

INFLUENCE OF IPNS (VINYLESTER / EPOXY / POLYURETHANE) ON THE MECHANICAL PROPERTIES OF GLASS / CARBON HYBRID COMPOSITES

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ABSTRACT: The main objective of this study is to compare the interpenetrating polymer networks' (IPNs) physical strengths with different variants of fibers. In this study, E-Glass, Carbon, and a combination of E-Glass and Carbon fiber (hybrid) have been taken as the reinforcement. Similarly, three combinations of the IPNs were chosen as the matrix material, namely Epoxy/Polyurethane (EP), Vinyl ester/Polyurethane (VP) and Epoxy/Vinyl ester (EV) as IPN blends. In order to thoroughly understand the physical characteristics of the combination of blends and fibers, nine variants (laminates) were fabricated: combinations of Epoxy/Polyurethane/E-Glass (EPG), Epoxy/Polyurethane/Carbon (EPC), Epoxy/Vinyl ester/Glass/Carbon (EPGC-hybrid), Vinyl ester/Polyurethane/Glass (VPG), Vinyl ester/Polyurethane/Carbon (VPC), Vinyl ester/Polyurethane/Glass/Carbon (VPGC), Epoxy/Vinyl ester/Glass (EVG), Epoxy/Vinyl ester/Carbon (EVC), and Epoxy/Vinyl ester/Glass/Carbon (EVGC-hybrid), all with help of a hand-layup technique. Furthermore, mechanical tests such as tensile, flexural, impact, and HDT (Heat distortion temperature) were performed on all the variants as per the ASTM standards. Results shows that carbon fiber reinforcement with all IPN combinations has shown extraordinary performance (double fold) over the E-Glass fiber reinforcement, whereas the hybrid (combination of E-Glass/Carbon) laminates have shown excellent characteristics over E-Glass fiber reinforcement, irrespective of IPN matrix material. All the results were compared with each other and their corresponding variations were plotted as bar charts.

ABSTRAK: Objektif utama kajian ini adalah bagi membandingkan kekuatan fizikal rangkaian polimer saling menyusuk (IPN) dengan pelbagai jenis gentian berbeza. Kajian ini menggunakan pakai gentian kaca-E, karbon dan gabungan kaca-E dan gentian karbon (hibrid) sebagai penguat. Begitu juga, tiga kombinasi IPN dipilih sebagai bahan matrik, iaitu Epoksi / Poliuretana (EP), Ester Vinil / Poliuretana (VP) dan Epoksi / Ester Vinil (EV) sebagai campuran IPN. Bagi tujuan memahami secara mendalam ciri-ciri fizikal gabungan campuran dan gentian, sembilan varian (lamina) dihasilkan, malalui kombinasi seperti Epoksi / Poliuretana / kaca-E (EPG), Epoksi / Poliuretana / Karbon (EPC), Epoksi / Ester Vinil / Kaca / Karbon (EPGC-hibrid), Ester Vinil / Poliuretana / Kaca (VPG), Ester Vinil / Poliuretana / Karbon (VPC), Ester Vinil / Poliuretana / Kaca / Karbon (VPGC), Epoksi / Ester Vinil / Kaca (EVG), Epoksi / Ester Vinil / Karbon (EVC), Epoksi / Ester Vinil / Kaca / Karbon (EVGC-hibrid) dengan teknik susun atur lapisan menggunakan tangan. Selain itu, ujian mekanikal seperti

tegangan, lenturan, hentaman dan HDT (suhu kelenturan panas) dilakukan pada semua varian mengikut piawaian ASTM. Dapatan kajian menunjukkan bahawa, penguat gentian karbon dengan semua kombinasi IPN telah menunjukkan prestasi luar biasa (dua kali ganda) daripada penguat gentian kaca-E, manakala lamina hibrid (campuran kaca-E / Karbon) telah menunjukkan ciri-ciri sangat baik berbanding penguat gentian kaca-E tanpa mengira bahan matrik IPN. Semua hasil dapatan dibandingkan antara satu sama lain dan padanan variasi diplot sebagai carta bar.

