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Mechanical Properties of High Density Polyethylene and its Composite

by

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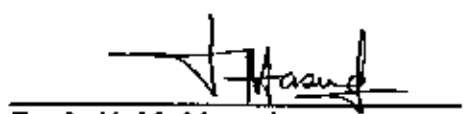

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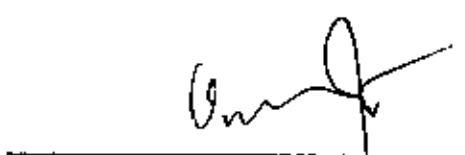

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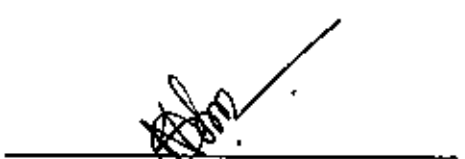

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To

My Parents

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Author

ABSTRACT

Composite materials involve a system where reinforcing material is added to a plastic resin matrix. Resin is reinforced with fiber or other filers, to overcome the fatigue failure, to resist a corrosive environment, to improve the physical and mechanical properties and to develop energy absorption capacity of the composite.

This paper presents an analysis of the mechanical properties of the High Density Polyethylene and its jute fiber-reinforced polymeric composite. A number of HDPE resin matrix specimens were manufactured on a hand injection-molding machine. Here jute fibers were employed as a filler material. Jute is an attractive natural fiber for use as reinforcement in composite because of its low cost, renewable nature and much lower energy requirement for processing. The jute fibers were straightly reinforced to the HDPE resin matrix to fabricate the composite specimens. Tensile tests were carried on a universal testing mechine to find out and compare the mechanical properties. The test results indicate significant improvement in mechanical properties of the composite as compared to HDPE. Microscopic tests were carried out to observe of the fractured planes of the specimens and the fracture mechanism was identified.

CONTENTS

CHAPTER 1

INTRODUCTION

1-1. Plastics and Composites

Plastics have become a universal material, used for everything from throwaway bags to wings for combat aircraft. Plastics are cheap, lightweight, strong, often attractive, and can be synthesized with a wide range of properties.

Plastics have become major design materials of the 21st century and they are increasingly shaping the objects we use and rely on every day. Compared to the long established technologies of wood, metal, glass and ceramics, the plastics industry is a late arrival, but it now enjoys a well-documented history and design in plastics has evolved its own distinctive industrial aesthetic. Traditionally associated with shiny, rounded shapes and gaudy colors, objects made of plastic now have more refined forms, sharper edges and softer, friendlier finishes. Where once synthetic materials were considered inferior, plastic is now the preferred material for many of the products, which have become essential to modern living. Examples include the shatterproof fizzy drinks bottle, the smart card, the CD-ROM, the automotive fuel tank etc.

Plastics have an ever-widening range of uses in both the industrial and consumer sectors. In industry, advanced plastics and composites are everywhere replacing metal components in processes from food production to nuclear reprocessing. Plastics have revolutionized the sports goods, household appliance and electronics industries, and tissue compatible plastics, notably carbon fiber and PTFE, have made a great impact on the design of medical equipment and prostheses.

"Polyethylene (PE)", sometimes known as "polythene", was discovered in 1933 by the Reginald Gibson and Eric Fawcett at the British industrial giant Imperial Chemical Industries (ICI). PEs are cheap, flexible, durable, and chemically resistant. This material evolved into two forms, "Low Density Polyethylene (LDPE)", and "High Density Polyethylene (HDPE)".

The packing industry is a leading user of plastics. Much LDPE (low-density polyethene) is marketed in rolls of cling film. High-density polyethene (HPDE) is used for some thicker plastic films, such as those used for plastic waste bags and containers, i.e., milk, water and juice containers, grocery bags, toys, liquid detergent bottles. HDPE is used for pipes. Copolymer HDPE, pigmented with a variety of colorants, is used for packaging toiletries, detergents and similar products.

In Bangladesh, HDPE is imported from Korea, India, Thailand, Australia, Japan, and Indonesia. Here Polyethylene is an important packaging material used when exporting ready-made garments and other exported items. REB using washer, anchor lock, meter board and electric spool which are locally made with plastics. In the kitchens there are bowls, small sieves, jars, mugs, jugs, spoons, basket, bucket, thermo-flask, water tank, chairs, stools, hangers. The beverage companies are facilitated by introducing the PET bottles replacing the glass bottles. Smaller companies outsource the PET bottles from the manufacturers, while some larger companies have setup their own PET bottle manufacturing plant. The cosmetic industries use blow-molded bottles for talcum powder, shampoo, laminated tube for toothpaste. Bangladesh Biman is facilitated by the local plastic industry by buying from the onetime use crockery items like coffee cup, tray etc. for their catering service. Other than these ballpoint pen is manufactured by plastics and it is used in various place.

Plastics are the materials of past, present, and future generations. With all the superior attributes of plastics, there are some of the difficulties associated with

the material. So plastics continue to be improved. To improve the mechanical properties filler materials are used for reinforcement to make composite materials. Composites have strength and stability comparable to that of metals but generally with less weight.

Plastic composites have been in use for long due to their lightweight, high specific strength and improved performance under stringent physical, chemical and environmental conditions. The use of composites in all products - from sporting goods to bridges to satellitos - is increasing. The essence of plastic composite materials technology is the ability to put strong stiff fibers or other fillers in resin, in the right place, in the right orientation with the right volume fraction. With the range of inherent characteristics of polymeric material and the possible modifications from fillers, reinforcements, and additives, the chemical and engineering potential of plastics and elastomers is limitless.

The individual materials that make up composites are called *constituents*. Most composites have two constituent materials: a binder or *matrix*, and a reinforcement. The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite its good properties. Reinforcements basically come in three forms: *particulate*, *discontinuous fiber*, and *continuous fiber*.

Fiber-matrix interfacial properties are very important in the mechanical properties of the composite. Fiber-reinforcement composites transmit the external load from the matrix to the fiber through the interface between the fiber and the matrix.

Continuous fibers are used in most high performance components. If long fiber is used to make composite then the fracture of the composite would need more energy and thus the energy absorption would be increased. With the increase in the energy absorption capacity, the resistanco to deformation would be increased.

Composite properties are best in the direction of the fibers. The most efficient composites have most of their fibers oriented in the primary load direction, and just enough fibers oriented in the other directions to carry secondary loads and hold the structure together.

Comparing to other types of composites natural fiber composites enjoy excellent potential as wood substitutes in building industry in view of their low cost, easy availability, saving in energy and pollution free production. In order to improve upon the laboratory-industry linkages towards application development & commercialization, the Advanced Composites Mission launched the projects on jute composites such as 'Jute-Coir Composites Boards', 'Jute-glass composite components for railway coaches', ' Thermoplastic composites based synthetic wood' and others.

The jute composites may be used in everyday applications such as lampshades, suitcases, paperweights, helmets, shower and bath units. They are also used for covers of electrical appliances, pipes, post-boxes, roof tiles, grain storage silos, panels for partition & false ceilings, bio-gas containers and in the construction of low cost, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes etc.

As there are many types of plastics, in this project work High Density Polyethylene has been selected with its composite reinforced by jute fibers, to know and compare the mechanical properties and also to identify the fracture mechanism. There are several reasons to select HDPE. It is widely used. It is a thermoplastic material, which, once formed, can be heated and reformed over and over again. This property allows for easy processing and facilitates recycling. It is a rugged material, which is easy to mould, has a high resistence to impact and is not affected by most chemicals. HDPE objects are products of the injection molding process.

1-2. Literature Review

Considerable works have been done on jute fiber reinforced polymeric composites [1-4]. Polyester resin forms an intimate bond with jute fibers up to a maximum fiber : resin ratio (volume/volume) of 60:40. At this volume fraction, the Youngs modulus of the composite is approximately 35 GN/m^2. For higher volume fraction of fiber, the quantity of resin is insufficient to wet fibers completely [5].

IIT-Delhi has been quite active in developing jute-based geo-textiles for applications in prevention of soil erosion, leaching etc. CGCRI - Calcutta has worked on jute-glass hybrid components for cost reduction without sacrificing the mechanical properties [6].

Phenolic resins is one of the first synthetic resin exploited commercially for fabrication of jute-composite products mainly because of its high heat resistance, low smoke emissions excellent fire retardanca properties and compatibility with jute fibers. Phenol-formaldehyde based jute composites products have been used for quite sometimes as wood & ceramic substitutes. Today, where costs & performance have a high impact on economics, phenolic resins have been accepted in many high performance applications in composite materials. Compression molding of cemposites based on jute-phenolic system has been commonly practiced since few decades. In this process, jute is impregnated with the phenolic resin by spraying process followed by drying under hot air drier. These pre-impregnated jute leyers are arranged together for desired thickness and compression molded et high pressure of 700-800 kg/m^2 and at temperature of eround 120-140^0 C [7,8]

Polymeric coating of jute fiber with phenol-formaldehyde or resorcinol formaldehyde resins by different epproaches are highly effective in enhancing the reinforcing character of jute fiber, giving as high as 20-40% improvements in flexural strength end 40-60% improvements in flexural modulus. These

modifications improve the fiber-matrix resin wettability and lead to improved bonding [7,8].

A report from the National Institute of Research on Jute and Allied Fiber Technology (NIRJAFT), Calcutta [9] reveals that, usually for molded jute composites with polyester resin, the resin intake can be maximum up to 40%. Both hot press molding and hand lay-up technique can be used for its fabrication. In the latter process, the resin take up may go up to 300-400 % on the basis of jute fiber used which is not economical. Also, it is seen that some pre-processing of jute/treatment of fiber is required so that the interface problem could be solved. Generally, when unsaturated polyester resin is used with glass fiber, the ratio maintained is 2.5:1. Whereas, for resin with jute, the ratio maintained is 3.5-4:1. However, increase in temperature increases the productivity. Even with unsaturated polyester resin, hot condition impregnation is usually done for higher productivity. Pavithran et al [10] found that higher cellulose content and lower micro fibril angle resulted in higher work of fracture in impact testing.

In order to overcome the poor adhesion between resin matrix and jute fibers, a multifunctional resin like polyesteramide polyol has reportedly been used as an interfacial agent. Significant improvement in mechanical properties of jute fiber composites was observed by incorporation of polyester amide polyol. Also, hybrid composites of glass at surface and treated jute fiber at inner core can be a good alternative [11,12].

1-3. Objectives of the Present Work

The main objective of the present work is to make experimental investigation of the mechanical properties, energy absorption and fracture mechanism of High Density Polyethylene and its composite reinforced by jute fiber.

The scopes of the present work are

i. fabrication of HDPE specimens and its composite specimens

and analysis of data by

i. testing the properties of the specimens using universal testing machine
ii. analyzing load-displacement diagram and data
iii. analyzing tensile stress-strain diagram and data
iv. comparing the energy absorption capacity of the specimens

and observation of the fractured plane of the specimens microscopically and identify the fracture mechanism according to the results of the microscopic test.

CHAPTER 2

MATERIALS USED FOR EXPERIMENTAL INVESTIGATION

2-1. Materials Used

High Density Polyethylene was used to produce the specimen matrix. Jute fiber was employed as the filler material for reinforcement. The present work, which is a very beginning one concerning reinforcement of jute fiber in HDPE resin matrix, is lack of investigating on the various features and properties of jute fiber and commercially used HDPE. Further work may include the necessary properties through experimental investigation and micro-mechanics.

