Influence of Temperature on Fracture Toughness of Jute Fiber Reinforced Unsaturated Polyester Resin

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Abstract

Jute fiber reinforced unsaturated polyester resin composites (J/UP) were subjected to low velocity impact tests in several Temperatures degree in order to study the effects of temperature variance on the intrinsic fracture toughness G_c impact properties. An investigation was conducted onto the effects of temperatures on impact resistance of jute fiber-reinforced unsaturated polyester resin composite. Impact tests were performed on the specimens at different temperatures. The temperatures were 27, 50, 75 and 100 C°. The results reflect the influence of ambient temperature on impact toughness measurements. The results indicate an obvious correlation between the ambient temperatures and impact load, total absorbed energy and fracture toughness. The prepared specimens exhibited brittle fracture behavior with a lower peak load, lower impact energy and less time to fail compared with results at temperature higher Tg. The impact test results show that the total energy absorbed at 100 C° have higher energy when the composite behavior changed from brittle to ductilebehavior. The intrinsic fracture toughness is higher for specimens tested in 100 C° and 75 C° and shows ductile behavior; while specimens tested with temperature lower than T_g show brittle fracture and lower G_c.

Keywords: Impact filling weight, ,Composite, Jute fiber, Intrinsic Fracture Toughness.

تأثير درجة الحراره على متانه التكسير النوعيه لمتراكب راتنج البولي أستر غير المشبع المقواة بالياف الجوت

الخلاصه

عرضت عينات من راتنج البولي أستر غير المشبع المقواة بالياف الجوت لاختبارت الصدمه بسرعه واطئه في درجات حراريه مختلفه لغرض دراسة تأثير تغاير درجات الحراره على مواصفات متانه التكسر النوعيه بالصدمه G_c · البحث يتعرض لتأثير درجات الحراره على مقاومة الصدمه لمتراكبات راتنج البولي أستر غير المشبع المقوى بالياف الجوت · أنجزت فحوص الصدم على العينات بدرجات حراره مختلفه · درجات الحراره التي أجريت بها الفحوص هي 27 ,50, 75 , 100 م° ·أن النتائج المستحصله تعكس تأثير درجه حرارة المحيط على قياسات متانة الصدم · عرضت عينات من راتنج البولي أستر غير المشبع المقواة بالياف الجوت لاختبارت الصدمه بسرعه واطئه في درجات حراريه مختلفه لغرض دراسة تأثير تغاير درجات الحراره على مواصفات متانه التكسر النوعيه بالصدمه G_c · البحث يتعرض لتأثير درجات الحراره على مقاومة الصدمه لمتراكبات راتنج البولي أستر غير المشبع المقوى بالياف الجوت · أنجزت فحوص الصدم على العينات بدرجات حراره مختلفه · درجات الحراره التي

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أجريت بها الفحوص هي 27 ,50, 75 , 100 م° ·أن النتائج المستحصله تعكس تأثير درجه حرارة البيئيه على قياسات متانة الصدم · تتشير النتائج الى أرتباطٍ واضحٍ بين درجاتِ الحرارة البيئيه وتحميل الصدم ,الطاقه الممتصه الكلي ومتانة التكسير. أن العينات التي حضرت تبدي سلوك تكسير قصيفا" يرافقه قمم تحميل واطئه وطاقة صدم واطئه وتستغرق زمنا" أقل للانهيار مقارنة" مع النتائج الحاصله للعينات في درجات حراريه أعلى من T_g

أن نتائج فحوص الصدم بينت أن الطاقه الكليه الممتصه بالفحص بدرجة حراره 100 م تستلزم طاقه أعلى عندما يتغاير سلوك المتراكب من القصيف الى المطيلي . أن متانة التكسير النوعيه تكون للعينات المفحوصه بدرجة حراره 100 و75 م تكون أعلى وتظهر سلوكا" مطيليا" بينما العينات المفحوصه بدرجات حراره أقل من T_g تظهر سلوكا" قصيفا" في التكسر وأقل قيمه ل G_c .