KEY WORDS: *Interpenetrating Polymer Networks, Epoxy, Vinyl ester, Polyurethane, E-Glass/Carbon.*

1. INTRODUCTION

Considerable research activity has been initiated in the area of materials, with the goal of finding new materials that can deliver high performance in the way that high performance engineering materials have, for example, composites. Meanwhile, the application of these composite materials is among the most important developments in the engineering field in recent years. These materials have become essential to different engineering applications, for example automobile part manufacturing and marine & aerospace applications. Since the composite materials explicitly have very high strength to weight ratio, are lightweight, and resistant to high temperatures, they are indeed considered to be pioneer materials in all applications. When compared with traditional metallic materials, composite materials present a wide spectrum of advantages over metallic materials, because metallic materials are prone corrosion when employed in corrosive environments [1-3]. In recent decades, thermoset polymer composites have become recognized and perhaps the most notably desirable materials in all sectors. The inherent properties like modulus to weight ratio, corrosion resistance, and fatigue resistance have further bolstered its wide acceptance in all sectors of engineering applications. On the other hand, thermoset FRPs (Fiberglass Reinforced Plastics) have lower toughness when compared with traditional metallic materials and alloys. This adverse effect of strength gain is mainly due to interfacial bonding and linkages between the fiber and matrix materials. This is purely based on the property of the modifications on the matrix. Meanwhile, researchers have kept trying various synthesis methodologies in the area of matrix modifications as well as adopting the newer techniques such as blending and concept of Interpenetrating polymer networks [4-6].

Generally, composites are explained as being a mixture of two or more materials that are combined to yield better characteristics than the individual materials in the mix. In contrast to traditional metallic alloys, each mixed material separately keeps its physical, chemical, and mechanical properties. Aside from the phase mixing of both materials, reinforcement agents are added that are usually much stronger, stiffer, and harder than the matrix material. Normally the reinforcement will be a fiber or a particulate. In the fabrication of particulate composites, the particulates uniformly occupy all areas of the composite material, whereas the strength of fiber-reinforced composites is completely based on the reinforcement direction, size, and shape. Different types of fiber and matrix materials are available on the market, where the traditional fibers like Glass and Carbon fibers are most common in the area of FRP fabrication. Similarly, in the area of matrix selection, common synthetic resins like epoxy, polyurethane and vinyl ester are often the only resin components considered for a fabricator. Each resin has its own unique nature of application in the fabrication of versatile components. Epoxy resin is considered to be the highest performance resin due to its inherent properties and resistance to environmental degradation. Generally, epoxy consists of a cross-linking reaction group, originally derived from the epoxy group [7-9].

Mostly, epoxy is used in the coating and fabrication industries because it shows good adhesion with fiber reinforcement. Epoxy also boasts very good chemical resistance, mechanical strength and electrical insulation property. Likewise, vinyl ester resin is considerably used in most polymeric industries. Basically, vinyl ester is produced by esterification process, where epoxy resin has been chosen as the prime ester substituent. Engineers widely consider vinyl ester to be an acceptable substitute material for epoxy resin since it has a comparatively lower cost than the epoxy resin. It is also commonly used in marine industries due to its corrosion resistance and reduced water uptake characteristics, and is extensively used in FRP tank vessel manufacturing and their allied components. Other classic resins in this series are polyurethane resins (PUR), from the family of thermoset and thermoplastic resins. PUR is predominately accepted as a versatile material throughout the world due to its inherent properties like toughness, durability, and tear resistance. It is important to remember that all resins have their own positive and negative impact on component fabrication. In order to tap the benefits of two resins, the concept of interpenetrating polymer networks has been suggested and research activity has been successfully initiated in that field. While undergoing the polymerization, each resin would undergo separate curing and have mutual entanglement with the mutual resin [10-12].

