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IZOD IMPACT CHARACTERISTICS OF POLYPROPYLENE FIBER (PPF)/POLYESTER COMPOSITE LAMINATE WITH STATISTICAL ANALYSIS*

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ABSTRACT

The main objective of the present paper is to study the impact characteristics of unidirectional polypropylene fiber (PPF)/polyester composite laminate. The PPF/polyester composite laminate was fabricated using the hand lay-up technique with fiber volume fraction of 30.28% and thickness of 6.2 ± 0.05 mm. The impact fracture characterization technique used is the notched Izod impact test. The failure modes of the impacted test specimens were investigated. Two-parameter Weibull distribution was used to analyze statistically both the absorbed impact energy and the impact strength of the studied composite in order to obtain the scatter values in the experimental test results. Also, a failure probability curve has been obtained to calculate the impact strength of PPF/polyester composite at different desired levels of failure probability. This curve can be used by the design engineers.
KEY WORDS: Izod impact test, Polypropylene fiber, Hand lay-up, Weibull distribution.

CARACTÉRISTIQUES AU CHOC IZOD DE FIBRES DE POLYPROPYLENE (PPF) / POLYESTER STRATIFIE COMPOSITE AVEC ANALYSE STATISTIQUE

L'objectif principal de cet article est d'étudier les caractéristiques de l'impact des fibres de polypropylène unidirectionnel (PPF) / polyester stratifié composite. Le stratifié PPF / polyester composite a été fabriqué en utilisant la main lay-up technique avec la fraction volumique de fibres de 30,28% et une épaisseur de 6,2 ± 0,05 mm. La technique de caractérisation d'impact fracture utilisé est l'essai de choc Izod entaillé. Les modes de défaillance des éprouvettes touchés ont été étudiés. Distribution de Weibull à deux paramètres a été utilisé pour analyser statistiquement la fois l'énergie de choc absorbée et la résistance aux chocs du composite étudié en vue d'obtenir les valeurs de dispersion dans les résultats des essais expérimentaux. Également, une courbe de probabilité de défaillance a été obtenue pour calculer la résistance au choc de PPF / polyester composite à différents niveaux souhaités de probabilité de défaillance. Cette courbe peut être utilisé par les ingénieurs de conception.

MOTS CLES: essais au choc Izod, fibres de polypropylène, main lay-up, de la distribution de Weibull.

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1. INTRODUCTION

Polymeric composites are increasingly substituted for metallic materials in mechanical structures because of their outstanding mechanical properties at a specific low weight, what allows engineers to design slender and stiff structures without loss of performance. Despite of their many virtues, they show a highly complex impact behavior and are very sensitive to non-visual damage that strongly influences their residual load bearing capability **[1]**. Therefore, the dynamic and static characteristics should be considered. Especially, the impact behaviors of composites are very important if composite structures are employed in auto-mobile or train structures **[2]**.

Recently polypropylene is used in many industrial applications. It has a number of advantages that make it an ideal material for the manufacture of a vast range of items. Chief amongst of these are low cost and low density **[3]**. Although the mechanical properties of polypropylene fiber do not compare with those of traditional engineering materials, they are sufficient that polypropylene fiber has found widespread use in applications such as ropes **[4]** and strapping **[5]** because of its high ductility.

Properties measured in mechanical tests exhibit wide variability. Many factors can affect test results. These factors are specimen manufacturing, preparation, handling, storage, test rig design and experimental technique. However, the more fundamental source of variability associated with the material nature has received little attention **[6]**.

In the past, the scatter in the mechanical properties data was relatively unimportant, because large safety factors were used. With the advent of aircraft, the strength variability takes on new significance. In particular, the designer must consider the weakest member of the population, not the mean, mode or other central tendency of the distribution **[7]**. Consequently, considerable penalty has to be paid by reducing the design strength when higher confidence and reliability are required **[8]**.

The scatter in the mechanical properties values measured from mechanical tests for composite materials is usually described by the Weibull statistical distribution, either two or three-parametric **[9]**.

The two-parameter Weibull distribution was previously used by Mottram **[10]** to examine the compressive strength property data of flat pultruded panels.

Weibull statistical analysis has been developed as an engineering design method for composites. Different calculation procedures are used to evaluate shape parameter, α and scale parameter, β of Weibull function. The most popular are the graphical method and the maximum-likelihood method. Each of these methods has its benefits and drawbacks **[11]**.

Even though polymeric materials display viscoelasticity when tested in a tensile or oscillatory mode, they tend to fail in a brittle manner under impact due to the high loading rate exerted on the test pieces **[12]**.