Introduction

Natural plant fibers can be economically and ecologically useful alternatives to reinforcement fibers in polymeric composites [1,2]. Due to their low density and low cost in comparison to conventional fibers, jute fiber reinforced composites have great potential for use in engineering applications [3,4]. A growing environmental awareness across the world has aroused interest in research and development of environmentally friendly and sustainable materials. Natural plant based fibres are used as reinforcements for composite materials and give various advantages compared to conventional fibers [5,6]. One of the main important aspects of the behavior of natural plant fiber reinforced polymeric composites is their response to an impact load and the capacity of the composites to withstand it during their service life.

Such damage may be caused by bumps or crashes and falling objects and debris. Some of the reported work has suggested that natural fiber composites are very sensitive to impact loading [7]. The major draw back is its low impact strength thermosets composites[8,9]. In the broader context, assessing the impact resistance of a composite material is always difficult since the damage manifests itself in different forms such as delamination at the interface, fiber breakage, matrix cracking and fiber pulls out[10,11]. Due to their complexity, many of their characteristics still remain unresolved [12,13]. Low velocity impact of fiber reinforced plastics has been the subject of many experimental and analytical investigations [14,15]. Susceptibility to low velocity impact damage of glass fiber reinforced polymeric composite materials has been well documented[16,17].

There are many studies of the behavior of carbon fiber reinforced epoxy composite. Laminates subjected to impact loads [18,19]. However, there is not much reported work on the impact response of natural fibre composites. In this study impact tests were carried out on jute reinforced unsaturated polyester composite specimens. Varying the temperature of the test was used with a view to analyzing the effect of temperature on impact intrinsic fracture toughness properties. A low velocity instrumented falling weight impact test method was employed to determine load–deformation, load–

time, absorbed energy–time and velocity–time behavior for evaluating the impact performance in terms of load bearing capabilities, energy absorption and failure modes. The post-impact damage and failure mechanism of morphology study.

The linear elastic fracture mechanics (LEFM) defines the fracture toughness as the material resistance to the growth of the crack or flaw. Some texts relates this toughness to the strain energy release rate G_c given by(18) :

$G_c = dU_{el}/ dA$ ……… (1)

Where U_{el} is the elastic strain energy stored within the loaded sample and A is the crack area. The response of the plastic material to an external load is not unique. they are either brittle or ductile; depending on test type and on test condition (19). Therefore a wide spectrum of toughness value for such material is expected.

A versatile system for impact test has been developed for studying the impact performance of polymers using a heavy weight falling dart(20). To obtain more accurate impact data the system was then improved as an instrumented falling weight (IFW) which is computerized(21).

Intrinsic fracture toughness an introduced by Leach and Moore(22) is calculated from Equation 1 with eliminating the losing energy from the total energy absorbed by the impact specimen. The result, however are only slightly altered. the aim of this work is to obtain the temperature change effect on the impact intrinsic fracture toughness values.

In the (IFWI) technique, the fracture toughness is determined from equation (1). the total energy for impact is :

$U=\int Fdx$ …………..(2)

Where F is the impact force for given by(23) :

$F = \pi EB/a_2 \ [K_1(ro,\upsilon)X/V + K_2(r,\upsilon)(3X/B)]$ ..(3)

Which is acting on the sample for a contact X. The other term of equation (3) are; the radius of poison ratio υ and the modules of elasticity of the specimen E, the elastic constants of the dart $K1(r_o,\upsilon)$ and of the material $K_2(r,\upsilon)$, the radius of the contact area r_o and finally B the specimen thickness.

The aim of the present work is to define an temperature effect on the intrinsic fracture toughness of jute reinforced unsaturated polyester polymer composites. the measurements obtained with quasi-static conditions leads to results more suitable for such definition. Alternatively a remarkable size effect is observed for G_c values with the specimen thickness. Such inconsistency with direct G_c values are not suggests some reconsideration for the energy terms expressed as$\mathbf{U_{el}}$.