In this present work, instead of choosing an individual polymer as the matrix material, the combination or blending of two resins has been implemented in order to fabricate the laminate. Three sets of combinations have been taken for physical examination in this study. Initially, epoxy with polyurethane was kept as the constant blend for glass, carbon, and glass/carbon fiber reinforcement. Then, a vinyl ester and polyurethane blend was taken as the blend for glass, carbon, and glass/carbon fiber reinforcement. Finally, epoxy and vinyl ester with a specific proportion was kept as the blend for the reinforcement of glass, carbon, and glass/carbon fiber. All the combinations underwent physical examination in order to have a detailed comparison of all the reinforcements with all blends. Tests like tensile, flexural, impact, and moisture exhibit the relative coherence of all the reinforcements [13].

2. MATERIALS AND METHODS

2.1. Materials

The epoxy resin used in the experimental process as well as diglycidyl ether bisphenol A, vinyl ester resin with corresponding hardener, promotor, and catalyst, and polyurethane and E-Glass/Carbon fiber with aerial density of 350 GSM were purchased from Sakthi fibers, Chennai. All fibers and resins used for fabrication were received from the supplier as shown in the figure 1.



Figure 1. Raw materials used to fabricate the IPN laminate

2.2. Sample preparation

Initially, the epoxy with hardener was mixed with a ratio of 10:6 wt%. Similarly, the vinyl ester and its corresponding hardener (methyl ethyl ketone peroxide), promotor, and accelerator were mixed with a ratio of 100:2:2. Finally, the polyurethane prepolymer was mixed with its respective hardener MOCCA. All the mixtures with their corresponding hardeners were kept for blending as mentioned in the Table 1.

Table 1. IPN – Blend with reinforcement Combinations

Notations	IPN – Blending Combination	Fiber Reinforcement
EPG	Epoxy + Polyurethane	Glass
EPC	Epoxy + Polyurethane	Carbon
EPGC	Epoxy + Polyurethane	Glass/Carbon
VPG	Vinyl ester + Polyurethane	Glass
VPC	Vinyl ester + Polyurethane	Carbon
VPGC	Vinyl ester + Polyurethane	Glass/Carbon
EVG	Epoxy + Vinyl ester	Glass
EVC	Epoxy + Vinyl ester	Carbon
EVGC	Epoxy + Vinyl ester	Glass/Carbon

2.3. Fabrication technique

Nine different types of composites, as mentioned in Table 1, were made by the hand-layup technique. Six plies of biaxial woven mat of the fibers were cut. To fabricate the laminate, the woven mat was initially placed on the flattened aluminum plate then completely covered with a polypropylene sheet. Following this, the blend was applied over the polypropylene sheet and the respective fiber mat was placed over the wet surface of the combination of IPN laminate. The mats were placed one over another until a 3 mm thickness was obtained. After every combination set was made, the specimens were kept at atmospheric temperature to ensure the complete polymerization. Also, laminates were kept in the hot air oven for a period of 2 hours to further enhance the complete polymeric condensation. All the specimens were cut to the sizes mentioned in Table 2 in order to subject the specimens to physical examinations. The specimens were cut with help of a diamond saw cutter with utmost care and accuracy [14].

Table 2. ASTM Standards with size of the specimens

ASTM Standards	Size of the specimen (Length x breadth x thickness in “mm”)
ASTM D 3039 - Tensile	250 x 25 x 3.2
ASTM D 790- Flexural	127 x 12.7 x 3.2
ASTM D 256 – Impact	63 x 12.8 x 3.2
ASTM D 648 – HDT	125 x 12.7 x 3.2

2.4. Experimental analysis

The tensile and flexural tests were done according to ASTM D3039 for all set of specimens by a universal testing machine, as mentioned in Table 2. In each test, five samples were tested and averages were noted down as the final value. The sample specimens of all the hybrid composites are shown in Figure 2.