The main objective of the present work is to study the impact properties of unidirectional polypropylene fiber (PPF)/polyester composite laminate using notched Izod impact test at constant impact velocity equals to 3.46 ms^{-1}. The failure modes of the impacted test specimens were investigated. Two-parameter Weibull distribution was used to statistically analyze both the impact absorbed energy and the impact strength of the studied composite.

2. EXPERIMENTAL WORK

2.1. Polypropylene Fiber/Polyester Composite Laminate Fabrication

Polypropylene fiber/polyester composite laminate, $[0^o]_4$ with fiber volume fraction equal to 30.28 % and 6.2 ± 0.2 mm thickness was manufactured using hand lay-up technique. The constituent materials of composite laminate are illustrated in **Table (1)**.

The parallel bundles of polypropylene fiber were fixed on the frame of the templates using small pins. The normal distance between each adjacent parallel bundles was 5 mm. The upper and lower surfaces of the mould were glass plates treated by wax. At first a thin layer of polyester resin plus hardener was spread over the lower glass plate. The first template with 0^o oriented fibers were placed on the resin. Rolling the fibers impregnates them, squeezes any excess resin, displaces the air outwards. When the ply was fully impregnated, the bundles were loosen from the template. An amount of polyester resin followed by another template and so on until the whole laminate is constructed. When the last ply was impregnated, a proper quantity of matrix was spread on it and covered by a sheet of caulk. The laminate was

Table 1: Constituent materials of the manufactured composite laminates.

Materials	Type
Matrix	- Polyester resin, (*SIROPOL 8230*) $\rho = 1.8 \pm 0.02$ g / cm^3.
Hardener	- Methyl Ethyl Ketene Peroxide (0.7% of matrix volume).
Reinforcement	- Polypropylene fiber (PPF) :- ρ_L = 2.248g/m, ρ = 0.905 g/cm^3.

rolled by a smooth round aluminum pipe to remove all visible air bubbles and squeeze any excess matrix from the laminate surface. The second glass plate was placed upon the laminate and a 25 kg weight was distributed over the glass plate. After 24 h, the glass plates and the sheet of caulk were removed and the laminate was completely cured at room temperature for 21 days. The manufactured laminate was cut to the required dimensions using sawing and milling machines. The fiber volume fraction (V_f) was determined theoretically. It can't be detected experimentally using the ignition test according to BS 3691 **[13]** because the melting temperatures of both PPF and polyester are approximately the same (160 ºC for polyester resin and 170 ºC for polypropylene fiber) according to ASTM D495. The average value of fiber volume fraction was 30.28%.

2.2. Theoretical Evaluation Of PPF Volume Fraction

The fiber volume fraction is calculated theoretically as follows:-

1- The fiber length per lamina (one layer) was measured and then multiplied by four (no. of layers) giving the PPF total length.

2- Knowing the PPF total length and PPF linear density (2.248 g/m) the PPF weight can be calculated.

3- The PPF volume can be calculated by dividing the calculated weight by the volumetric density (910 g/mm^3).

4- The PPF volume fraction is obtained by dividing PPF volume by composite sample volume.

From the previous calculations, it is found that the PPF volume fraction (V_f %) = 30.28%.

2.3. Preparation of Notched Impact Test Specimens

The dimensions of the notched mounting of the impact test specimen into Izod impact machine vise. The dimensions of the notched test specimens are 64 mm length, 12.7 mm width and 6.2 mm thickness. A 45^o V-notch has been machined at its mid-length through the thickness of the specimen using form milling cutter for a depth of 2.5 mm. The test specimen dimensions are shown in **Fig. 1**. **Fig. 2** shows the mounting of impact test specimen into impact machine vise.

2.4. Impact Testing Machine

Notched Izod Impact test was performed on Izod impact testing machine (type Avery Denison) according to the ISO 180:2000 standard. Rectangular notched bars were tested at 3.46 ms^{-1} in accordance with ISO 13802:1999 for the verification of pendulum impact testing machine. The impact machine makes use of a manual clamping vise with a specimen adapter for ISO geometry, as show in **Fig. 3**.

2.5. Test Procedure

Ten test specimens have been tested. The test specimens were cut from the fabricated composite laminate noting that the test specimen length has been taken parallel to the PPF fiber direction. The test procedure is a standard procedure which is:-

- Positioning the prepared specimen in the vise and securing it, setting the hummer (impactor) in the raised position, setting the pointer on upper limit of the scale, releasing the pendulum, recording the results and examining the mode of failure of the test specimens.

In the test, the V-notch produces a stress concentration which promotes a brittle, either than a ductile, fracture. The results of all tests are reported in terms of energy absorbed per unit of specimen width.

