

Impact Load Response of Polymer Matrix Composite Materials

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ABSTRACT

In this paper, we study how the polymer composite materials will experience the impact strength at different combinations of matrix composition in different fiber orientations. The polymer matrix composite laminates were made into specimens of dimensions according to ASTM standards and are experimentally investigated by Izod & Charpy impact tests with and without notching the specimens. In the experimental program the laminates were prepared by matched die mould and filament winding techniques.

The laminates were made with GFRP, CFRP, and Bi-directional glass fabrics are used as reinforcement, lapox L-12, Araldite LY 556 as resins and lapox K-6, Araldite HT-972, Aradur 5200 as hardeners. The stacking sequences, of laminates are as follows [0/90/0/90], [+45/-45/+45/-45] and [90/-45/+45/0].

KEYWORDS: Glass fiber reinforced plastics, Carbon fiber reinforced plastics, filament winding.

INTRODUCTION

Composite material can be defined as a macroscopic combination of two or more materials that results in better properties than those of individual components used alone.

Progresses in the field of materials science and technology have given birth to these fascinating and wonderful materials. Composites are heterogeneous in nature and are very versatile and can be tailor-made. Therefore, they can be a solution to the needs in the future. The matrix materials may be metallic, ceramic or polymeric in origin. These are well known materials which satisfy many of the traditional requirements. Despite the tremendous advantages that advanced composites have over metals in applications requiring high strength, stiffness, and low weight in applications where impact by foreign objects is a design consideration, the advantages inherent in composites are overshadowed by their poor response to impact loading.

LITERATURE STUDY

A considerable amount of literature has been written on the behavior of glass fiber composites exposed to impact energy covering different aspects of the topic.

Dr. Donald F. Adams discusses the methods for impact testing of composites. The impact response of composite materials used were primarily reinforced with glass fibers, which performed well under impact loads. This soon proved not to be true for carbon fibers, which are relatively brittle. But since their static strength and stiffness properties were very attractive, development of carbon fiber reinforcements for structural applications continued. The Charpy impact testing for metals and plastics where a simple tensile failure could be induced at the notch root, the failure mode of composite materials was often complex. The mode of failure of the composite is inconsistent, and thus it is difficult to relate the measured absorbed energy of the Charpy specimen to that of an actual structural component. Thus, after considerable research, Charpy impact testing of composites was abandoned.

Mr. Amal A.M. Badawy studied determining of the impact behavior of glass fibers reinforced polyester (GFRP) was experimentally investigated using notched Izod impact test specimen. The experimental program was carried out on unidirectional laminate of GFRP in directions 0, 45 and 90 in addition to cross-ply laminate (0/90/0)s. The effect of fiber volume fraction, test results showed that fiber volume fraction on impact strength of GFRP composite depends on the parameter controlling the mode of failure, i.e. matrix or fiber. The failure characteristic changed from fiber pull-out to fiber breakage with increasing the exposure temperature.

Mahmood M Shokrieha, Mohammad A Torabizadeh This paper demonstrates results of an experimental study on glass/epoxy laminated composites subjected to low velocity impact energy levels and low temperatures by a Charpy device were experimentally investigated. The configuration of laminates was quasi-isotropic. Low temperature and its weakening influence on the material properties including maximum absorbed energy, elastic energy, maximum crack length and maximum delamination length are highlighted. Moreover, the effects of geometry index and notch orientation are determined based on the test results.

SELECTION OF MATERIALS

E-Glass Fabric

Over 95% of the fabric used in reinforced plastics are glass fabric, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced.

Their low density, resistance to chemicals, insulation capacity are other bonus characteristics, although the one major disadvantage in glass is that it is prone to break when subjected to high tensile stress for a long time.

However, it remains break-resistant at higher stress-levels in shorter time frames. This property mitigates the effective strength of glass especially when glass is expected to sustain loads for many months or years continuously.

Period of loading, temperature, moisture and other factors also dictate the tolerance levels of glass fibers and the disadvantage is further compounded by the fact that the brittleness of glass does not make room for prior warning before the anamorphic failure.