Cooper (24) discussed the processes which expected to give rise to G_c. Their discussion which summarized those process by pulling of the fiber, debonding the fiber from matrix, stress relaxation, fiber failure, and the matrix yielding. Using the available data in literature the energy terms representing the processes have been estimated. A slightly modification for $\mathbf{G_c}$ values have been observed (25) beside the optical macrographs.

Williams and Hodgkinson (26) have show that an increase in impact speed causes remarkable increase G_c values. Their results, however, where restricted to very fast speed where the loading time are not exceeding 10^{-3} sec. An interval much less than the time spanned in the present test; t≈ 1 sec. Nikpur and William's (26) proposed an energy relationship which contains a tern for the plastic work. Jabur (25) used their relationship and calculated G_c values of polyester composites. Irland (27) Realized that U_T must include some other important energy terms. His relation for U_T was given as :

$$UT = U_el - U_I + U_d + U_{sub} \quad ....(4)$$

With the following provisions; The energy required for indenting the specimen with the dart is :

$$U_i = \int P\, dV \quad ....(5)$$

For fully plastic deformation observation, the pressure P equals to $3\sigma_Y$, and V_o Is the residual volume of the indented zone (28). For highly brittle composites where reinforcement was maid with J/UP fibbers a plastic – elastic and or Hertizian type cracking , the term U_i in the form stated above will under estimate G_c values . Hence an amendment to U_i for such observations should be considered in the future work.

(ii) Debonding the fibers from a matrix of volume V required an energy U_d which can be estimated from (25);

$$U_d = \sigma_Y^2 \; V / E \quad ....(6)$$

(iii) The last term of equation (4). The sum of a other subsidiary terms is involved in Γ_p which represent the sum of all energy terms which leads to the plastic flow associated with the propagation of the crack the free surface energy. They are the bonding energy, the vibrational energy, the sound energy, and the tossing energy of the fractured fragment. The estimation of each of these subsidiary terms is beyond the scope of this text. A reasonable approximation, however, has been suggested in which U_{sub} is assumed invariant if the impact speed and environmental conditions are fixed.

Brittle behavior remarked the fracture in temperature from room temperature to range near T_g, while above T_g the fracture transfer to ductile behavior and for more than T_g.

Materials and Sheet Casting

The resin used as A matrix for the composite was Vipal H265 unsaturated polyester resin. Through the casting process the matrix was hardened by adding 0.5 gm of cobalt nafthenate to 100 gm polyester and accelerated by adding 2 gm of methyl ethyl ketone peroxide (MEKP) at a concentration of 0.02 w/w of the matrix. Jute fiber of (316 $gm\backslash m^2$) density woven (0\90) used as reinforced fibers with (3) layer for all samples with 20% fiber to composite ratio and (4.2 mm) thickness.

Processing

A hand lay-up method was used to prepare the composite samples. A measured quantity of unsaturated polyester resin mixed with a formulated catalyst (MEKP) for rapid curing was poured on a pre-weighed amount of woven jute fiber which was placed in a mould. The mould was coated with a semi-permanent, polymer mould release agent, Frekote FRP90-NC. After pouring the resin, each layer was left for a few minutes to allow the resin to soak into the fiber mat. Trapped air was gently squeezed out using a roller. The jute fiber and polyester resin were then left for about 3 min to allow air bubbles to escape from the surface of the resin.

The panel was left to cure at a temperature of 22 ºC for 24 h before being removed from the mould. Subsequently, post-curing was carried out at a temperature of 60 ºC for 2 h. Sheet 20×20 cm 2 area of jute fiber prepare to cast J/UP with three layer of fiber, making the composites using hand lay-up technique. A similar processing method is explained in our previous work (22).