2-2. High Density Polyethylene

High Density Polyethylene (HDPE) is naturally milky white in appearance. It is a crystalline plastic which means polymers arranged in a regular order. HDPE is a rolatively straight chain structure, but, as its name implies, exhibits a higher density. The chemical nature of a HDPE is defined by the monomer that makes up the chain of the polymer. It is a polyolefin; its monomer unit is ethene (formerly called ethylene). It appears in crystalline structure, which is produced by addition polymerization process. Addition polymerization is comprised of three basic steps: initiation, propagation, and termination. During the initiation phase of the polymerization of polyethylene, the double bonds in the ethylene "mers" break and begin to bond together. A catalyst or promoter may be necessary to begin or speed up the reaction. The second phase, propagation, involves the continued addition of monomers together into chains.

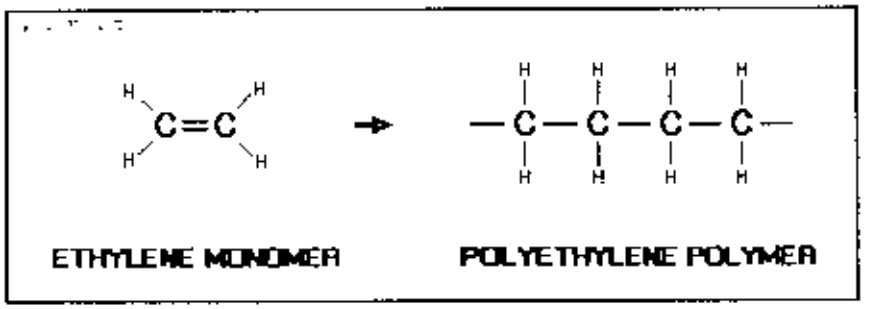


Fig. 2(a) Chain structures of ethylene monomer and polyethylene polymer [13]

The final step is termination. During termination all monomers may be used, causing the reaction to cease. A polymerization reaction can cease by quenching the reaction. Similar to quenching someone's thirst, water can be used to quickly cool a reaction. Very simply, addition polymerization describes the process of "mers" joining by each one adding on to the end of the last "mer." A simple visual of the process is paper clips joined together to form a long chain.

HDPE is flexible, translucent/waxy, weatherproof, easy to process by most methods, low cost, melt process-able, have good toughness and stiffness, permeability to gas, good corrosion, abrasion, and chemical resistance, and lightweight. The properties of HDPE depends upon the chemical system used, cure condition, specification of cure agent, cure schedule (rate and amount of hardener appropriate to the resin, temperature, duration and control of curing processes), perfection of operation and length and quality of the linking network.

The HDPE material used in this work is of Injection type, Grade: HMA 016, imported from Saudi Arabia. It is commercially used in our local market.

2-3. Jute Fiber

Polymeric composites reinforced by glass fibers have been replacing metals in a variety of applications in mechanical and civil engineering in the past years. Besides the conventional fiber composites there is a growing interest in plant fiber composites [2,3].

The scope for using jute fibers in place of the traditional glass fibers in different forms partly or fully as reinforcing agents in composites stems from the higher specific modulus and lower specific gravity of jute (~ 40 Pa and 1.29 respectively) compared with those of glass (~ 30 GPa and 2.5 respectively) [11].

Table 2.1 shows a comparison of selected physical and mechanical properties of some synthetic and natural (plant) fibers [1, 14].

Table 2.1 Typical Properties of Some Synthetic and Natural Fibers

Fiber Type	Density ($Mg\ m^{-3}$)	Young's modulus ($GN\ m^{-2}$)	Tensile strength ($MN\ m^{-2}$)	Failure strain (%)
Synthetic fibers				
E-glass	2.56	76	2000	2.6
High strength carbon	1.75	230	3400	3.4
Kevlar™ (aramid)	1.45	130	3000	2.3
Boron	2.6	400	4000	1
Natural fibers				
Flax	1.4-1.5	50-70	500-900	1.3-3.3
Hemp	1.48	30-60	310-750	2-4
Jute	1.4	20-55	200-450	2-3
Sisal	1.45	9-22	80-840	3-14
Cotton	1.5	6-10	300-600	6-8

The properties of jute fiber, used in this project work were not represented in the above table. It was due to the lack of authorized data about the properties of the used jute fiber. The necessary investigation about jute fiber as a reinforcing one with its composite can be done in further extension of this project.

Although the tensile strength and Young's modules of jute are lower than those of glass fibers, the specific modulus of jute fiber is superior to that of glass and on a modulus per cost basis, jute is far superior. The specific strength per unit cost of jute, too, approaches that of glass. Therefore, where high strength is not a priority, there jute fiber can be a very potential candidate in making of composites, especially for partial replacement of high-cost glass fibers without entailing the introduction of new techniques of composite fabrication. As such, commercial exploitation of jute composites for non-structural applications promises excellent potential.

Rated fibers of jute have three principal chemical constituents, namely, a - cellulose, hemi cellulose and lignin [15,16]. In addition, they contain minor constituents such as fats and waxes, inorganic (mineral) matter, nitrogenous matter and traces of pigments like b - carotene and xanthophylls. As in synthetic fiber composites, the mechanical properties of the final product depend on the individual properties of the matrix, fiber and the nature of the interface between the two. Where the fiber is an egricultural one, it is possible to tailor the end properties of the composite by selection of fibers with a given chemical or morphological composition. Several studies of fiber composition and morphology have found that cellulose content and micro fibril angle tend to control the mechanical properties of cellulosic fibers [10].

A composite has three entities that are susceptible to failure – the reinforcement, the matrix and the interface. The failure of one can initiate failure of the others, and the actual process that takes place in any particular case is determined by the stress required to activate each individual mechanism. The mechanism activated by the lowest stress will normally govern composite failure [9].

Thus, in order to increase the potential application area of jute fibers as reinforcement in composites, it is necessary to concentrate more on three major aspects (a) fiber modification (b) resin matrix and (c) coupling agents.

Jute is available in continuous forms such as yarn, mat, roving, tapes etc. In this project, roving type jute fiber was used for fabricating the HDPE composite specimens. Roving is the slightly twisted strand of many long fibers together. Roving used here are approximately of 01 mm in normal condition (slight twist), less than 01mm in twisted condition. Figure 2(b) shows the jute fiber roving used as reinforcement.

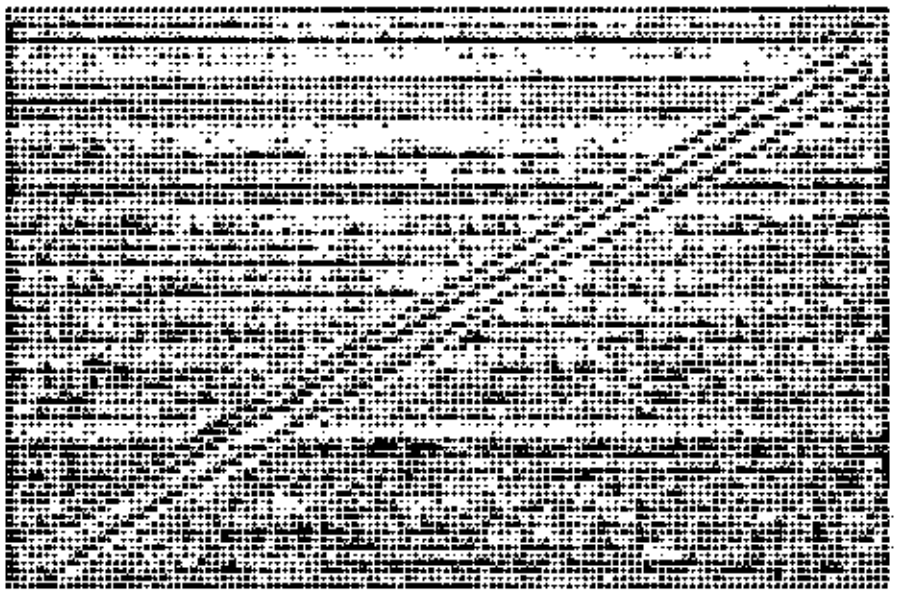


Fig. 2(b) Jute Fiber Roving used in this Project

CHAPTER 3

FABRICATION AND TEST OF THE SPECIMENS

3-1. Fabrication of the Specimen

A schematic diagram of the HDPE specimen matrix with necessary dimensions is shown in figure 3.1. The specimen is 271 mm long and 27 mm wide. The neck/mid portion is 18 mm wide having a gauge length of 90.6 mm. The thickness of the specimen is 3.99 mm. A designed mild steel die was used to fabricate the specimens.

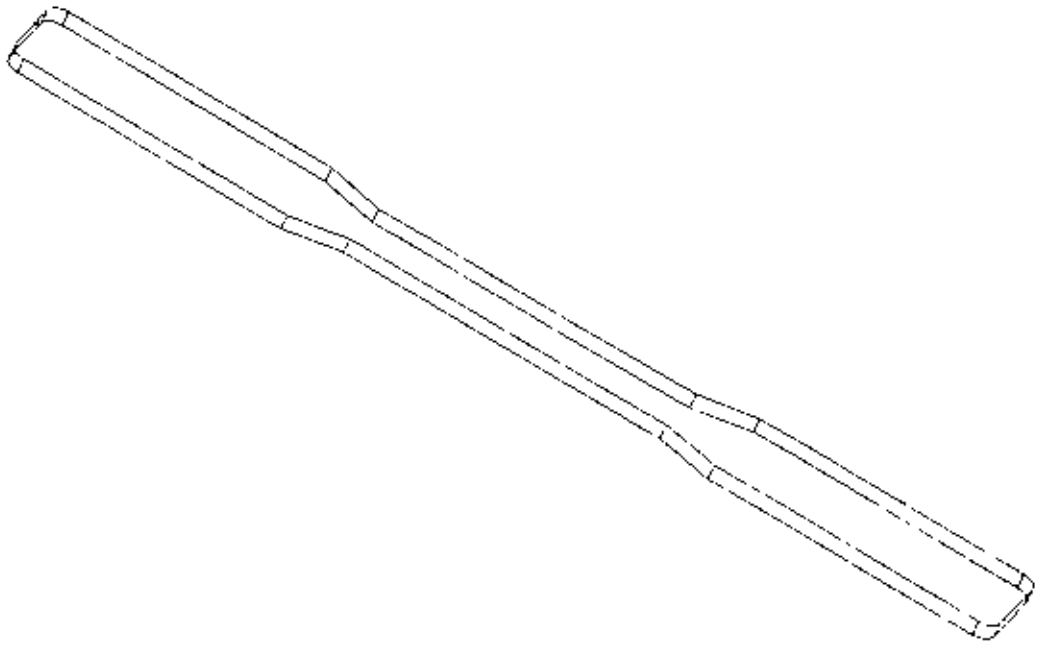


Fig. 3.1 (a). Isometric View

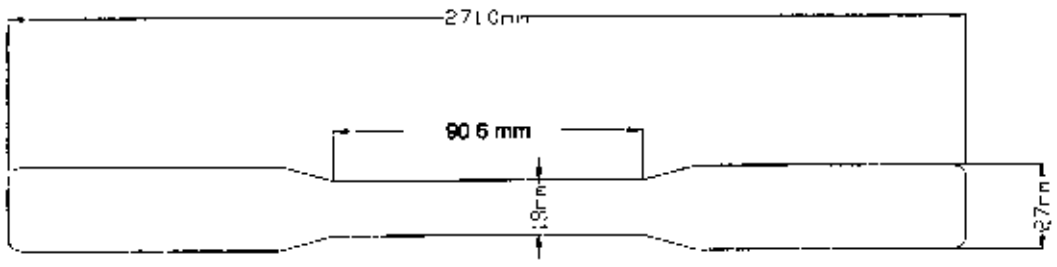


Fig. 3.1 (b). Top View

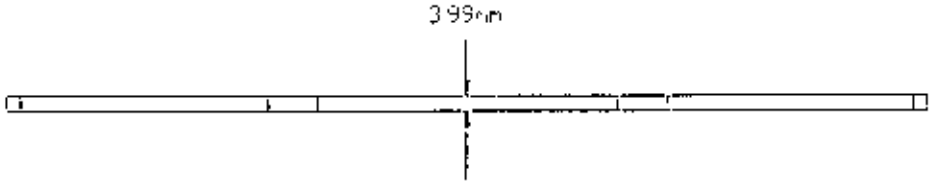


Fig. 3.1 (c). Front View

Fig. 3.1 Different Views of the HDPE Specimen Matrix

Figure 3.2 represents the schematic diagram of the HDPE composite specimen reinforced by jute fibers and shows how jute roving is set in the die (mold).