But all this can be easily overlooked in view of the fact the wide range of glass fiber variety lend themselves amicably to fabrication processes like matched die-molding, filament winding lay-up and so on. Glass fibres are available in the form of mates, tapes, cloth, continuous and chopped filaments, roving and yarns.

Addition of chemicals to silica sand while making glass yields different types of glasses.

E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fibre forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiber glass.

The use of E-Glass as the reinforcement material in polymer matrix composites is extremely common. Optimal strength properties are gained when straight, continuous fibers are aligned parallel in a single direction. To promote strength in other directions, laminate structures can be constructed, with continuous fibers aligned in other directions.

Glass fiber technical specifications:

1. Nomenclature : 13 MIL E GLASS FABRIC
2. Thickness, mm : 0.36
3. Width, inch : 40"
4. Type of Weave : 4 Harness-Satin
5. Construction :
 - Warp, Threads/inch : 48
 - Weft, Threads/inch : 36
6. Weight per Sq.mtr : 456.900 gms
7. Breaking Strength per 50 mm:
 - Warp : 361.000 Kgs
 - Weft : 274.000 Kgs

Carbon fiber Technical specifications:

A fiber manufactured by pyrolysis of organic precursor fibers in an inert atmosphere at extremely high temperatures.

Product Description: 100% recycled carbon fibers which have been purified by pyrolysis and milled to specified lengths.

Standard Filament Diameter: 6 microns
 Nominal Filament Length : ~100 microns (0.1mm)
 Tensile Strength : >3,200 MPa
 Electrical Resistance : $1.6 \times 10^{-3} \Omega\text{cm}$
 Thermal Expansion Coefficient: -0.1 (10⁻⁶ K⁻¹)
 Specific Gravity : 1.8 g/cm³

Resins

2.3.1 Bisphenol A epoxy resin (LAPOX-L12)

Lapox L12 is a liquid, unmodified epoxy resin of medium viscosity which can be used with various hardeners for making glass fiber reinforced composites. Important epoxy resins are produced from combining epichlorohydrin

and bisphenol to give bisphenol a diglycidyl ethers. Structure of bisphenol-A diglycidyl ether epoxy resin: n denotes the number of polymerized subunits and is typically in the range from 0 to 25.

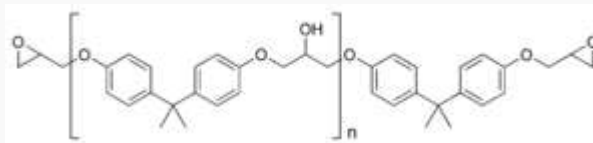


Fig 1 structure of biphenol-A

Increasing the ratio of bisphenol A to epichlorohydrin during manufacture produces higher molecular weight linear polyether's with glycidyl end groups, which are semi-solid to hard crystalline materials at room temperature depending on the molecular weight achieved. As the molecular weight of the resin increases, the epoxide content reduces and the material behaves more and more like a thermoplastic. Very high molecular weight polycondensates (ca. 30 000 – 70 000 g/mol) form a class known as phenoxy resins and contain virtually no epoxide groups (since the terminal epoxy groups are insignificant compared to the total size of the molecule). These resins do however contain hydroxyl groups throughout the backbone, which may also undergo other cross-linking reactions, e.g. with aminoplasts, phenoplasts and isocyanates.

Technical Specifications: Lapox L-12

Description	: Clear Viscous Liquid
Epoxide equivalent	: 182-192 gm/eq
Epoxy value	: 5.34 eq/kg
Viscosity @ 25°C by Brookfield:	11990 mPa
Volatile Content	: 0.17 % w/w
Colour on gardener scale	: 0.3 GS
Hydrolysisable Chlorine-PO:	0.03 %
Martens value	: 153°C

ARALDITE LY-556

ARALDITE LY-556 is Medium-viscosity, unmodified liquid epoxy resin based on bisphenol-A. Possesses excellent mechanical properties and resistance to chemicals, which can be modified within wide limits by using different hardeners as well as fillers. Has low tendency to crystallize. Used in aircraft and aerospace adhesives.