Measurements Instrumented falling weight impact test

A low velocity instrumented falling weight impact test method was employed with a hemispherical nose impact up with a diameter of 20 mm fitted in the impactor at a height of 500 mm and total impact mass of 11.5 kg. This mass in combination with a release height of 500 mm provided an incident energy of 11.47 J at a striking velocity of 2.42 m/s. Square specimens of side length 70 mm were cut from the composite laminate, 200 · 150 ·3 mm, using a diamond-cutting wheel. The specimens were firmly fixed at all edges using annular clamps with inner and outer diameters of 100 and 150 mm, respectively and were impacted producing damage up to penetration. After the first impact of the specimen, a catcher mechanism was activated to prevent a second striker. The striker was of 11.5 Kg. steel cylinder with a hemispherical end of radius 1 cm. As shown in figure (1) the striker was released from position S which is 50 cm above the sample O to hit the sample which is clamped circularly at O with the radius equal to 2.5 cm, Samples tested at variable temperature at 27, 50, 75 and 100 C°. The test was conducted in accordance with the British Standard BSEN ISO 6603-2 recommendations [23]. A Zwick/Roell impact test machine (IFW 16758/000) was used for the test and the drop-tower arrangement. During the impact in this system, the resistive force exerted by the specimen on the striker was measured by a load cell as a function of time and stored in a computer for subsequent display and analysis. From the basic force-time information, the software calculated important parameters such as load deformation, absorbed energy and velocity, which were used to characterize the impact event.

Tensile test:

Sample of Rectangular tension test – shape were cut according to ASTM standard out of composite sheet The geometry of the specimens used followed the recommendation given in ASTM Standard A 370 S, using Phywe machine 1715/000 tensile testing unit, it was tested in tension at room temperature with cross head speed of 0.05 mm/ min, this test to obtain Young modules E and tensile yield stress σ_y.

Results and discussion

The result of the tests obtained from IFWI test appear as five curves for each test, four of them are load time as a function of (impact speed), the displacement through sample , load which impact sticker applied to push through the sample, while the fifth is the load of striker applied as a function of displacement done from the initial of the impact until penetration of striker through sample to fracture. Fig. 2 Force – Displacement, figure 3 Energy – time, figure 4 velocity – time and figure 5 striker speed – time, from fig. 2 force or load applying by striker on the specimen with displacement and fig. 3 ;noted that the specimen tested at 100 C° required higher energy to fractured than the other temperature, lower for specimen tested at 75 C°, 50C° and for 27 C° the former need 20 Joule more energy than required energy for later. The load– Displacement curves for 100 C° temperature test reinforced specimens reveal that the peak impact load increases with increasing temperatures degree of test. When damage initiates and reaches its peak value, the impacted specimens are seen to be bearing higher loads and absorbing more energy. This is attributed to effect of high temperature. As the damage continues to propagate beyond the peak load, the reinforced coupons still seem to absorb energy until the specimen finally perforates. This situation is probably related to the appearance of visual damage. Once visual damage occurs, the specimens rapidly lose their load carrying capability.

The velocity of the striker of IFWI for specimen tested at 100 Cº initially 2.95 m\s, dropped to 2.05 m\s as shown in fig. 4, indicated that this specimen resisted sticker more than other specimens.

Fig. 5 Displacement – time curves shown an arrangement results except those of 100 Cº temperature test which have lower fitting than other samples. Instrumented falling weight impact testing involves very small time scales, as seen in Fig. 6. The time taken for damage initiation and propagation through the entire specimen to the point of its total collapse is approximately 4–16 ms for 100 Cº, 75 Cº samples. The duration of the impact event 50 Cº, 27 Cº samples is approximately 2–16 ms a time difference of approximately 2 ms. This indicates that the time variation of the peak impact load is strongly influenced by the stiffness of the composite temperature. It is clear that the contact time for an impact event increases with increase in temperature test, which progressively stiffens the composite. The damage states 100 Cº temperature test reinforced specimens mentioned in load/displacement traces in Fig. 2 are illustrated in Fig. 5 [29]. The load/displacement trace of other temperature test specimen is chosen as a representative curve for the purpose of this illustration.