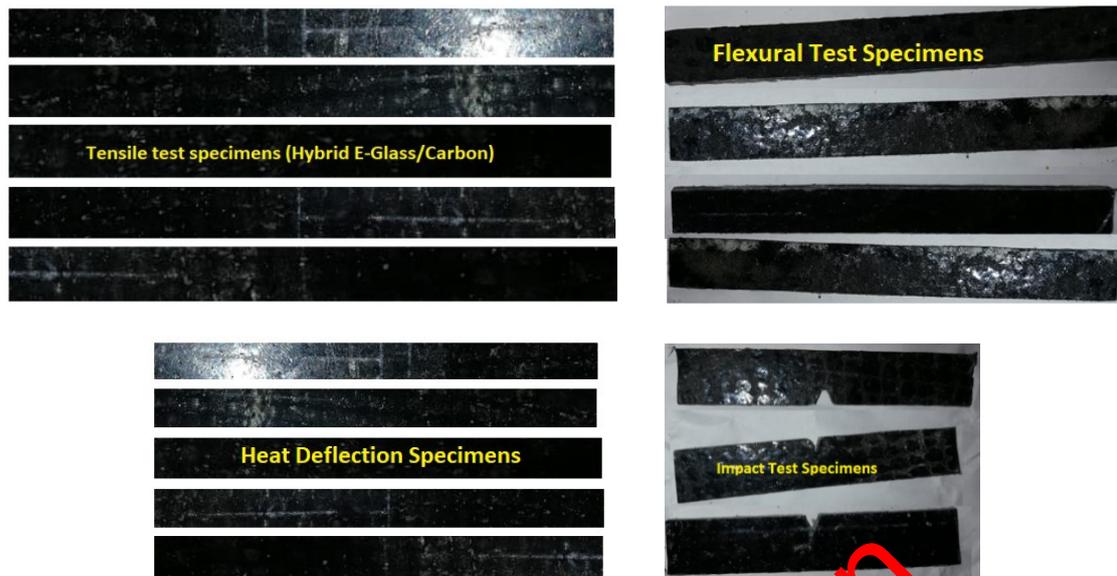


Figure 2. Hybrid test specimens of IPN composite

3. RESULT AND ANALYSIS

Table 3 illustrates test results of the various IPN blends with E-Glass and carbon fiber reinforcements. All physical property tests were conducted at ambient temperature.

Table 3. IPN – Blend (E-Glass/Carbon – reinforced) physical properties

IPN – Blending Combination	Mechanical Properties			
	Tensile (MPa)	Flexural (MPa)	Impact (kJ/m ²)	HDT (°C)
Epoxy + Polyurethane + Glass (EPG)	625	415	16	74
Epoxy + Polyurethane + Carbon (EPC)	1025	752	19	89
Epoxy + Polyurethane + Glass/Carbon (EPGC)	834	554	17	81
Vinyl ester + Polyurethane + Glass (VPG)	452	376	12	68
Vinyl ester + Polyurethane + Carbon (VPC)	854	725	19	79
Vinyl ester + Polyurethane + Glass/Carbon (VPGC)	667	501	16	72
Epoxy + Vinyl ester + Glass (EVG)	554	386	15	76
Epoxy + Vinyl ester + Carbon (EVC)	954	786	20	88
Epoxy + Vinyl ester + Glass/Carbon (EVGC)	776	512	17	81