Technical specifications: Araldite LY 556

Product Type	: Epoxies (EP) > Bisphenol A-based Chemical Composition: Bisphenol-A based epoxy resin
Physical Form	: Liquid Appearance : Clear
Vapor pressure @ 20 °C (balance)	: < 0.01 Pa
Density @ 25°C (ISO 1675)	: 1.15 g/cm ³
Flash point (Pensky Martens, ISO 2719):	> 200 °C
Color (Gardner, ISO 4630)	: 2GS
Epoxy index (ISO 3001)	: 5.30 - 5.45 eq/kg
Epoxy equivalent (ISO 3001)	: 183 - 189 g/eq
Viscosity @ 25 °C	: 10000 - 12000 mPa

Hardeners

LAPOX K-6

Hardener K6 is a low viscosity room temperature curing liquid hardener. It is commonly employed for hand lay-up applications. Being rather reactive, it gives a short pot life and rapid cure at normal ambient temperatures. Laminates can be subjected to operating temperatures of 1000 C.

Technical Specifications hardener k-6:

Visual appearance	: clear liquid
Colour on GARDENER SCALE	: 0.4 GS
Refractive index at 25°C	: 1.4951
Water content by KF	: 0.18 % max
Shear strength	: 1.4Kg/mm ²

ARALDITE HT-972

Araldite is medium viscosity, unmodified liquid epoxy resin based on Bisphenol Araldite hardener HT-972 is a solid state hardener which upon heating turns into a low viscous fluid. Glass fibre laminates are dimensionally stable. Glass fibre laminates are practically free from internal stress. Excellent water resistance

Technical specifications: HT 972

Physical state	: solid
Colour	: pale yellow
Odor	: pungent
Melting point	: 100 ⁰ C (15min)
Flash point	: >18
Viscosity at 25 ⁰ C:	Dynamic 10-20mPa.s
Density	: 0.97-0.99g/cm ³ [25 ⁰]

ARADUR 5200**Technical Specifications: ARADUR 5200**

Physical state	: liquid
Colour	: brown
Odor	: pungent
Boiling point	: 308 ⁰ C (586.4 ⁰ F)
Flash point	: Closed cup >120 ⁰ C (>248 ⁰ F) : Open cup 168 ⁰ C (333.4 ⁰ F)
Decomposition	: >200 ⁰ C (>392 ⁰ F)
Vapour pressure	: <0.00013KPa (<0.000975mm Hg)
Specific gravity	: 1.02
Partition coefficient	: 1.17
Viscosity	: Dynamic 160 mPa.s (160cp)
Density	: 1g/cm ³ [20 ⁰ (68 ⁰ F)]

Pigment:

A pigment is a material that changes the color of reflected or transmitted light as the result of wavelength-selective absorption. This physical process differs from fluorescence, phosphorescence, and other forms of luminescence, in which a material emits light. Many materials selectively absorb certain wavelengths of light. Materials that humans have chosen and developed for use as pigments usually have special properties that make them ideal for coloring other materials. A pigment must have a high tinting strength relative to the materials it colors. It must be stable in solid form at ambient temperatures.

For industrial applications, as well as in the arts, permanence and stability are desirable properties. Pigments that are not permanent are called fugitive. Fugitive pigments fade over time, or with exposure to light, while some eventually blacken.

Pigments are used for coloring paint, ink, plastic, fabric, cosmetics, food, and other materials. Most pigments used in manufacturing and the visual arts are dry colorants, usually ground into a fine powder. This powder is added to a binder (or vehicle), a relatively neutral or colorless material that suspends the pigment and gives the paint its adhesion.

A distinction is usually made between a pigment, which is insoluble in its vehicle (resulting in a suspension), and a dye, which either is itself a liquid or is soluble in its vehicle (resulting in a solution). A colorant can act as either a pigment or a dye depending on the vehicle involved. In some cases, a pigment can be manufactured from a dye by precipitating a soluble dye with a metallic salt. The resulting pigment is called a lake pigment. The term biological pigment is used for all colored substances independent of their solubility.