Characteristics of impact events load/displacement curves from the impact testing are shown in Fig. 2. These show that the time the striker was in contact with the impacted specimens is longer for 100 Cº temperature test than for other specimens. When the test coupons were subjected to impact force, the load/displacement curve was linear up to the damage initiation point. The peak load values for 27Cº – 100 Cº temperature test reinforced specimens were approximately 5, 5.5, 8, and 34 kN, respectively. The load/displacement curves for 100 Cº temperature test reinforced specimens reveal that the peak impact load increases with increasing temperature of test. When damage initiates and reaches its peak value, the impacted specimens are seen to be bearing higher loads and absorbing more energy. This is attributed to effect of temperature rising. As the damage continues to propagate beyond the peak load, the coupons still seem to absorb energy until the specimen finally perforates. This situation is probably related to the appearance of visual damage. Once visual damage occurs, the specimens rapidly lose their load carrying capability. Low temperature test samples show very little indication of a propagation phase since these contain no plastic deformation. The time elapsed for damage initiation to penetration is shorter for low temperature test than for high temperature test samples.

However, the composite is based on the combination of fiber and resin and therefore any degradation of the resin or of the fiber-resin bond will degrade the composite. Since resin properties are affected by heat, especially as temperatures approach and exceed the glass transition temperature, this effect can be expected to affect the primer and the resin used to bond the composite to the fiber as well.

Impact damage in fiber reinforced composites involves four major failure modes: namely matrix cracking; delimitation; fiber breakage; and penetration of the impacted surface [29,30]. The important step in studying the impact behavior of composite materials is to characterize the type and extension of the damage induced in the impacted specimens.

Several failure mechanisms may appear in the composite Materials It is evident for these specimens that a combination of matrix cracking, delimitation and fiber breakage are the predominant failure modes. These failure mechanisms agree very well the impact damage observed by Errajhi et al. [31] for an aluminized E-glass fiber reinforced unsaturated polyester composites.

The impact performance of target specimens can be characterized by calculating the loss of kinetic energy of the impact mass during impact. By measuring striking velocity and residual velocity, the energy absorption by the impacted specimens can be analyzed using the following formula:

$$E=\frac{1}{2} m(v_1^2- v_2^2) \qquad \ldots\ldots\ldots\ldots(10)$$

From eq. (4) the energy relation and by measuring U_d,U_{el} and U_i. Using eq. (4,5 and 6) with E= 3 GPa and $\sigma_Y=11MN\backslash m^2$ results obtained from tensile test :all increased with increasing test temperature which strongly effected specially with 75 and 100 C° temperature test samples, that indicate that sample test in 27 C° start with brittle behavior, where no plastic deformation , binding , vibration energy or debonding fiber from matrix energy, these energy appear immediately as the test temperature increase over T_g, fig. (6) U_{el}, U_i and U_d energies values increased above 50 C and become effected parameters as shown in fig. (6).

Measuring U_T need to subtraction these energies from the total impact energy to obtain real strain energy released rate to fracture the sample, and obtain the intrinsic fracture toughness G_c. Samples tested at 75 C° and 100 C° become ductile, U_d, U_i and U_{el} appear as effective parameter as shown in fig. (8) which show the difference between Direct G_c and intrinsic G_c. Known that unsaturated polyester resin have T_g about 69 C° the brittle to ductile temperature(34).

Impact fracture features sketch in fig. 7, where circular fracture for brittle fracture make by splitting from the specimen tested, this portion with the same diameter of the striker. Morphology of the fracture surfaces shown in fig.9 (a and b) that for specimen of 27 and 50 C tested temperature are brittle behavior with splitting. Radial or horizontal crack with affected plastic deformation zone area clear appear at 75 and 100 C as shown in fig.9 (c and d), a ductile fracture convert the behavior of these samples .