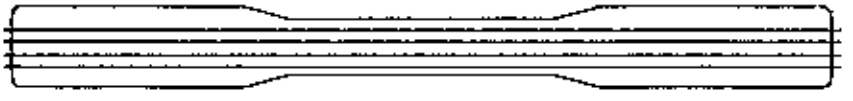


Fig. 3.2 HDPE Composite Specimen Reinforced by Jute Fibers

3-2. Manufacture of the HDPE Specimens

The manufacture of plastic and plastic products involves procuring the raw materials, synthesizing the basic polymer, compounding the polymer into a material useful for fabrication, and molding or shaping the plastic into its final form. Injection molding process was used to fabricate the specimen. Here hand injection machine was used to manufacture the specimens. Machine capacity was 01 ounce. The variations, in small content, in the dimensions of the specimens are due to the manual operation of the machine. The material, after heated, is injected into the mold by manually rotating the wheel.

Figure 3.3 shows the picture of hand injection molding machine.

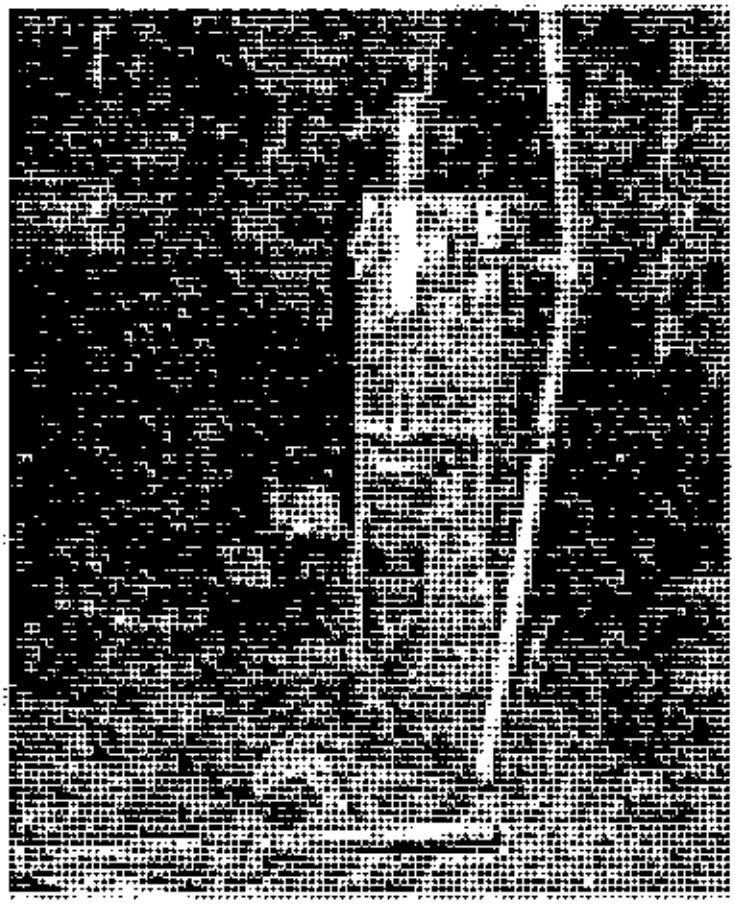


Fig. 3.3 Hand Injection Molding Machine

In this machine at first the die is set in the position (A). High Density Polyethylene is supplied in the form of pellets. The pellets are fed through the cylinder throat into the cylinder/heating chamber (B). The cylinder is where all the real work is done and it's essentially an electric coil spiraled outside of the cylinder. The electric coil gives heat to the material inside the heating chamber when connected to the power source. Then the HDPE is heated to form the liquid within minutes. The manual rotating wheel (C) is used to compress, and convey the material under pressure. As the wheel rotates, it gives the pressure to the liquid form of HDPE to get poured to the mold. The tip of the cylinder is called the "nozzle". Hot, molten HDPE is forced to inject under pressure into the cold mold through the nozzle. Then the die is set out and the shaped material is removed from the mold immediately after the part cooled and solidified. No chemical reaction occurs during the molding process.

Forty specimens of HDPE matrix of required dimensions have been manufactured for the tensile test. Figure 3.4 shows the picture of a manufactured HDPE resin matrix speciman.

Fig. 3.4 The Manufactured HDPE Resin Matrix Specimen

3-3. Fabrication of the HDPE Composite Specimens

Long jute roving are straightly set in the longitudinal direction of the die along the length of the specimen, as shown earlier in the figure 3.2. Then HDPE is compressed and injected manually by the hand injection machine. The numbers of jute ropes set in various specimens are randomly selected having a range 5 to 6, for a variety of observations.

It was observed after manufacture, one or two roving were torn out in some cases. The torn-out pieces were not counted. In section 3-4-1, Table 3.2 lists the number of undisturbed jute pieces in each specimen tested. It may be mentioned here that the quality of the manufactured composite specimens was not good due to the lack of advanced manufacturing technology.

Figure 3.5 shows the picture of a manufactured composite specimen.

Fig. 3.5 The Manufactured HDPE Composite Specimen

3-4. Experimental Procedure and Conditions

Tensile test was carried out to determine the mechanical properties of the specimens under uniaxial tensile loading and to understand the mechanisms of deformation and the mode of failure. Tensile test method is designed to produce tensile property data for the control and specifications of plastic materials [17]. These data are also useful for qualitative characterization and for the research & development. Tensile properties may provide useful data for plastics engineering design purposes. By gripping the ends of a thin, dog-bone shaped specimen (see Figure 3.1) with a pair of crosshead grips and pulling at a constant speed, mechanical properties can be determined. Five specimens of HDPE resin matrix and three specimens of HDPE composite matrix were tested.

A SHIMADZU UTM 500 KN having a lowest limit of 10 KN with proper capacity and appropriate attachments wes used to carry out the tensile test. The crosshead speed wes kept constant at 2 mm/min. Each specimen was loaded into the grips of the testing machine, taking care to align the long axis of the specimen and the automated testing program initiated. The material, thickness, and width of each specimen tested was carefully recorded and input into the Shimadzu program when prompted by the software. The major dimensions are outlined in table 3.1 and table 3.2. Close attention was paid to the specimen, noting the different stages of deformation The response of the load and the displacement was measured and recorded automatically in the computer by a "load cell," which is attached to the crosshead and connected to a CPU. The raw data was saved on the computer in a .txt file. This was later imported into Excel to obtain plots of load vs. displacement and stress vs strain.

3-4-1. Dimensions of Test Specimens

The width and thickness of each specimen tested were measured with a micrometer at several points along the gauge length. The effective representative dimensions of the test specimens, which have been tested, are shown in table 3.1.

Table 3.1 Dimensions of HDPE Specimens

Sample No	Total Length (mm)	Gauge Length (mm)	Thickness (mm)			Average Thickness (mm)
A01	271	90.6	4.013	3.962	3.988	3.990
A02	271	90.6	4.039	4.013	3.988	4.013
A03	271	90.6	4.013	3.861	3.886	3.920
A07	272	90.6	4.140	4.064	4.089	4.098
A13	273	90.6	4.140	4.064	4.115	4.163

Table 3.1 shows that the average thickness is not always the same. The actual theoretical thickness of the designed specimen is 3.99 mm. As the process was done manually, the injection pressure may not always the same, exact required amount of material may not be poured and the material may not removed from the mold at the exact time, before it cooled and solidified. So, the average thickness varies

Here in all the specimens, the gauge length remains the same. It is 90.6 mm. Width is also same. It is 27 mm (major) and 18 mm (neck).

The effective dimensions of the composite specimens tested with comments on the embedding criteria of the jute roving in the HDPE specimens, as observed after manufacturing, are shown in table 3.2.

Table 3.2 HDPE Composite Specimens Reinforced by Jute Fiber

Sample No.	Length (mm)	Thickness (mm)	Average Thickness (mm)	Lowest Thickness (mm)	No of Jute Roving	Comments
B02	274	4.191 4.166 4.115	4.157	4.115	5	One roving was embedded well; three roving were on one surface and one roving on other, along the edge These were partially embedded.
B04	275	4.116 4.166 4.140	4.157	4.140	6	Four roving were on one surface; among them two roving were diagonally set, other two on the opposite side. All the roving were partially embedded.
B09	275	4.140 4.115 4.089	4.115	4.115	6	Four roving were on one side, among them one along the middle and two roving on other side. All of them were partially embedded.

Table 3.2 also shows an increase in average thickness. The possible causes for the variation in dimensions have been discussed earlier, while observing HDPE specimens. Here also the gauge length and the width are same as in the HDPE specimens.

The pieces of jute roving have not been found well embedded in HDPE. Due to the pressure of liquid material while pouring into the mold, long jute roving have been floated on the surface of the specimen, and consequently partially embedded.

CHAPTER 4

FRACTURE MECHANISM

4-1. Appearance of the Fractured Specimens

Figure 4.1 represents a HDPE specimen matrix after failure. The specimen in the figure shows a brittle failure. All the specimens showed brittle failure, as observed. Brittle fracture occurred with little or no plastic deformation.

Fig. 4.1 A HDPE Specimen Matrix After Failure

The figures 4.2, 4 3 and 4.4 shows the appearance of the composite specimens tested namely B02, B04 and B09 respectively after the failure. The fractured composite specimens indicate that the fiber failure does not always occur in the crack plane because of the statistical distribution of the surface flaws and fiber orientation. In some instances multiple cracks are formed in the matrix normal to the fiber direction [18]. The reasons below the fracture phenomenon of the composite specimens represented in these figures have been discussed later in this thesis.