3.1. Tensile strength analysis of IPN laminate

The results of the tensile strength of the E, E/SF, E/BF, E/CF, and E/SBCF fiber-reinforced composites are shown in Figure 3. It was observed that the tensile strength of the pure EPG composite had a value of 625 MPa. However, during this test, it was observed that the fracture on the specimen occurred at the gauge length of the specimen. Though epoxy is known for its good strength and stiffness, due to the loading of the polyurethane on the epoxy, the strength of the specimen showed a little dip when its tensile strength is considered. Past studies have shown that the pure epoxy with glass reinforcement show a predominant tensile strength value against all other sets of thermoset resins. Similarly, the fracture purely relied on the phenomenon of crack initiation on the matrix, with subsequent loss of the interfacial strength between the fiber and matrix. Also, it was common to notice that the fibers were broken as pull out fractures on the gauge length. The EPC specimen showed a tensile strength value of 1025 MPa; this value was nearly 64% higher than the EPG specimens. This high tensile strength shows that carbon fiber reinforcement has caused the rise in the tensile strength value.

Normally, carbon fibers are known for their higher strength, lower weight, and stiffness ratio. The characteristics of the carbon fiber showed the overwhelming response, when present, in its hike in tensile strength. The same failure mechanism seen in the EPG was observed in EPC. The EPGC specimen showed a mixed response, where half of its strength seems due to the glass fiber and half due to the carbon fiber.

The specimen showed a 45% increase over previous EPC specimens. However, the values obtained on the vinyl ester matrix material showed a different trend, unlike the epoxy-based composites. Proof of this is seen in the VPG tensile strength value of 452 MPa. This value was nearly 88% lower than the value obtained from the EPGC. Although the vinyl ester resin was proven to have a good toughness and impact resistant matrix, it showed a dip in tensile strength value even when loaded with polyurethane matrix. For a second time, it was interesting to note that the VPC had a tensile strength value of 854 MPa, which was nearly 22% higher than the value obtained from VPG.

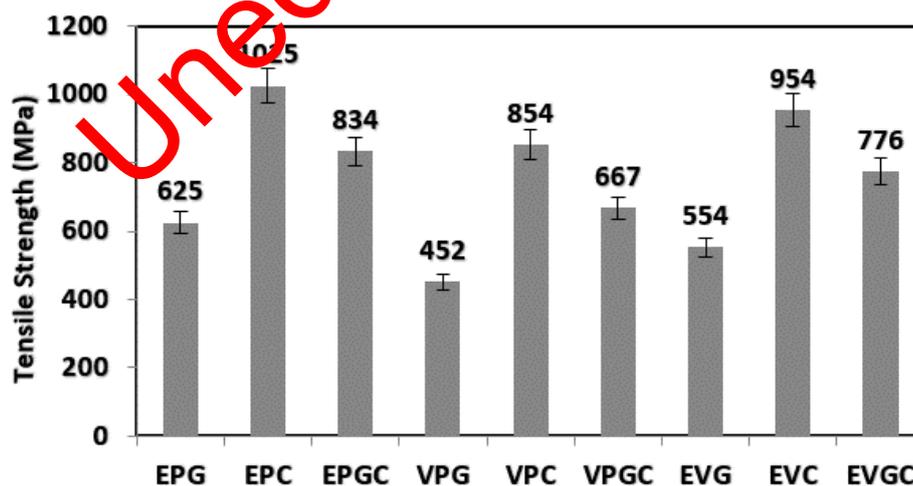


Figure 3. Tensile strength analysis of E-Glass/Carbon fiber reinforced IPN (EP/VP/EV) laminate

From the results, it is proven that the carbon fiber reinforcement maintained a high value when reinforced, irrespective of the matrix material. On the contrary, the VPGC showed an increase in the tensile strength value against the VPC. The obtained value was 667 MPa; this

was nearly 17% lower than the carbon fiber reinforcement. From all the results, it was observed that, irrespective of matrix, carbon fiber often offers a very high and good strength bearing capability. In line of the above, the EVG shows a tensile strength value as 554 MPa. The obtained value was not higher than EPG, but not lower than VPG, from the obtained value, it was proven that the epoxy holds a greater load bearing capability than the other two matrices, namely, the polyurethane and the vinyl ester. The EVC exhibits the tensile strength value of 954 MPa, and this was higher than the corresponding EPC and VPC. At last, the EVGC shows a tensile strength value of 776 MPa, this value is nearly 19% lower than the value of EVC. All the results clearly show that the carbon fiber holds the higher load bearing capacity irrespective of IPN matrix materials, similarly the hybridization on the composites increases the laminate strength to many folds greater than the glass fiber and many folds lower than the carbon fiber reinforced IPN laminate [15].