Conclusions

1- J\UP composites appear brittle behavior for impact test under T_g temperature , and ductile behavior over it .

2- The composite appear no plastic deformation until the test temperature approach or exceed T_g , then total strain energy released rate must be corrected .

3- Intrinsic fracture toughness G_c reduced when plastic deformation energy , debonding energy vibration energy and binding energy subtraction from the total energy released to impact .

4- Dynamic test required an correction to obtain intrinsic fracture toughness.

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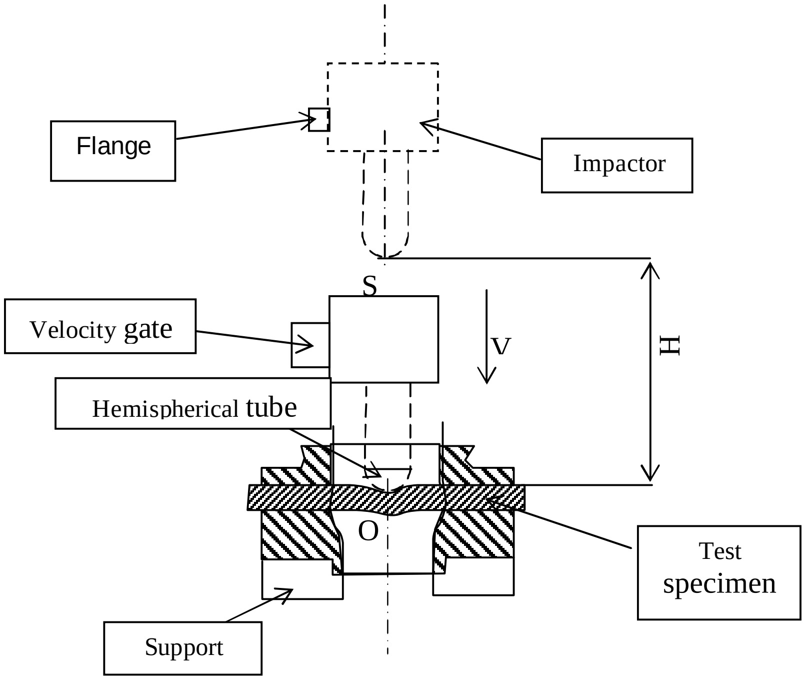

Figure (1) The instrumented drop-tower arrangement on the IFW 16758 impact machine.

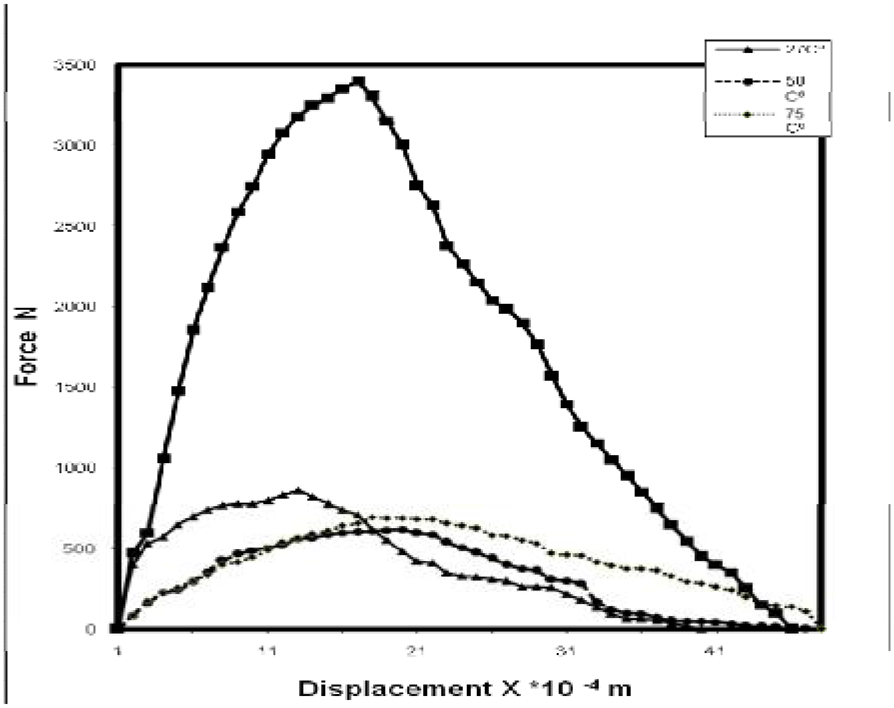

Figure (2) Load –Displacement curves.