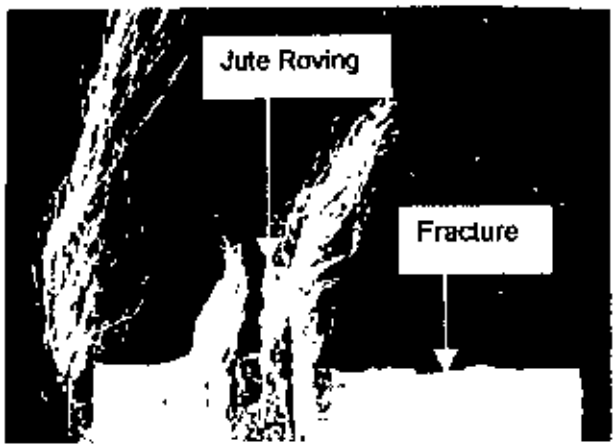


Fig. 4.2 Composite Specimen B02 After Failure

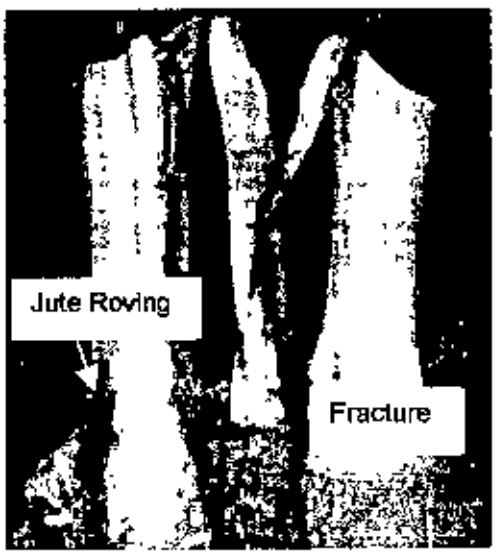


Fig. 4.3 Composite Specimen B04 After Failure

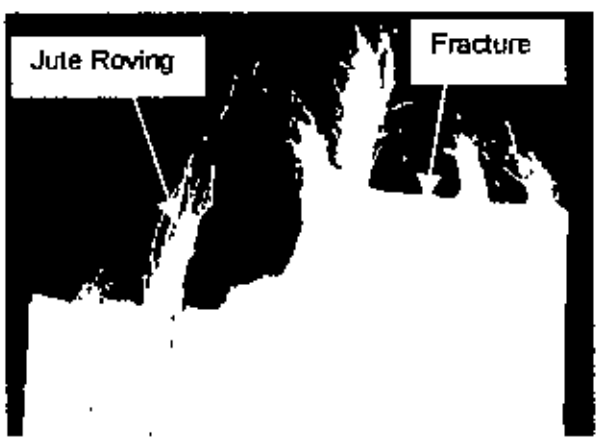


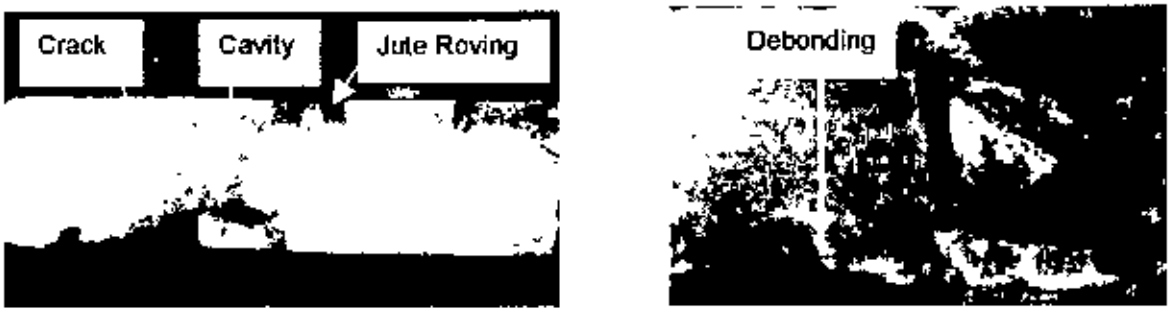
Fig. 4.4 Composite Specimen B09 After Failure

4-2. Microscopic Test

Microscopic tests were carried out to observe the fracture mechanism of the HDPE specimens and its composites. Figure 4.5 and 4.6 show the microscopic views of the fractured specimens of HDPE and composite specimen respectively, where (a) represents the top view and (b) represents the zoom view (magnification X20).

(a) (b)

Fig. 4.5 Microscopic View of a Fractured HDPE Specimen (a) & (b)



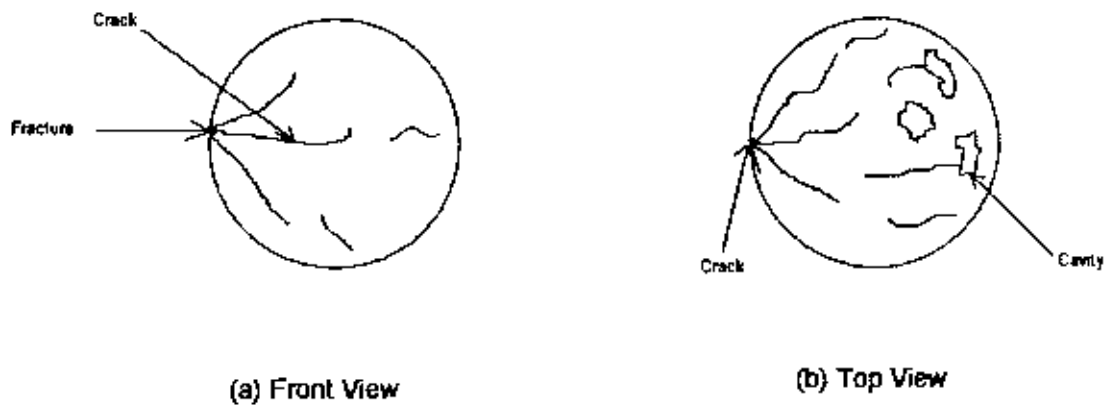
(a) (b)

Fig. 4.6 Microscopic View of a Fractured HDPE Composite Specimen (a) & (b)

From the microscopic views of the fractured specimens it was observed that crack was initiated and cavity was formed in all the cases. High stress concentration and shrinkage cause some portions of the specimen to be hard. As crack is propagated in these directions, cavity is formed. In case of composite, the matrix crack grows around the fiber and the fiber-matrix interface is debonded due to high interfacial shear stresses before the fiber failure. High fiber strength and low interfacial strength promote debonding over the fiber tensile failure [18].

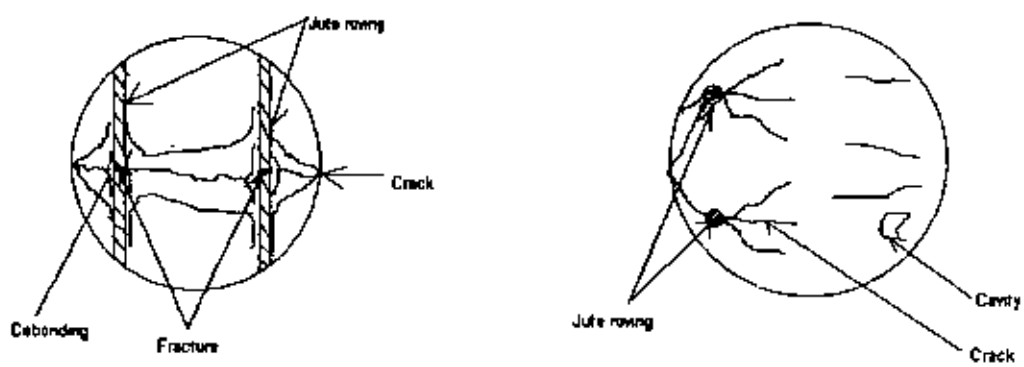
4-3. Identification of Fracture Mechanism of HDPE and its Composites

With careful observation of the fractured planes of the specimens microscopically, the fracture mechanism is identified here considering the results of the microscopic test.



(a) Front View (b) Top View

Fig. 4.7 Fracture Mechanism of HDPE



(a) Front View (b) Top View

Fig. 4.8 Fracture Mechanism of HDPE Composite

CHAPTER 5

RESULTS AND DISCUSSION

5-1. Experimental Results

Table 5.1 and Table 5.2 represent the summaries of tensile test results of HDPE and composite specimens respectively showing the maximum load, maximum displacement, maximum stress, break load, break displacement and break stress. The mean breaking values of the table 5.2 show the average values of specimens B02 and B09 only because of having no breaking parameters for B04.

Table 5.1 Summary of the Test Results of the HDPE Specimens

Sl No.	Max. Load KN	Max. Disp. mm	Max. Stress MPa	Break Load KN	Break Disp. mm	Break Stress MPa
A01	1.082	6.153	15.0654	1.002	6.274	13.9515
A02	1.028	5.775	14.2421	1.016	5.824	14.0759
A03	0.886	3.871	12.5566	0.88	3.902	12.4716
A07	1.084	5.827	14.6883	0.89	5.858	12.0596
A13	1.486	18.521	19.845	1.44	19.906	19.2307
Mean	1.1132	8.0294	15.2795	1.0456	8.3528	14.3579

Table 5.2 Summary of the Test Results of the HDPE Composite Specimens

Sl No.	Max. Load KN	Max. Disp. mm	Max. Stress MPa	Break Load KN	Break Disp. mm	Break Stress MPa
B02	1.758	10.316	23.4775	1.632	12.824	21.7948
B04	1.824	10.21	24.3589	--	--	--
B09	1.794	9.374	24.1909	1.764	9.414	23.7864
Mean	1.792	9.96667	24.0091	1.698	11.119	22.7906

5-2. Linear Comparison

Now a table can be formulated for linear comparison of the summary of results obtained from the tensile test. Table 5.3 lists the linear compare of the mean values of both the specimens HDPE and its composite for all the six parameters, with average direct increase and percentile increase.

Table 5.3 Linear Comparison of HDPE with its Composite

Material Specimens	Mean Values					
	Max. Load KN	Max. Disp. mm	Max. Stress MPa	Break Load KN	Break Disp. mm	Break Stress MPa
HDPE	1.1132	8 0294	15.2795	1.0456	08.3528	14.3579
Composite	1.7920	9.9667	24.0091	1.6980	11.1190	22.7906
Direct Increase	0.6788	1.9369	8 7296	0.6524	02.7662	8.4327
% Increase	60.98	24.1226	57.1328	62.3948	33.117	58.7321

Table 5.3 allows a closer look and confirms that HDPE composite specimens give a higher value of all the parameters, than that of the HDPE specimens. Percentile increase is calculated in all the six parameters, of the composite with respect to that of the HDPE. Average direct increase shows a linear increase in the values of composite specimens, for all the parameters than that of HDPE specimens. Maximum and break load show an increase over 60%, also the stresses are nearer to that. Increases in maximum and breaking displacement are also significant. So far, it has been found that composite shows better performance, as expected.

5-3. Load-Displacement and Stress-Strain Diagrams

The following figures represent the load vs. displacement and stress vs. strain diagrams for all the specimens tested.

