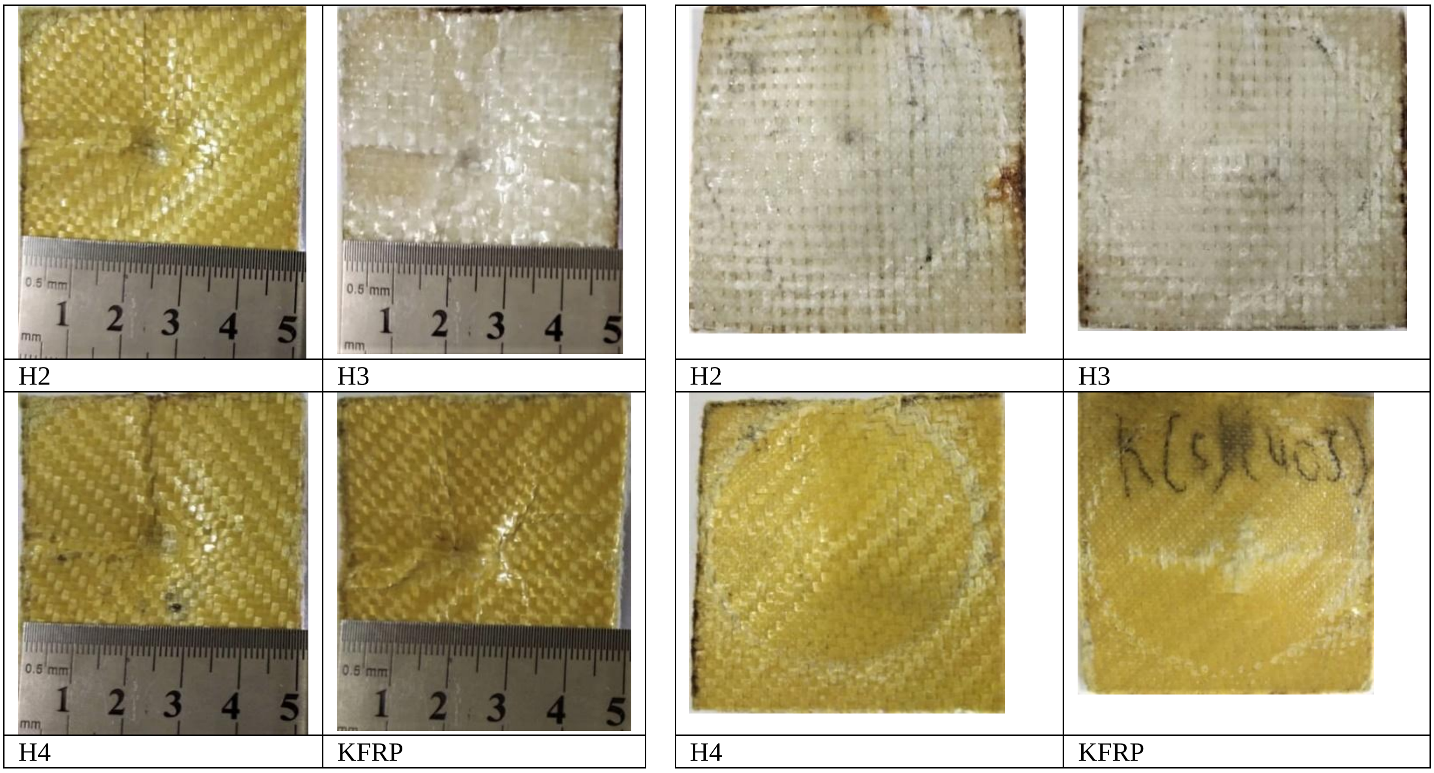


Fig. 6. Visual observation of impacted and non-impacted side of FRP composite laminates impacted at 40 J

In hybrid composite less damage was observed in H3 specimen, which is tallied with low ductility index of the specimen. At impact energy of 40 J, the rear face of H4 specimen was observed to have much more damage compared to H1, H2, and H3 specimens. This indicates that the H4 specimen's initiation energy is less compared to propagation energy.

IV. CONCLUSION

For the low velocity impact test conducted, value of impact load and other impact parameters of specimen were observed to be dependent with the impact energies. At all impact energies, KFRP displayed better load carrying capability and tougher than GFRP. Hybridization of Kevlar fiber with glass fiber significantly increases the load carrying capability and impact resistance of the specimen. In comparison to hybrid composites, H3 specimen recorded a higher value in peak load, maximum initiation energy, high impact strength, high strength to weight ratio and high total energy absorbed to weight ratio. The H3 specimen with highest number of glass fibre in the exterior and Kevlar fibre in the interior was observed to be the optimized stacking sequence.

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