3.2. Flexural strength analysis of IPN laminate

The obtained results of the flexural strength of the E, E/SF, E/BF, E/CF and E/SBCF fiber-reinforced composites are shown in Figure 4. The specimen was held between the two rollers in a horizontal direction and the load was applied in the vertical direction. Similar trends were seen in the flexural analysis as were seen in the previous tensile strength analysis. The EPG showed the flexural strength value of 415 MPa, this was mainly due to the epoxy matrix. Epoxy would usually have good interfacial strength; thus, the inter-laminar strength was further increased in all combinations. The carbon fiber reinforced IPN laminate exhibited a higher value than the glass fiber reinforcement. This increased percentage (81%) in the EPC was due to the carbon fiber reinforcement's stiffness characteristics. The carbon fiber played a major role in increasing the strength of the laminates to higher levels.

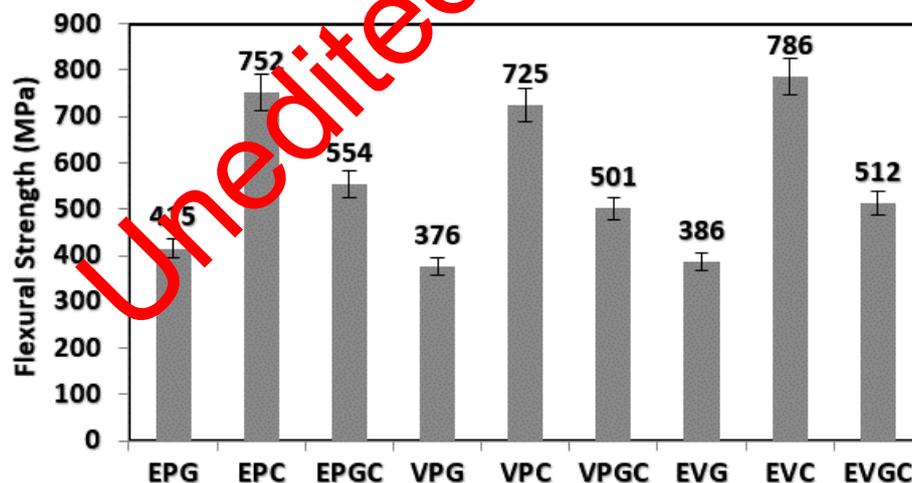


Figure 4. Flexural strength analysis of E-Glass/Carbon fiber reinforced IPN (EP/VP/EV) laminate

The hybrid IPN laminate, with a combination of glass and carbon fiber reinforcement showed a lower value than the neat carbon fiber reinforcement. The obtained value shows that the load bearing capacity of the hybridization was based on the tailoring property of the glass and carbon fiber. Nevertheless, the VPG, VPC, VPGC showed the flexural strength values of 376 MPa, 725 MPa, and 501 MPa, respectively. The obtained value for VP (vinyl ester and polyurethane) showed again that the matrix influences the load bearing strength of the laminate as discussed in the tensile strength analysis. However, the EV (Epoxy and vinyl ester) showed

that, for every epoxy-based IPN, the strength of the IPN laminate largely increased the load bearing capacity to a massive level [16].

3.3. Impact strength analysis of IPN laminate

Figure 5 shows the result of impact strength analysis of different variations of IPN blends with E-Glass/Carbon fiber reinforced laminates.