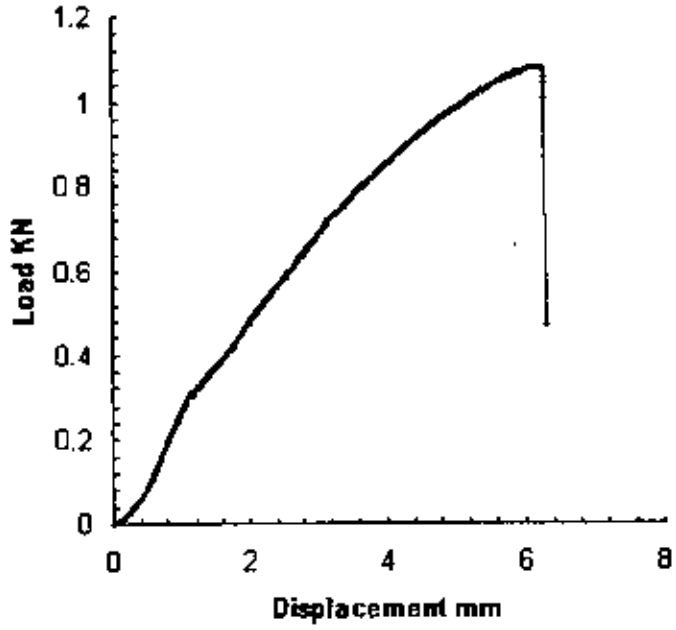


Fig. 5.1(a). Load-Displacement Diagram of the HDPE Specimen A01

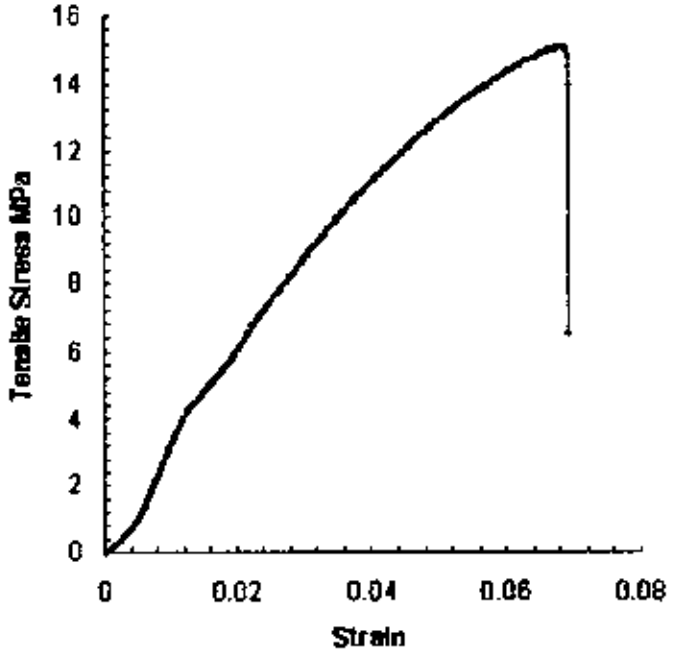


Fig. 5.1(b). Tensile Stress-Strain Diagram of the HDPE Specimen A01

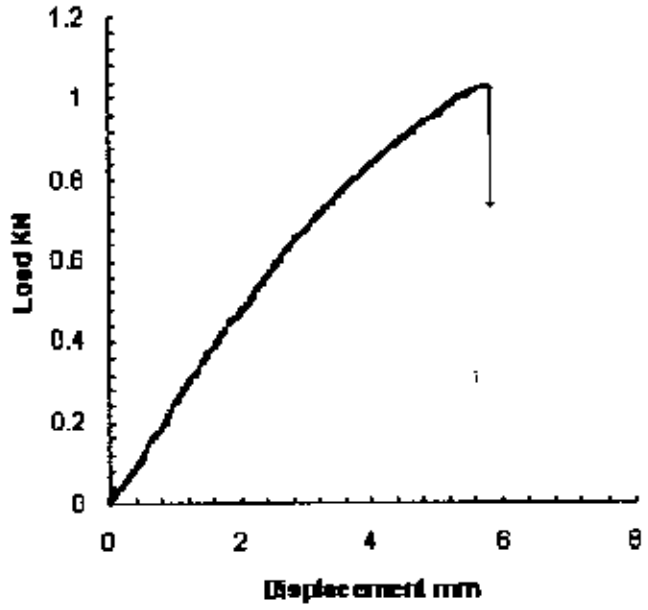


Fig. 5.2(a). Load-Displacement Diagram of the HDPE Specimen A02

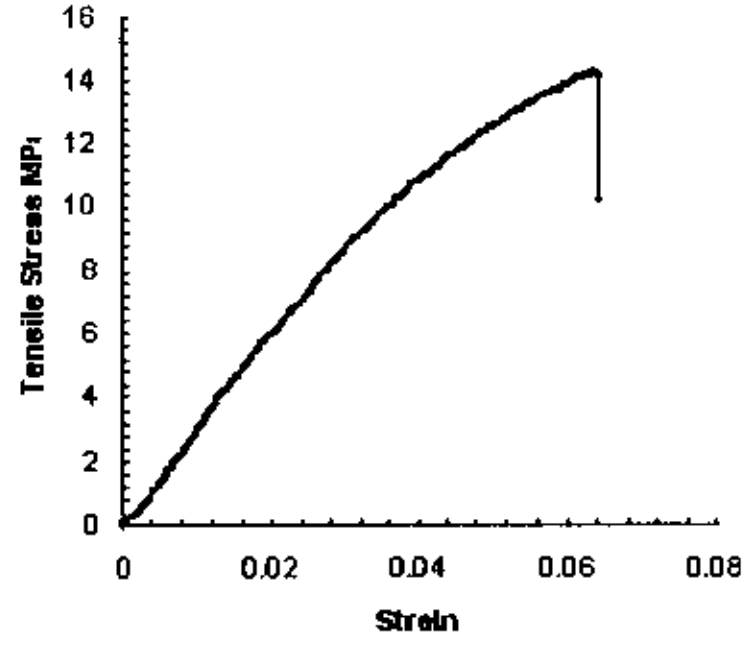


Fig. 5.2(b). Tensile Stress-Strain Diegram of the HDPE Specimen A02

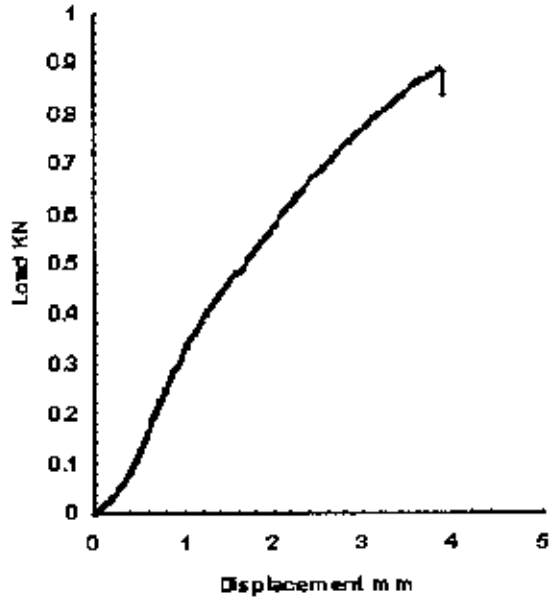


Fig. 5.3(a). Load-Displacement Diagram of the HDPE Specimen A03

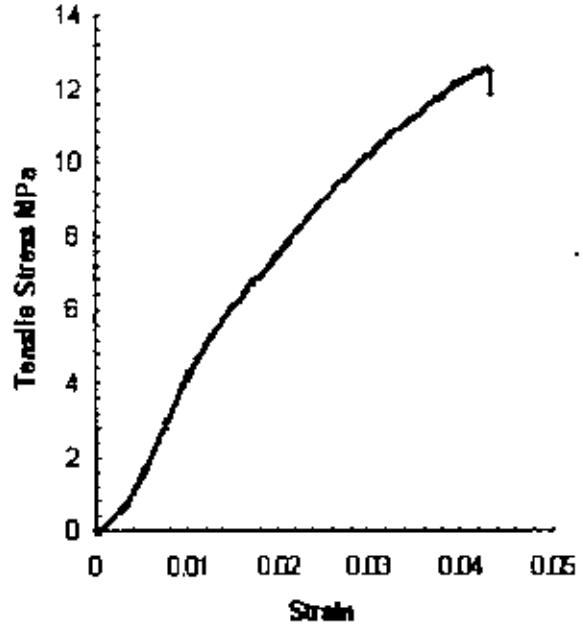


Fig. 5.3(b). Tensile Stress-Strain Diagram of the HDPE Specimen A03

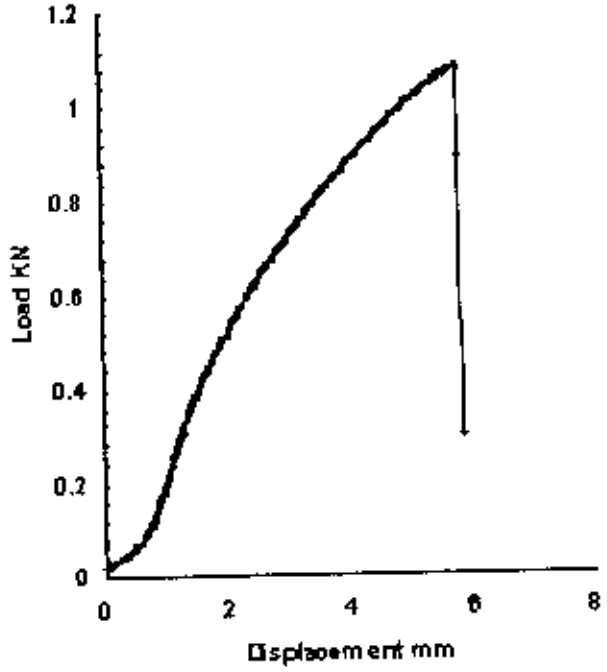


Fig. 5.4(a). Load-Displacement Diagram of the HDPE Specimen A07

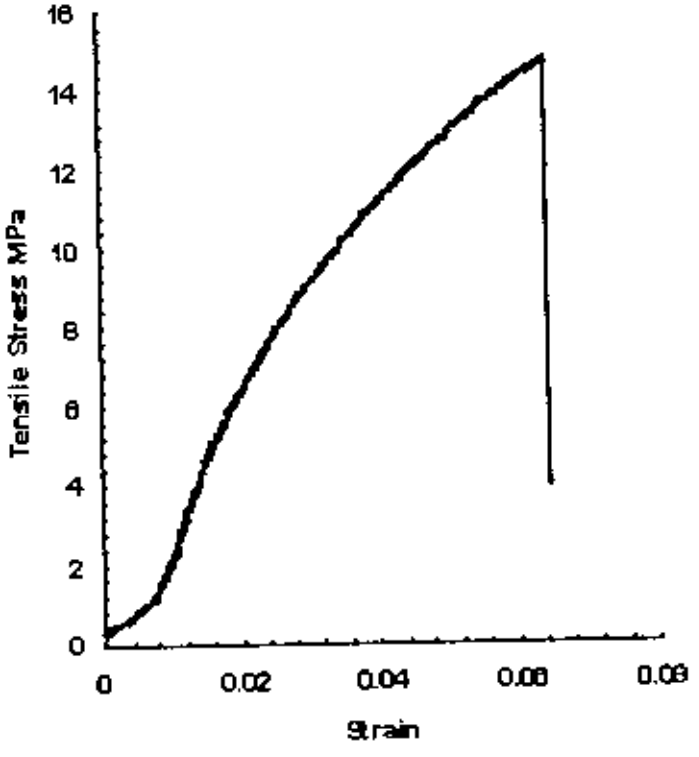


Fig. 5.4(a). Load-Displacement Diagram of the HDPE Specimen A07

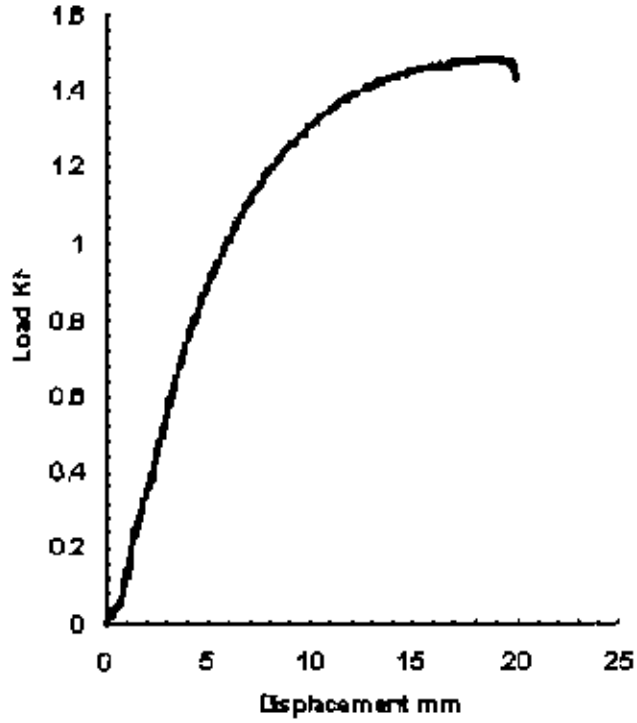


Fig. 5.5(a). Load-Displacement Diagram of the HDPE Specimen A13

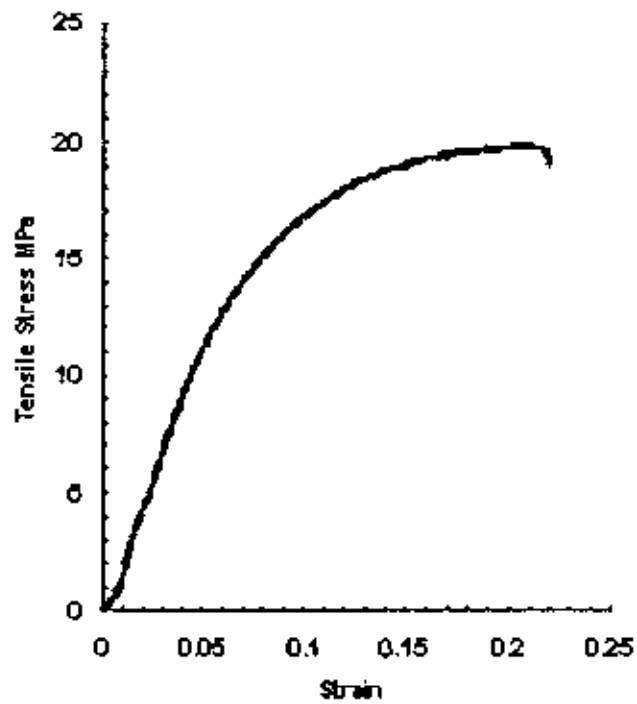


Fig. 5.5(b). Tensile Stress-Strain Diagram of the HDPE Specimen A13

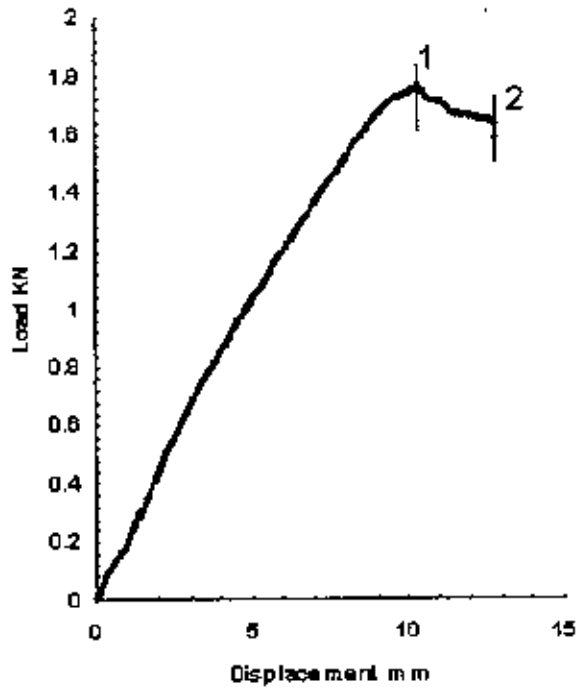


Fig. 5.6(a). Load-Displacement Diagram of the HDPE Composite Specimen B02

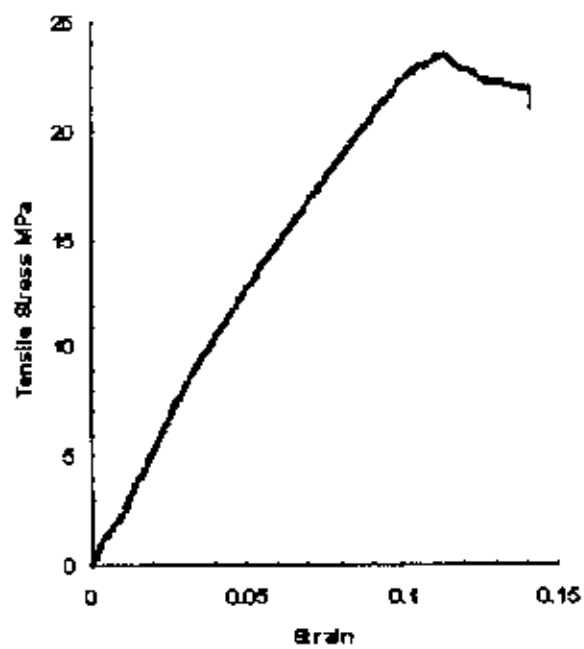


Fig. 5.6(b). Tensile Stress-Strain Diagram of the HDPE Composite Specimen B02

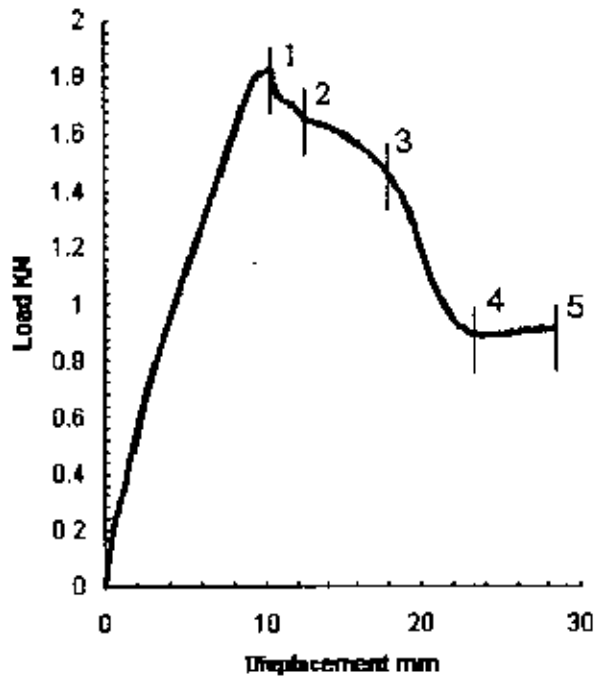


Fig. 5.7(a). Load-Displacement Diagram of the HDPE Composite Specimen B04

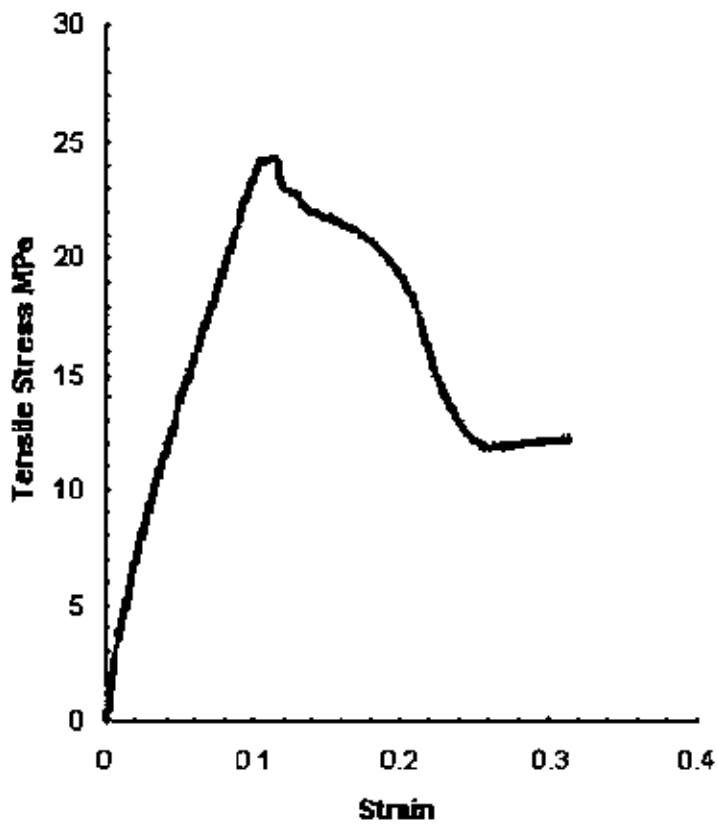


Fig. 5.7(b). Tensile Stress-Strain Diagram of the HDPE Composite Specimen B04

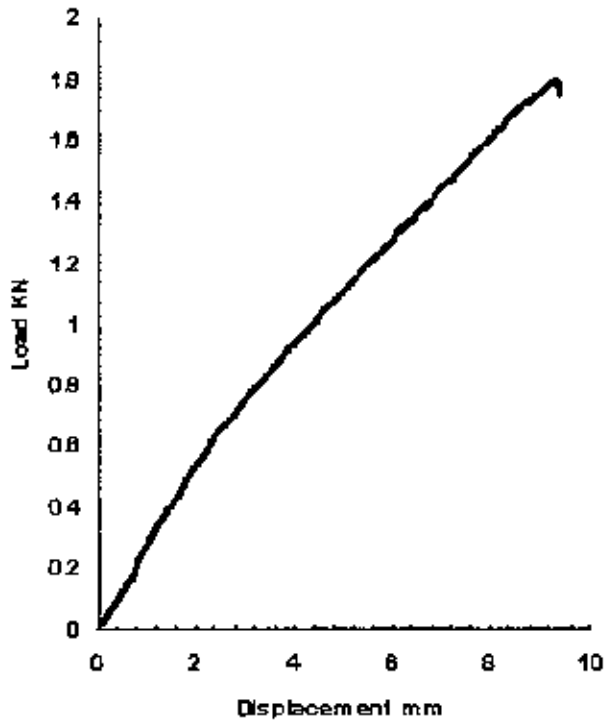


Fig. 5.8(a). Load-Displacement Diagram of the HDPE Composite Specimen B09

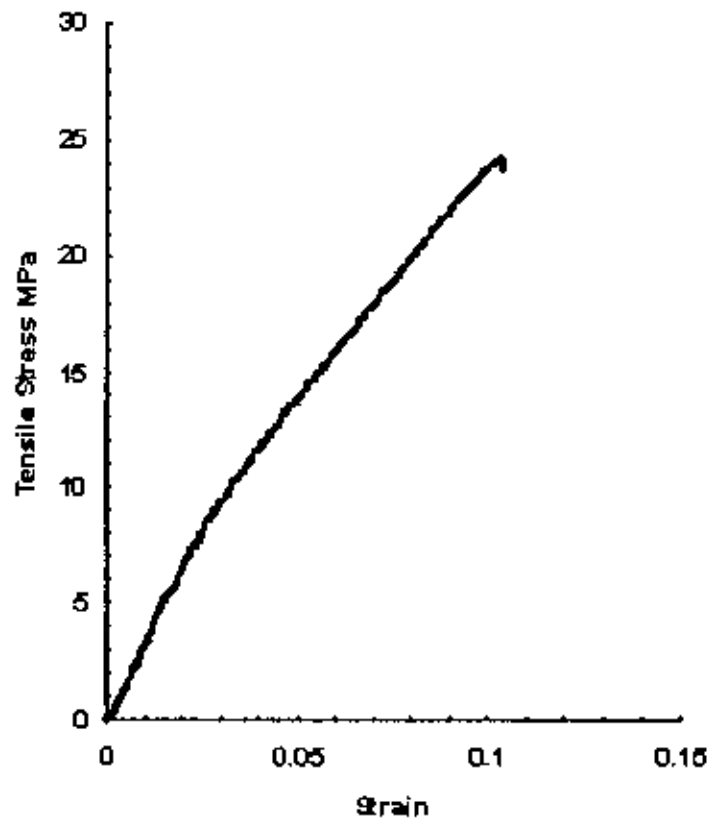


Fig. 5.8(b). Tensile Stress-Strain Diagram of the HDPE Composite Specimen B09

5-4. Discussion