SELECTION OF FABRICATION PROCESS

Several factors should be considered before selecting the manufacturing process for a particular part;

- User requirements
- Performance requirements
- Total production volume
- Production rate
- Cost of production
- Size of the production

- Surface finish of the final product
- Geometry of the product
- Material

These are important for all manufacturing processes and even more so for composite materials. Ideally, structural design of the product, and design of the required manufacturing process should be completed using a concurrent approach.

Matched die mould process

Even though the method has been replaced with automated techniques, the lay-up of pre impregnated material by hand is the oldest and most common fabrication method for advanced composite structures. Furthermore, the basic features of the method remain unchanged. A pictorial essay showing each step in the hand lay-up of a flat composite laminate is shown

Each step must follow in successive fashion in order to obtain a high-quality composite laminate after final processing. A description of these steps follows.

A single layer of a laminated composite material is generally referred to as a ply or lamina. It usually contains a single layer of reinforcement, unidirectional or multidirectional. A single lamina is generally too thin to be directly used in any engineering application. Several lamina are bonded together to form a structure termed as laminate. Properties and orientation of the lamina in a laminate are chosen to meet the laminate design requirements. Properties of a laminate may be predicted by knowing the properties of its constituent lamina.

EXPERIMENTAL WORK

In this experimental work the laminates were with the following orientations.

1. $0-90^0$ ($0-90^0-0-90^0-0-90^0-0$)
2. ± 45 ($45,-45,+45,-45,+45,-45,+45$)
3. $90/\pm 45/0/\pm 45/90$ ($90,-45,+45,0,+45,-45,90$)

Manufacturing process

1. Preparation of mould

Here mould of dimensions 390mmx340mm is prepared and surface is cleaned with acetone, and if there is any imperfections, the mould is rubbed with 0⁰emry paper to get the clean surface as shown in figure 4.1.

2. Measuring of matrix for laminate as per equal weight ratio of matrix and reinforcement. That is weight of reinforcement for one laminate equals to weight of matrix.

3. The fabric is laid on the workbench which is covered with polythene sheet and then marking is taken by using required dimensions and orientations with help of templates as shown in figure 4.2

4. Bonding agent(epoxy resin) is applied to create bonding between layers. This is usually accomplished by rollers or brushes, with an increasing use of roller type impregnators for forcing resin in to the fabric.

5. Cut the fabric into laminas as per marking, and place on the mold before peel outing the polythene sheet. Repeat the same process for all laminas. shown in figure 4.3

6. After closing the mold properly, allow it for curing as per cure cycle.

7. Extract the laminate gently and cut the specimens according to required dimensions as per ASTM standards.



*Fig 4.1 mold.**Fig 4.2 application of matrix over fabric**Fig 4.3 applying of plies over mould by sequence*

IMPACT TESTING PROCEDURE

Impact tests are performed to assess shock absorbing capacity of materials subjected to suddenly applied loads. In Izod test, the specimen is placed as 'cantilever beam'. The specimens have V-shaped notch of 45°. U-shaped notch is also common. The notch is located on tension side of specimen during impact loading. Depth of notch is generally taken as $t/5$ to $t/3$ where 't' is thickness of the specimen.

machine specifications

Its specifications along-with their typical values are as follows:

1. Impact capacity = 164joule
2. Least count of capacity (dial) scale= 2joule
3. Weight of striking hammer = 21.79 kg.
4. Swing diameter of hammer = 1600mm.
5. Angle of hammer before striking = 90°
6. Striking velocity of hammer = 5.6m/sec.
7. Length of the pendulum = 0.796m
8. Specimen size = 64x12.7x3.2 mm³.
9. Type of notch = V-notch.
10. Angle of notch = 45°
11. Depth of notch = 2 mm.



Testing procedure

Check that the pendulum machine has the specified velocity of impact and that it is in the correct range of absorbed energy

Conduct a blank test and record the measured values of the total frictional loss. Ensure that this energy loss does not exceed the appropriate value as per the standard.