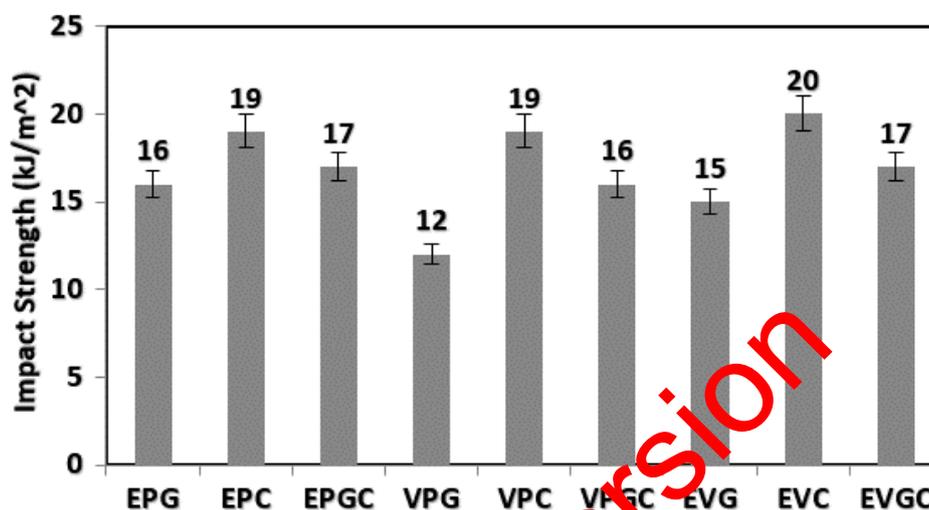


Figure 5. Impact strength analysis of E-Glass/Carbon fiber reinforced IPN (EP/VP/EV) laminate

The EPG specimen showed an impact strength value of 16 kJ/m². This obtained value was comparatively high with respect to all sets of IPN specimens. Similarly, the EPC showed a value of 19 kJ/m². This value was much higher than the glass fiber reinforcement. Again, this study proves that the carbon fiber reinforcement has better entanglement and adhesion property with all sets of IPN matrixes. EPGC showed a comparatively lower value than that of EPG and EPC. Similarly, the VPG, VPC, VPGC showed an impact strength value of 12 kJ/m², 19 kJ/m², 16 kJ/m², respectively. Though vinyl ester is universally accepted as being a good impact resistant material, when it is mixed with the epoxy, the showed values of 15 kJ/m², 20 kJ/m², and 17 kJ/m², respectively. From all the tests, it was clearly observed that the IPNs with hybridization significantly provided higher impact strength than the individual fiber reinforcement [17].

3.4. Heat Deflection Test of the IPN laminate

The heat deflection temperature (HDT) was measured in order to find out the distortion temperature of the respective composites under elevated temperature (0.25 mm deflection), while the specimen was subjected to a standard load. Results are shown in the Figure 6. While doing the test on the EPG specimen, it exhibited an HDT value of 74°C. Though the neat epoxy reinforced composite exhibited higher HDT value in previous literature, in this study, it showed a lower value than the original neat epoxy-based composites. The main reason behind the lesser distortion was the loading of the polyurethane into the hybrid composite. Variation in HDT value was far less than variation in the strength tests. Since polyurethane is an elastic material, it loosens its entanglement with the epoxy very quickly as the temperature increases into the system.