The mechanical properties are extremely important and useful in choosing a material for a particular application. Depending upon the results of the tests, mechanical properties were established and also discussed for further research and improvement. Tensile test was carried out for different High Density Polyethylene specimens and its composite specimens reinforced by jute fiber. The summaries of the test results were represented in table 5.1 and 5.2; a linear comparison was done in table 5.3. It was observed that the max. load, max displacement, max. stress, break load, break displacement, break stress were increased in the composite specimens than that of the HDPE specimens.

Specimen A13 shows the highest values of parameters for the HDPE specimens and specimen B04 also shows the highest values for the composite specimens. A reason behind this may be as all of the specimens were manufactured manually, there might be some variation in the pressure, temperature and pouring rate, so there might be some change in the properties and the fiber orientation were not maintained exactly as desired for the same reason.

The tensile stress and strain were calculated by using the test results. Stress σ (MPa) was determined by dividing load (KN) by cross-sectional area and strain ε (mm/mm) was determined by dividing displacement (mm) by the gauge length of the specimen (mm).

The values of the tensile loads were plotted against the values of the corresponding displacements with the ordinate representing the load and the ebscissa representing the displacemant. Displacement is the distance the crosshead travels. Similarly the values of tensile stress were also plotted as ordinates against the corresponding values of tensile strain as abscissas. The load-displacement curve and the tensile stress-strain curve were approximately linear.