1. Lift the hammer to an appropriate knife edge position and notch the energy stored in the hammer. For the standard Izod test the energy stored should be 164j.
2. Locate the test specimen on the m/c supports shown in fig 5.1
3. Release the hammer. The hammer will break the piece and shoot up the other side of the specimen.
4. Note the residual energy indicated on the scale by the hammer.
5. Impact strength of the test specimen is the difference of the initial energy stored in hammer and the residual energy.

Calculation:-

- Notch impact strength = Absorb energy / Effective cross section area

$$\text{Impact Strength} = \frac{\text{Impact Energy (joules)}}{\text{Cross section area (mm}^2\text{)}}$$

Precautions:-

1. The specimen should be prepared in proper dimensions.
2. Take reading more frequently.
3. Make the loose pointer in contact with the fixed pointer after setting the pendulum.
4. Do not stand in front of swinging hammer or releasing hammer.
5. Place the specimen in proper position.
figure 5.1 izod test rig

TEST RESULT AND DISCUSSIONS

Glass fabric with lapox -L-12 and K-6 as matrix in (0/90⁰), (±45), (0/90/±45/0/90) orientations

Table 6.1 glass fabric (0-90)

IZOD TEST-(0/90) GLASS FABRIC(L-12 RESIN + K-6 HARDNER)									
S.NO	NOTCHED		S.NO	REV NOTCHED		S.NO	UN NOTCEHD		
	impact energy (joules)	impact strength (j/mm ²)		impact energy (joules)	impact strength (j/mm ²)		impact energy (joules)	impact strength (j/mm ²)	cross sectional area (mm ²)
1	6	0.14764	1	4	0.098425	1	6	0.14764	40.64
2	5	0.12303	2	6	0.147638	2	6	0.14764	40.64
3	4	0.09843	3	8	0.19685	3	8	0.19685	40.64
4	4	0.09843	4	8	0.19685	4	6	0.14764	40.64
5	4	0.09843	5	6	0.147638	5	7	0.17224	40.64
6	5	0.12303	6	6	0.147638	6	8	0.19685	40.64
7	4	0.09843	7	6	0.147638	7	8	0.19685	40.64
8	5	0.12303	8	6	0.147638	8	8	0.19685	40.64
9	4	0.09843	9	6	0.147638	9	7	0.17224	40.64
10	8	0.19685	10	6	0.147638	10	8	0.19685	40.64
Average	4.9	0.1206		6.2	0.15256		7.2	0.1772	

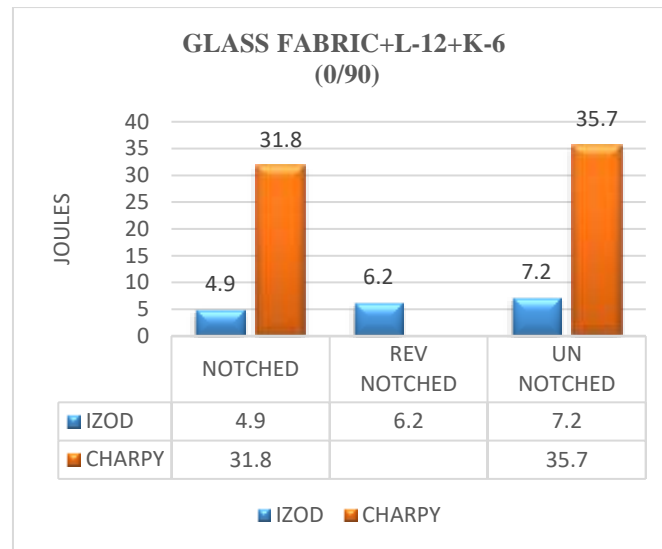


figure 6.1

In (0/90) orientation of glass fabric with Lapox and K-6 exhibits good impact characteristics in un notched conditions.

whereas with the same matrix and reinforcement but with orientation of fiber is in (±45) is performing better impact result as 12.6 joules than (0/90/±45/0/90) as 9.1 joule in izod.