2.6. Impact Specimen Failure Modes

The V-notch in the Izod specimen serves to concentrate the stress, minimize plastic deformation, and direct the fracture to the part of the specimen behind the notch. Scatter in energy-to-break is thus reduced. However, because of differences in the elastic and visco-elastic properties of plastics, response to a given notch

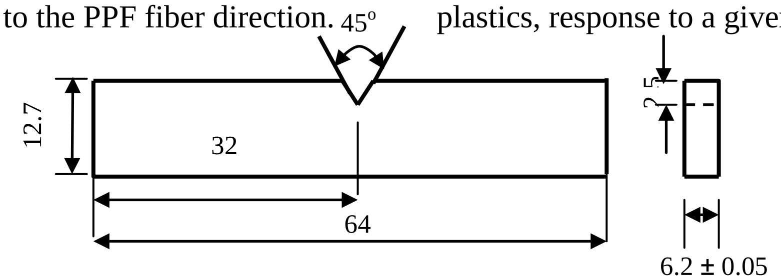

Fig. 1 Dimensions of Izod test specimen (DIMS in mm) according to ASTM-D256-81

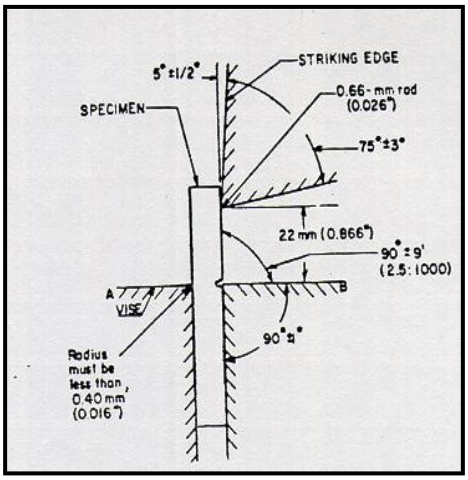

Fig. 2 Izod impact test specimen mounting.

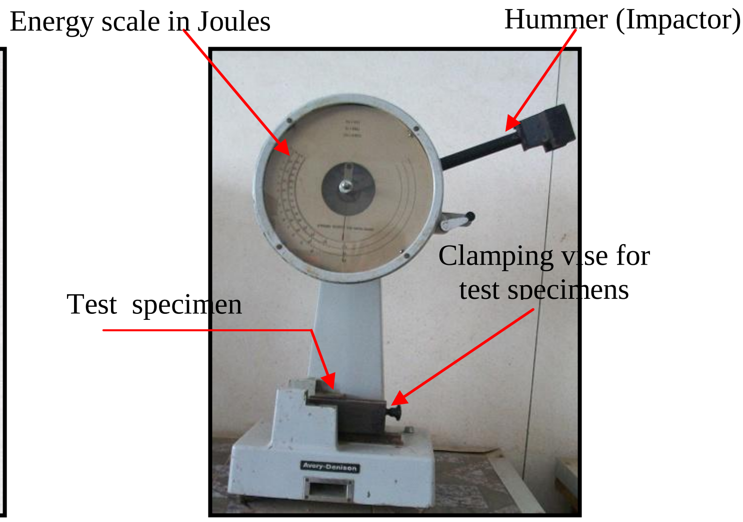

Fig . 3 Izod impact testing machine (type Avery Denison).

varies among materials. A measure of a plastic's "notch sensitivity" may be obtained by comparing the energies to break specimens with identical notches, except for the radius at the base of the notch. The excess energy pendulum impact test indicates the energy to break standard test specimens of specified size under stipulated condition of specimen mounting, notching (stress concentration), and pendulum velocity at impact.

The energy lost by the pendulum during the failure of the specimen is the sum of the energies required to:-

- Initiate and propagate the specimen fracture.

- Bend the specimen and produce vibration in the pendulum arm or horizontal

movement of the machine frame.

- Overcome friction in the pendulum bearing.

The failure mode for each specimen can be one of the following four modes; complete break**,** hinge break**,** partial break and non-break**.**

3. STATISTICAL ANALYSIS OF IZOD IMPACT RESULT DATA

Two-parameter Weibull distribution function is used to analyze statistically Izod impact data results. It is characterized by a probability density function f(n) and the associated cumulative distribution function F(n) as follows:-

$$f(n) = (\frac{\alpha}{\beta})(\frac{n}{\beta})\exp\left[-\left(\frac{n}{\beta}\right)\right] \qquad (1)$$

$$F(n) = 1 - \exp\left[-\left(\frac{n}{\beta}\right)^{\alpha}\right] \qquad (2)$$

"n" is the (impact strength or energy), "α" and "β" are the shape and scale parameters.