Figure 5-1 to 5-8 show the typical failure process of High Density Polyethylene resin matrix and its composite reinforced by jute fiber under tensile loading. All the curves are almost identical to that of the typical ones. In the load-displacement diagram of all the HDPE specimens and the composite specimon B09, it was found that the load increased gradually in a approximately linear rate with the displacement, up to a certain point, i.e., peak load, and after then dropped suddenly, i.e., fractured. So the specimens showed a brittle like fracture behavior. The appearance of the specimens showed that they were divided into two portions just exceeding the peak load. Thus after failure, the specimens would have no displacement with respect to load.

Figure 5.7 for specimen B04 show that after the load reaches its peak value then there is a zigzag decline. For easy explanation, the curve is divided into five segments. At load level of segment 1, the load was within the proportional limit up to a fixed point, and then the curve started to deviate from linearity and increase up to the peak load in segment 1. At load level of segment 1 to 4, beyond the peak load, the load shows a zigzag decline with the displacement. From load level of segments 4 to 5 the load remains constant with increasing displacement. After then fracture occurs. Here initiation of micro crack was observed in the in the middle portion of the gauge length. Plastic deformation (micro yielding) occurred in the matrix and the crack started to broaden and the specimen started to fracture macroscopically without dividing into two portions as represented in figure 4.3. The cause behind this behavior is the reinforcement and embedding criteria of jute fibers.

It was observed that the jute roving were not reinforced to a significant level due to manual operation. But, embedding of jute fibers in B02 and B04 was better than that in B09. In case of B09, all the roving were slightly embedded; almost floated to the surface due to the pressure of liquid HDPE while making composite specimen. Figure 4.4 shows the fractured specimen B09. But in case of B02 and

B04, two and three pieces of ropes, respectively, were embedded well into HDPE. Hence gave a better sustain.

Figure 5.6 of specimen B02 also shows that after attaining the peak load, the load decreases gradually with the displacement from segment 1 to 2, and then fails. The appearance of the fractured specimen B02 is represented in figure 4.2. This behavior shows no significant plastic deformation that result in ductile failure. In brittle fracture, a little plastic deformation may occur, but ductile fracture is characterized by plastic deformation.

The decreasing criterion, after the maximum sustain, of the load-displacement curves of the both specimens, B02 and B04, argues that, though, crack is generated immediately after the peak load value, the rate of crack propagation time is much slower than that of HDPE specimen. And this is due to the reinforcement of jute fibers. Hence show a more sustain rather breaking. And the cause of decline is that the specimen has already started cracking.

So the composite materials have better sustain capacity than HDPE specimens, because of the fibers. A composite specimen does not fracture totally until all the pieces of jute ropes break. As soon as they reach the maximum sustain, HDPE specimens break within the generation of crack, killing any further time. Hence it is clear that composite material show better mechanical properties than that of the HDPE.

During the tensile test of all the composite specimens, with increasing load, it was observed that fibers continued to break randomly at various locations in the lamina. Thus broken fibers acted as a bridge between the two faces of matrix crack [18].

CHAPTER 6

ENERGY ABSORPTION

6-1. Introduction

Energy is defined as the ability or capacity to perform work. The amount of work done by any object is stored in the body as potential energy. Work depends upon the force and the force varies in proportion to the resistance encountered. Energy can neither be created nor destroyed; the resistive forces acting along within the object create internal deformations and produce an equivalent amount of internal work. If an equivalent amount of work were not developed, unrestrained motion or instability would result. The dynamic form of energy produces stresses of much greater magnitude upon impact than those produced by the same weight applied gradually. The kinetic energy of the load at impact is equivalent to the total internal energy developed inside the object to resist the external one.

A load gradually applied to an elastic body would create a gradual increase in deformation, which attains its maximum value at the time of full load (capable to hold by the specimen) application. The product of the average load applied or the transferred to the body and the deformation produced by the full load is the measure of external energy put into the body. The value of the externally applied energy is measured as the areas under the load-displacement curve. As a result of the externally applied force, energy is developed internally as the resisting forces. The internal energy developed is equal to the average force or couple times its maximum internal deformation. The internal or resisting forces must be equal to the external force.

6-2. Energy Absorbed by the Specimens

The energy absorbed by HDPE and its composite reinforced by jute fiber was calculated from the area under the curve of the tensile load with respect to the displacement. The area was calculated by integrating the polynomial equation that best fits the corresponding Load-Displacement curve from a range of 0 to maximum displacement of that specimen. The equations of the curves were established and compared by using the Microsoft Excel and the Kaleida Graph for Windows software. Trend/Regression type – Polynomoal. The highest power of X represents the order of an equation. For example, equation of the curve of the sample A01 is of order 2. Here Y represents the load and X represents the displacement. The equations corresponding to load-displacement curve and energy absorbed by the specimens are given below.

A01

$Y = -0.0188\ X^2 + 0.2969\ X - 0.035$ ($R^2 = 0.9954$)

Area = $\int_0^{15.3} Ydx = 5.40$ joule

A02

$Y = 0.0182\ X^2 + 0.2869\ X - 0.0212$ ($R^2 = 0.9987$)

Area = $\int_0^{17.78} Ydx = 5.84$ joule

A03

$Y = 0.0379\ X^2 + 0.3829\ X - 0.0361$ ($R^2 = 0.9983$)

Area = $\int_0^{8.71} Ydx = 2.73$ joule

A07

$Y = -0.0015\ X^3 - 0.0106\ X^2 + 0.301\ X - 0.0545$ ($R^2 = 0.9896$)

Area = $\int_0^{15.27} Ydx = 3.65$ joule

A13

$Y = 0.0003\ X^3 - 0.015\ X^2 + 0.2599\ X - 0.812$ ($R^2 = 0.9989$)

Area = $\int_0^{18.521} Ydx = 6.43$ joule

B02

$Y = -0.0001\ X^3 + 0.0083\ X^2 + 0.188\ X - 0.026\ (R^2 = 0.9981)$

It can also be considered by two segments. One segment is polynomial and the other is straight line.

For segment 1, $Y_1 = -0.001\ X^3 + 0.0083\ X^2 + 0.188\ X + 0.026$

For segment 2, $Y_2 = -0.0673X + 2.44$; from (10.226,1.753) to (12.828,1.578)

Area = $\int_0^{10.226} Y_1 dx + \int_{10.226}^{12.828} Y_2 dx = 14.65$ joule

B04

$Y = 0.0004\ X^3 - 0.0293\ X^2 + 0.378\ X - 0.124\ (R^2 = 0.9711)$

The curve can also be divided by five segments. One segment is polynomial and the other four are straight lines.

For segment 1, $Y_1 = 0.0004\ X^3 - 0.0239\ X^2 + 0.378\ X - 0.124$

For segment 2, $Y_2 = -0.072X + 2.562$; from (10.4, 1.808) to (12.592, 1.65)

For segment 3, $Y3 = -0.0378X + 2.125$; from (12.592, 1.65) to (18.144, 1.44)

For segment 4, $Y4 = -0.1369X + 3.923$; from (18.144, 1.44) to (21.942, 0.92)

For segment 5, $Y5 = -0.000933X + 0.94$; from (21.942, 0.92) to (28.372, 0.914)

Area = $\int_0^{10.4} Y_1 dx + \int_{10.4}^{12.592} Y_2 dx + \int_{12.592}^{18.144} Y_3 dx + \int_{18.144}^{21.942} Y_4 dx + \int_{21.942}^{28.372} Y_5 dx = 34.1$ joule

B09

$Y = 0.0011\ X^3 - 0.0223\ X^2 + 0.3109\ X - 0.01439\ (R^2 = 0.9997)$

Area = $\int_0^{9.374} Y dx = 9.53$ joule

6-3. Analysis of Energy Absorption by the Specimens

The total area under the load-displacement diagram represents total energy of the HDPE resin matrix and the composite. Here, the composite reinforced with jute fiber shows increase in strength as well as increase in the amount of energy absorption. The gradual increase in tensile load would be withstood by the combined resistive action by the fiber and the matrix. The applied load would be distributed among the individual fibers at the fracture plane. The reinforcement of

the matrix made by the jute fiber mainly depends upon the content of the fiber in the plane along which fracture would occur.

The energy absorbed by a composite depends upon the intrinsic properties of the resin and the matrix as well as the interfacial properties of the fiber / matrix. But fiber orientation plays a crucial role in the inter-relation between the fiber and the matrix. It was assumed that crack may appear but hesitate to propagate, because the crack change its direction when meets any fiber on the way and the force also changed and so is the energy. No doubt that in the energy absorption, fibers along the loading direction would have more contribution than that of inclined fibers. It was considered that the tensile force would be along the neutral axis of the specimen. Strength of the composite increased with the number of fiber in a particular plane and the orientation of the fiber. The fiber would have enough interfacial shear loads between the fiber and the matrix in the composite. So to overcome the value more force would have to apply and as a result the energy absorbed in the fracture would be greater than that of the normal resin specimen. The energy absorption increases with the increase in the number of fibers and fiber orientation. The matrix in the composite has a constant contribution in the energy absorption of the composite. The fiber-reinforced composites acquire sufficient internal energy due to the fiber to resist the applied energy and at this load the matrix fails but the interfacial shear between the fiber and the matrix provides adequate energy to resist the applied load.

These facts clearly justify the reasons why the composite materials absorbed more energy than that of the HDPE in our project. Energy absorption increases with fiber reinforcement and centent of the fibers. So it can be concluded that the composite specimens reinforced with jute fiber shows better energy absorption capacity and performance than that of the normal specimens made by the same materials without fiber reinforcement.

CHAPTER 7

STATISTICAL ANALYSIS

7-1. Statistical Point of View

Statistical analysis can determine the potentiality and confidence level of any process by considering the maximum and minimum values of the experimental results as the allowable range.

Here statistical analysis is performed over maximum load, tensile strength and energy absorption. Six-sigma 6σ, the experimental actual process spread, is calculated to find process potential index, C_p, and confidence level. So, the comparison between HDPE and its composite, over the three parameters mentioned above will have an easier and simpler look.

7-2. Actual Process Spread, 6σ, and Control Limits

Table 7.1 represents the values of actual process spread, 6σ, for HDPE and its composite.

The equation for calculating sigma is given by

$$\sigma = \sqrt{\frac{\Sigma(X - \overline{X})^2}{N}}$$

Where,

X = Corresponding value of the samples

N (no of samples) = 5; for HDPE

= 3; for Composite

Table 7.1 Process Spreads (6 σ) of HDPE and its Composite

Parameter	HDPE		Composite	
	σ	6 σ	σ	6 σ
Max. Load (KN)	0.1998	1.1988	0.02698	0.1619
Tensile Strength (MPa)	2.4384	14.6304	0.3821	2.2926
Total Energy (J)	1.3937	8.3622	10.5855	63.5131

Table 7.2 shows the specification limits of HDPE and its composite corresponding to the maximum load (KN), tensile strength (MPa) and energy absorption (J).

Table 7.2 Specification Limits of HDPE and its Composite

Parameter	HDPE					Composite				
	UL	LL	M	m	D	UL	LL	M	m	D
Max. Load (KN)	1.486	0.88	1.1132	1.183	0.0698	1.824	1.758	1.792	1.791	0.001
Tensile Strength (MPa)	19.85	12.556	15.279	16.201	0.922	24.359	23.477	24.009	23.918	0.091
Energy (J)	6.43	2.7292	4.8096	4.5795	0.2301	34.1	9.5253	19.425	21.813	2.3874

N.B. UL = Upper Limit

LL = Lower Limit

M = Process Mean

m = Midpoint of UL and LL (Center Point)

D = Difference between M and m (off-centering)

6 σ = Actual process spread

Table 7.2 shows the upper limit, UL, and lower limit, LL, which are the maximum and minimum values of the experimental findings. These limits are regarded as the specification limits. And the actual process spread (6 σ) tells if any process data point would fall beyond the limit of UL and LL.