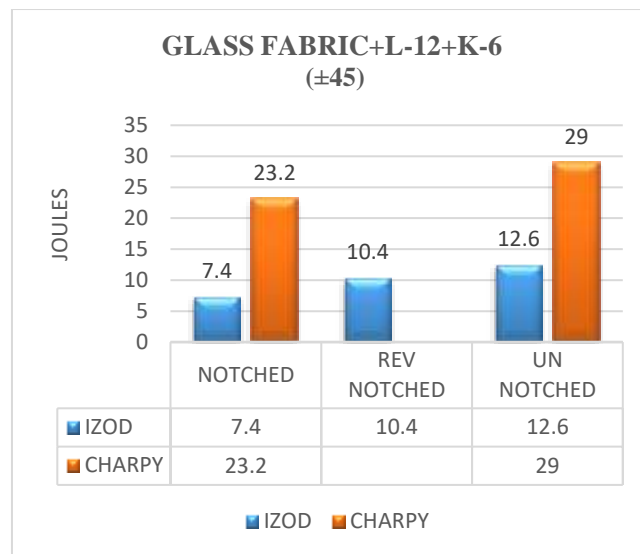


figure 6.2

4.All fibers are oriented to 45° to pendulum in ±45 orientation this helps to absorb more impact energy and the same reason this orientation absorbs less in charpy test compared to (0/90).

6.2 Carbon fiber with lapox -L-12 and Aradur 5200 as matrix in (0/90/±45/0/90) orientation

Table 6.2 carbon fibre (0/90/±45/0/90)

IZOD TEST-COMBINATIONAL CARBON FIBER(L-12 + ARADUR 5200)					
S.NO	NOTCHED	S.NO	REV NOTCHED	S.NO	UN NOTCEHD

	impact energy (joules)	impact strength (j/mm ²)		impact energy (joules)	impact strength (j/mm ²)		impact energy (joules)	impact strength (j/mm ²)	cross sectional area (mm ²)
1	10	0.24606	1	14	0.344488	1	13	0.31988	40.64
2	14	0.34449	2	12	0.295276	2	12	0.29528	40.64
3	10	0.24606	3	12	0.295276	3	15	0.36909	40.64
4	12	0.29528	4	12	0.295276	4	18	0.44291	40.64
5	12	0.29528	5	13	0.319882	5	15	0.36909	40.64
6	11	0.27067	6	12	0.295276	6	15	0.36909	40.64
7	12	0.29528	7	10	0.246063	7	15	0.36909	40.64
8	13	0.31988	8	10	0.246063	8	14	0.34449	40.64
9	13	0.31988	9	12	0.295276	9	15	0.36909	40.64
10	12	0.29528	10	12	0.295276	10	8	0.19685	40.64
Average	11.9	0.24606		11.9	0.29281		14	0.3445	

- 6.2 Carbon fiber with lapox -L-12 and Aradur 5200 as matrix in (±45), (0/90/±45/0/90), orientations
1. Carbon fiber with Aradur 5200 hardener giving good izod impact results in (±45) orientation than the (0/90/±45/0/90) and (0/90).
 2. In (0/90) fiber orientation both glass and carbon fiber performing good charpy impact results.
 3. The izod impact characteristics carbon with aradur 5200 hardener is exhibiting approximately same results when fiber oriented in (0/90/±45/0/90) and (±45). This is because fibers oriented in ±45 will give great shear strength.
 4. Where as in the case of charpy the number of fibers which are oriented in (0/90) will gives better results than (0/90/±45/0/90), (±45).