3.1 Analysis of Impact Data Results By The Graphical Method

The reliability function, **L_R(n)** is defined as $L_R(n) = 1 - F(n)$. Substituting this value of F(n) in Eq. (2) it is converted to:-

$$L_R(n) = \exp\left[-\left(\frac{n}{\beta}\right)^{\alpha}\right] \quad (3)$$

By taking the logarithm twice of both sides of Eq. (3), it becomes:-

$$\ln\left[\ln\left(\frac{1}{L_R(n)}\right)\right] = \alpha \ln(n) - \alpha \ln(\beta)$$

(4)

From Eq. (4), it is clear that the relationship between ln[ln(1/L_R)] and ln(n) is a linear one. The line slope presents the shape parameter (α) and scale parameter β can be obtained from the second term of Eq. (4).

In order to obtain a graph from Eq. (4), the impact strength and impact energy are first arranged in ascending order , serial number is given for each value (i = 1,2,3,…..,n) and the reliability function **L_R** for each **n** is calculated from the following expression:-

$$L_R = 1 - \left[\frac{(i-0.3)}{(k+0.4)}\right]$$

(5)

Where:- "**i**" is the failure serial number reliability function in the form of **ln[ln(1/L_R)]** for each "**n**" (impact energy or impact strength) is plotted on a graph against **ln(n)**. Then shape parameter (α) and the scale parameter β can be determined.

3.2 Scatter of Izod impact test results

Mean (M), standard deviation (SD) and coefficient of variation (C.V.) of two-parameter Weibull distribution were calculated from the following Equations.

$$MTTF = \beta\,\Gamma(1+\frac{1}{\alpha}) \quad (6)$$

$$SD = \beta\sqrt{\left[\Gamma\left(1+\frac{2}{\alpha}\right) - \Gamma^2\left(1+\frac{1}{\alpha}\right)\right]} \quad (7)$$

$$C.V. = \frac{\sqrt{\left[\Gamma\left(1+\frac{2}{\alpha}\right) - \Gamma^2\left(1+\frac{1}{\alpha}\right)\right]}}{\Gamma\left(1+\frac{1}{\alpha}\right)} \quad (8)$$

Where (Γ) is gamma function.

3.3 Failure Probability P_f of The Fabricated Composites

Two parameter Weibull distribution function is used to show failure probability **(P_f)** of the manufactured composite laminates. Failure probability is defined as **(P_f)** = F**(n)**. Substituting this value of **F (n)** in Eq. (2) it is converted to:-

$$(P_f) = 1 - \exp\left[-\left(\frac{n}{\beta}\right)^{\alpha}\right] \quad (9)$$

Eq. (9) is used to calculate impact strength of polypropylene/polyester and "**k**" is the total test number of samples under consideration. The composite laminate corresponding to chosen different failure probabilities (**P_f**).

4. RESULTS AND DISCUSSION

4.1. Impact Energy and Impact Strength

Estimating the breaking energy for the test specimen requires the selection of suitable pendulum. The striking velocity 3.46 meters/second. Impact strength (S_{imp}) is normally calculated as follows:-

$$(S_{imp}) = \frac{\text{Energy to break)}}{\text{Area at notch section)}} \ (J/m^2) \quad (10)$$

The results of impact tests indicate the behavior of unidirectional PPF/ polyester composite laminate. The impact tests include ten test specimens of a standard notch (45^o) machined at room temperature.

From the test results, it is found that the values of impact energy and strength are as follows:-

-Min. impact energy = 5.8 J.

-Min. impact strength = $8.015*10^4$ J/m^2.

-Max. impact energy = 7.2 J.

-Max. impact strength=$10.817*10^4$ J/m^2

-Aver. impact energy = 6.45 J.

-Aver. impact strength = $9.52*10^4$ J/m^2.

The low values of impact energy and strength results is attributed to the variation of the cross section area at the V-notch.

4.2. Impact Specimen Failure Modes

The impact specimens' failure takes a common form which is a hinge break including fiber breakage, matrix fretting and debonding at the notch area as shown in **Fig. 4**.