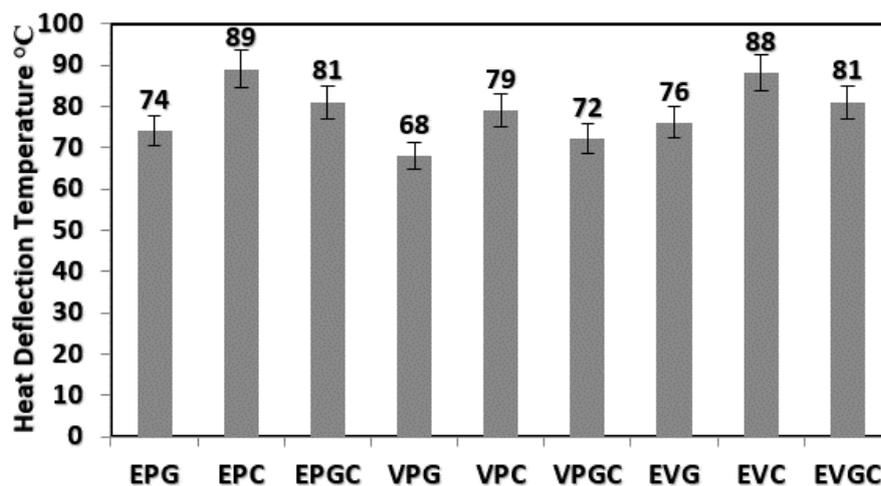


Figure 6. Flexural strength analysis of E-Glass/Carbon fiber reinforced IPN (EP/VP/EV) laminate

The EPC hybrid composite showed an HDT value of 89°C, this value was nearly 9% higher than the EPG. Although the EPC laminate contains polyurethane, its HDT value was higher than the EPG. This was due to the carbon reinforcement into the laminate. However, the carbon reinforcement sustained maximum transverse load when the laminate was subjected to the transverse load. The EPGC showed a mixed response much like the value obtained from tensile and flexural tests. The combination shows the mixed strengthened value of E-Glass and Carbon fiber. This value was 16% lower than the EPC. Correspondingly, the VPG exhibited an HDT value of 68°C and the VPC showed an HDT value of 79°C. Though it exhibited a 16% higher value than the earlier reinforcements, the increase in the HDT value clearly showed that the carbon fiber reinforcement takes the maximum load. It also showed the better adhesion characteristics over the matrix material. In the same way, the EPGC also showed a reduction in their HDT value as compared with the VPC. As with the EPGC, the glass fiber took less load and the carbon fiber took the maximum load. This is the reason why the specimen showed a mixed response of glass fiber and carbon fiber. The EVG showed an HDT value of 76°C whereas its corresponding carbon fiber reinforcement exhibited a value of 88°C. From all the tests, it was clearly shown that the polyurethane resin-loaded hybrid composite showed a predominantly lower HDT value as compared with the neat laminates. By the same token, the carbon fiber reinforced IPNs showed a higher value, irrespective of the type of IPN used. Equally, the hybrid laminates showed mixed responses from glass and carbon fiber reinforcement.

4. CONCLUSION

The three sets of IPNs (Epoxy/Polyurethane, Vinyl ester/Polyurethane, Epoxy/Vinyl ester) were prepared with a ratio of 70:30 with the variant reinforcements of E-Glass, Carbon, E-Glass/Carbon fiber reinforcement. All the variants were subjected to physical tests and their corresponding results are drafted below:

1. During tensile test, EP (Epoxy/Polyurethane) and EV (Epoxy/Vinyl ester) specimens showed better tensile strength values as compared to VP (vinyl ester/polyurethane) specimens. This is because of the matrix contributions to the IPN blends.
2. Similarly, in flexural stress analysis, the EP (Epoxy/Polyurethane) specimens exhibited excellent flexural strength values over the remaining set of IPN blends.

3. On the contrary, during the impact strength analysis, the EV (Epoxy/Vinyl ester) showed better impact resistance value as compared with the remaining set of two variants. This was mainly because of the toughness characteristics of the vinyl ester.
4. While doing the HDT test, it was observed that polyurethane significantly played a role in terms of negative dip in the HDT value. However, carbon fiber reinforcement into the epoxy-based composite cumulatively increased the HDT value.
5. Overall, important findings were that carbon fiber reinforcement into the IPN blend significantly increased the physical strengths of the laminates to double fold that of the E-glass fiber reinforcement. This shows that the carbon fiber had considerably better adhesion property with all sets of IPNs.

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