Table 6.3 carbon fiber (±45)

IZOD TEST (±45) CARBON FIBER(L-12 + ARADUR 5200)									
S.NO	NOTCHED		S.NO	REV NOTCHED		S.NO	UN NOTCEHD		
	impact energy (joules)	impact strength (j/mm ²)		impact energy (joules)	impact strength (j/mm ²)		impact energy (joules)	impact strength (j/mm ²)	cross sectional area
1	12	0.29528	1	1	0.246063	1	16	0.3937	40.64
2	12	0.29528	2	2	0.295276	2	15	0.36909	40.64
3	11	0.27067	3	3	0.221457	3	15	0.36909	40.64
4	12	0.29528	4	4	0.246063	4	11	0.27067	40.64
Avg	11.75	0.2891		10.25	0.25221		14.25	0.3506	40.64

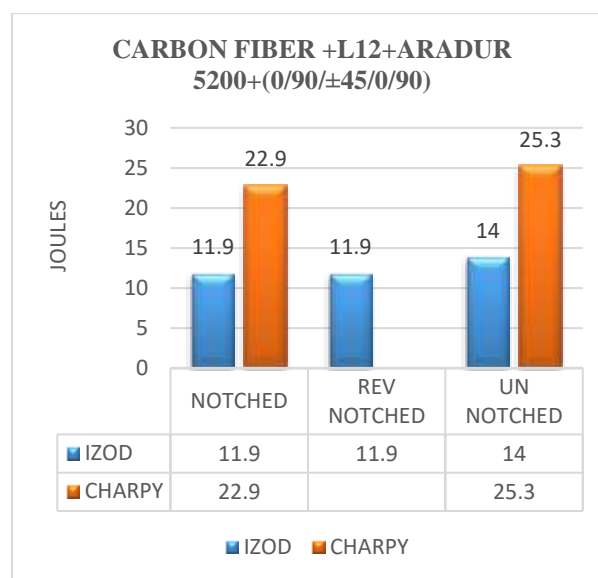


figure 6.3

Glass fiber with lapox -L-12 and Aradur 5200 as matrix in (± 45), (0/90/ ± 45 /0/90), orientations

Glass fiber with Lapox L-12 and aradur 5200 combination performing good impact results in izod (13.33joules) than glass fabric with the same matrix composition(12.6 joules) in ± 45 fiber orientation and in (0/90/ ± 45 /0/90) fiber orientation also glass fiber shows improvement over fabric shown in figure 6.4.

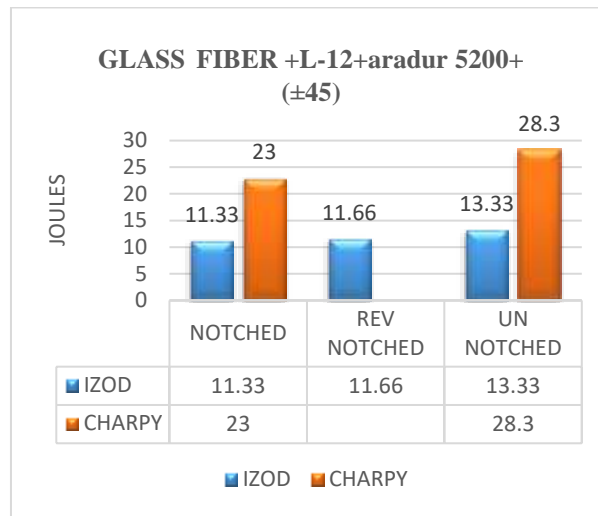


figure 6.4

CONCLUSIONS

1. In the present investigation on impact characteristics of polymer matrix composites, depends upon reinforcement , orientation of the reinforcement and matrix composition.
2. The characterization was carried among three reinforcements glass fabric, glass fiber, carbon fiber , and three orientations that is (0/90),(0/90/ ± 45 /0/90), (± 45), with different matrix systems (lapox L-12+ K-6), (lapox L-12+ aradur 5200).
3. Carbon fiber with (± 45) orientation in composition of Lapox L-12+ Aradur 5200 giving best in both izod and chary impact characteristics.
4. Glass fiber in (± 45) orientation in composition of Lapox L-12+ Aradur 5200 giving approximate results with carbon fiber in both izod and chary impact characteristics.
5. Glass fabric with (lapox L-12+ K-6) in (0/90) orientation giving lowest izod impact result.
6. In (0/90/ ± 45 /0/90) orientation the reinforcement giving intermediate results of reinforcement in (0/90), (± 45) in respective matrix composition.

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