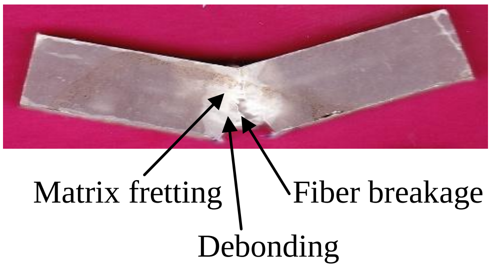

Fig. 4 Izod impact test specimen hinge break failure mode

4.3. Statistical analysis of PPF/ Polyester Izod impact test results

Figs. 5, **6** and **Table. 2** represent graphical and statistical analysis of Impact strength and energy data for PPF/polyester composite laminates respectively. Failure probability (P_f) curve of the fabricated composite is shown in **Fig. 7**. The obtained failure probability curve can be used by the design engineers to obtain the impact strength of PPF/polyester at the desired strength are due to the small fiber volume fraction (V_f = 30.28%).

shown in table 2, it is clear that the coefficient of variations (C.V.) of the test results are 0.08 and 0.12 for impact energy and strength respectively which reflect a visible accuracy for the test results.

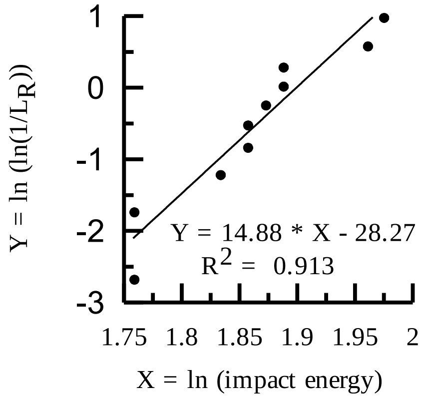

Fig. ٥ Graphical analysis of impact energy data for polypropylene / polyester specimens.

level of failure probability.

From the statistical analysis results

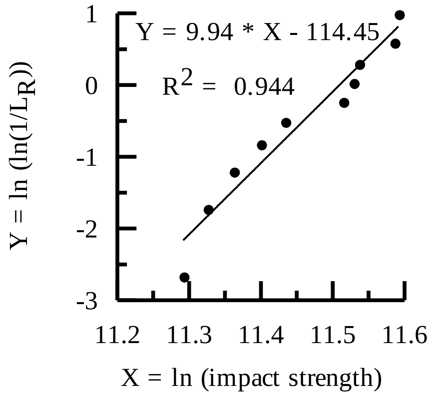

Fig. ٦ Graphical analysis of impact strength data for polypropylene / polyester specimens.

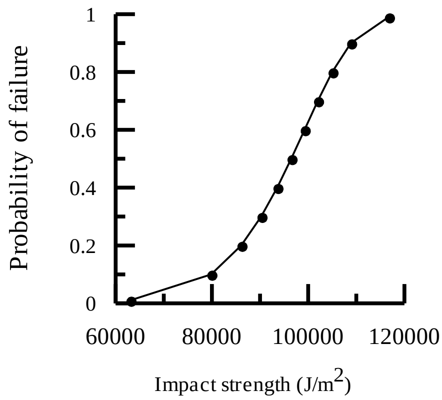

Fig. ٧ Probability of failure for polypropylene / polyester composite

Table 2 : Izod Impact test results of PPF/polyester composite laminate

Test no.	Impact energy (J)	Impact strength (J/m^2) $*10^4$
1	5.8	8.015
2	5.8	8.290
3	6.25	8.597
4	6.4	8.928
5	6.4	9.235
6	6.5	10.012
7	6.6	10.158

8	6.6	10.235
9	7.1	10.752
10	7.2	10.817
α	**14.88**	**9.94**
β	**6.68**	**10.01*10^4**
Mean	**6.45**	**9.52*10^4**
Standard deviation (SD)	**0.53**	**1.17*10^4**
Coefficient of variation (C.V.)	**0.08**	**0.12**

5. CONCLUSIONs:

Based on the experimental results the following conclusions can be drawn:-

1- For PPF/polyester composite laminate with fiber volume fraction equal to 30.28 % investigated in the present study, different failure modes are observed which establish different damage mechanisms. The impact specimen failure takes the form of (hinge break) which contains the following signs fiber breakage, matrix freeing, and debonding at the notch area.

2- The Izod impact energy of the PPF/ polyester composite test specimens ranges from 5.8 to 7.2 Joule whilest the impact strength ranges from 8.015 × 10^4 to 10.817 × 10^4 Joule/m^2.

3- Two-parameter Weibull distribution can be used to analyze the impact data results for the investigated PPF/ polyester composite laminate. Both shape parameter (α) and scale para-meter (β) of Weibull distribution are different for the impact energy and impact strength. The obtained failure probability curve can be used by the design engineers to obtain the impact strength of PPF/polyester at the desired level of failure probability.

5- From the Weibull statistical analysis of the experimental data the different values of scatter (C.V.) have been obtained and reported. The C.V. for Impact energy is equal to 0.08 J and for Impact strength is equal to 0.12 J/m^2.

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