However, from the manufacturing point of view, it is required to consider the upper and lower control limits (UCL and LCL). The formula is given as follows

$UCL = M + 3\sigma$

$LCL = M - 3\sigma$; considering the process mean (M) as base point.

For example, for maximum load (KN) of HDPE, all points have to fall within this limit. The used HDPE can withstand a load of 1.7127 KN and the value can fall down to 0.5137 KN.

Table 7.3 represents the upper and lower control limits of both HDPE and its composite.

Table 7.3 Upper and Lower Control Limits of HDPE and its Composite

Parameter	HDPE		Composite	
	UCL	LCL	UCL	LCL
Max Load (KN)	1.7127	0.5137	1.8729	1.7111
Tensile Strength (MPa)	22.5913	7.9605	25.1553	22.8627
Energy Absorption (Joule)	8.9907	0.62845	51.185	-12.3316

Figures 7.1, 7.2 and 7.3 show the graphical representations comparing the experimental data limits (allowable limits) with control limits. It is observed that the values for the composite are higher than that of the normal resin matrix without fiber

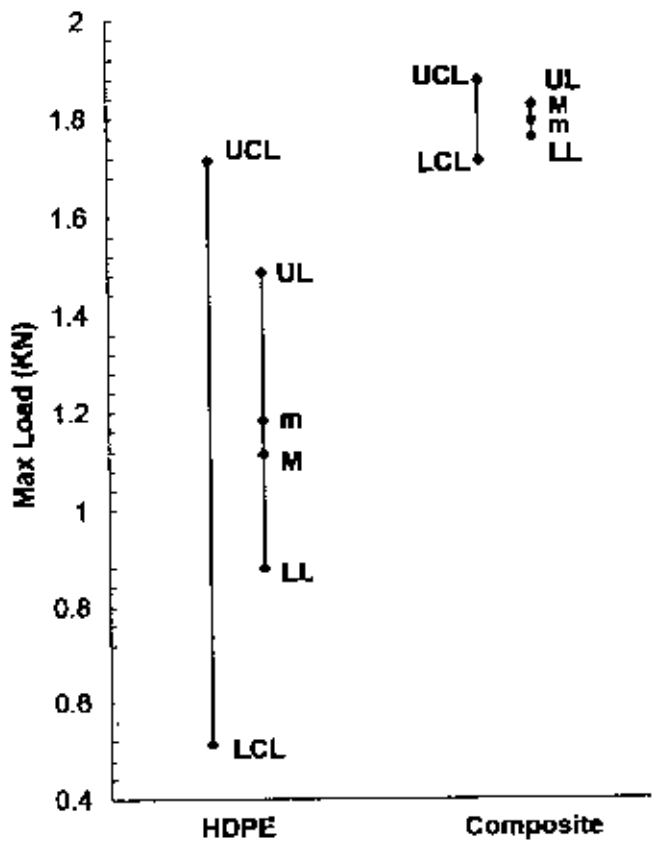


Fig. 7.1 Control Limits of Max. Load between HDPE & its Composite

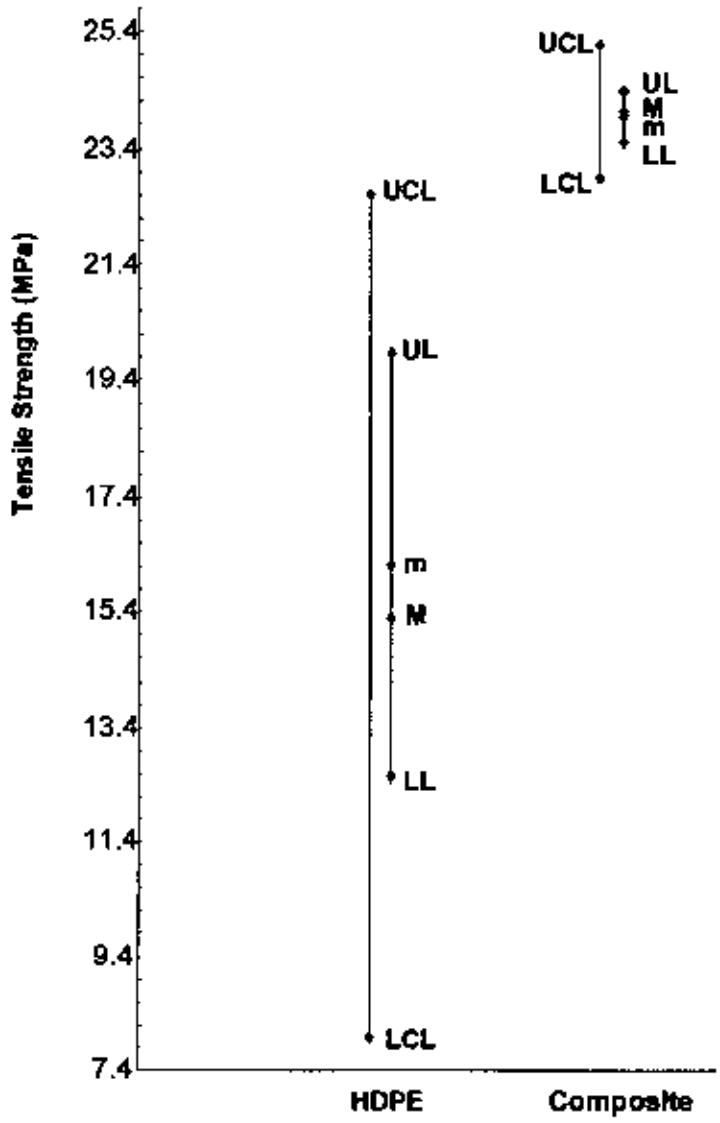


Fig. 7.2 Control Limits of Tensile Strength between HDPE & its Composite

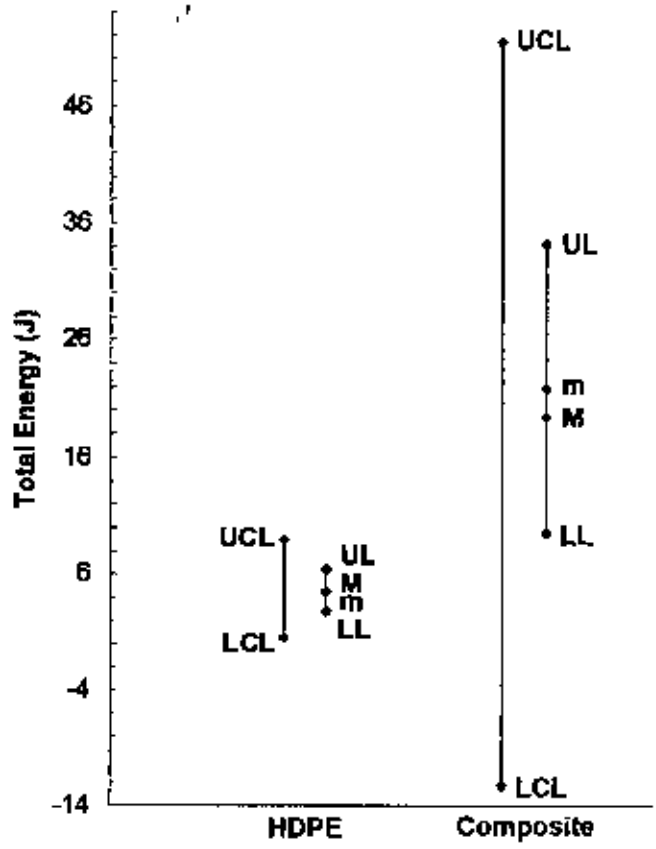


Fig. 7.3 Control Limits of Energy between HDPE & its Composite

The figures show that in case of M staying below m, the average point fall in the lower half of the process width. The reverse is the case when m stays below M. Any data point may fall within the control limits i.e., between the upper and lower control limits.

7-3. Process Potential Index

When the allowable process spreads (difference between upper limit and lower limit) and six-sigma is equal then the percentile specification will be 100%. When the upper and lower limits of a process are specified, then they are called upper specification limit (USL) and lower specification limit (LSL). And their difference is called the allowable process spread.

Allowable Process Spread = USL – LSL

A process is said to be capable only when its actual process spread (6 σ) stands within the allowable spread. If actual spread goes beyond allowable range, then the process is not capable. The formula for the process potential index, C_p, is given by,

$$C_p = (USL - LSL) / 6\sigma$$

When Cp ≥ 1 then the process is capable. The reverse is true if C_p is less than 1.

In case of $C_p = 1$, the midpoint of the specification limit, m, and process mean, M, are the seme. It is generally assumed that a minimum C_p of 1.33 (75% of specification width) is required for most manufacturing processes. This allows some flexibility if the process is slightly off center.

Table 7.4 lists the process potential index, C_p for HDPE and its composite, corresponding to the three parameters:

Table 7.4 Process Potential Index for HDPE and its Composite

Parameter	HDPE		Composite	
	APS	C_p	APS	C_p
Max Load (KN)	0.606	0.51	0.066	0.41
Tensile Strength (MPa)	7.2884	0.45	0.8816	0.385
Energy (J)	3.7005	0.44	24.5747	0.387

N.B. APS = Allowable Process Spread = USL - LSL

From table 7.4, it is found that the potentiality of the process, C_p is very insignificant and there is always a chance for many data-points to fall beyond the allowable range, i.e., range between of upper limit and lower limit.

7-4. Confidence Level

Level of confidence shows how much a process is confident to lie within the specification limit. For a given process, percentile area under a distribution curve, bounded by the specification range, is the percentile confidence level for that process.

The distribution is assumed to be normal. First of all the corresponding Z values are calculated. Z is formulated as

$$Z = \frac{X - M}{\sigma}$$

Where, X = Experimental Data Limit (UL and LL)

M = Process Mean

Sigma, σ = Standard Deviation.

Here only the absolute values of Z are considered. Addition of Z_1 and Z_2 gives the total area under the specification limit (width of upper and lower limits). Table 7.5 shows the percentile total area, which is the percentile level of confidence for the process carried out.

Table 7.6 Area under Z Curve

Parameter		HDPE			Composite		
		Z value	% Area under Z	% Total Area	Z value	% Area under Z	% Total Area
Max. Load (KN)	Z_1	1.87	46.93	84.83	1.19	38.30	77.92
	Z_2	1.17	37.90		1.26	39.62	
Tensile Strength (MPa)	Z_1	1.87	46.93	83.79	0.92	32.12	73.89
	Z_2	1.12	36.86		1.39	41.77	
Energy (J)	Z_1	1.16	37.70	80.89	1.39	41.77	74.66
	Z_2	1.49	43.19		0.95	32.89	

Hence the confidence level for composite specimens shows lower confidence than that of HDPE matrix specimens.

CHAPTER 8

CONCLUSION

The mechanical properties of High Density Polyethylene resin matrix and its jute fiber-reinforced polymeric composite were considered and analyzed. The experimental results obtained from the tensile test of HDPE and its composite were compared graphically. The fractured specimens after the tensile test were observed microscopically and the fracture mechanism was identified.

Energy absorption by the specimens was calculated and analyzed. Energy was obtained from the area under the load-displacement curve. Statistical analysis was carried out corresponding to maximum load, tensile strength and energy absorption to identify the process spread, control limit, process potential index and confidence level. As the number of specimens tested was limited due to unavailability of the UTM, the stetistical analysis has little significance. But it facilitates to identify the possible data range. Thus required load/strength can be spocified while making any product.

It can be stated that composite material shows improved mechanical properties and absorbs more energy than those of the normal resin matrix. Mechanical properties of composite increase with the increase in the number of reinforced fibers and fiber orientation. The results also indicate how much the value in tensile strength and other mechanical properties of the composite is increased at what content than that of HDPE to allow the manufacturers to select either HDPE or its composite depending upon their manufacturing requirement.

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