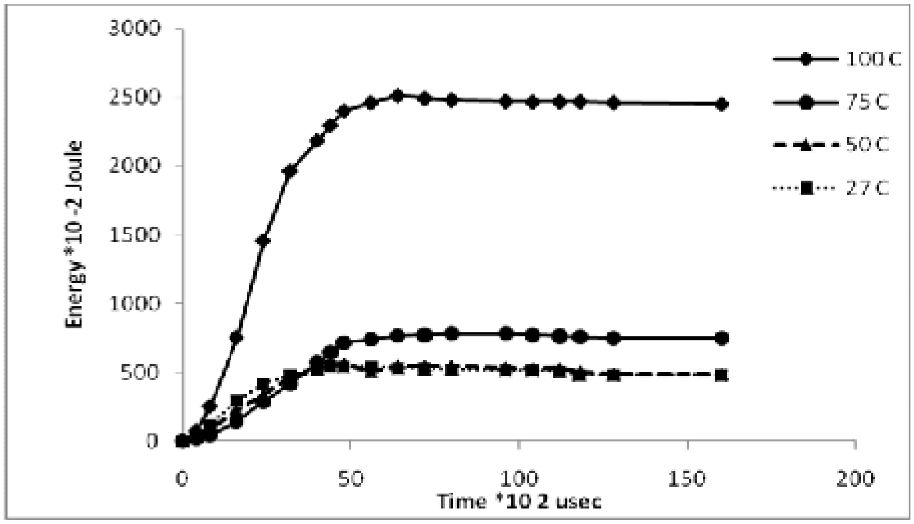

Figure (3) Energy – time curves

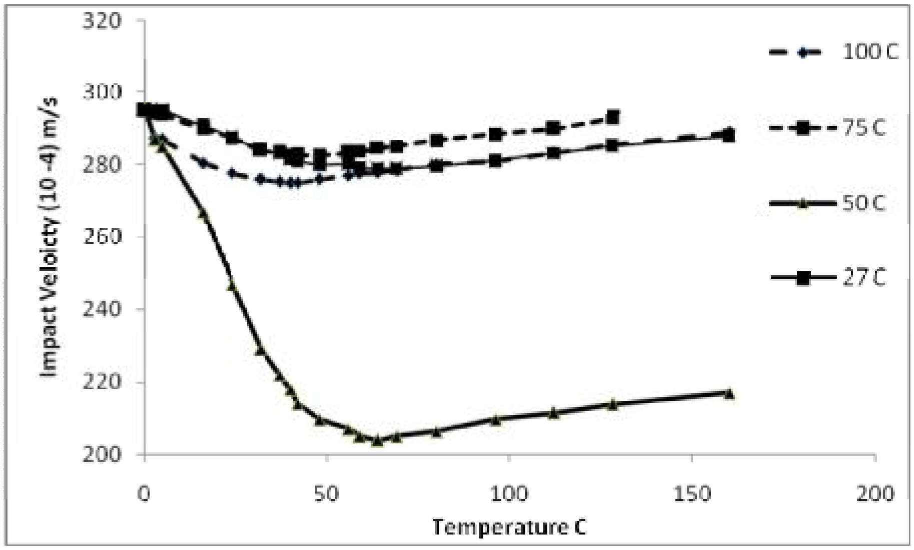

Figure (4) **Velocity – time curves**

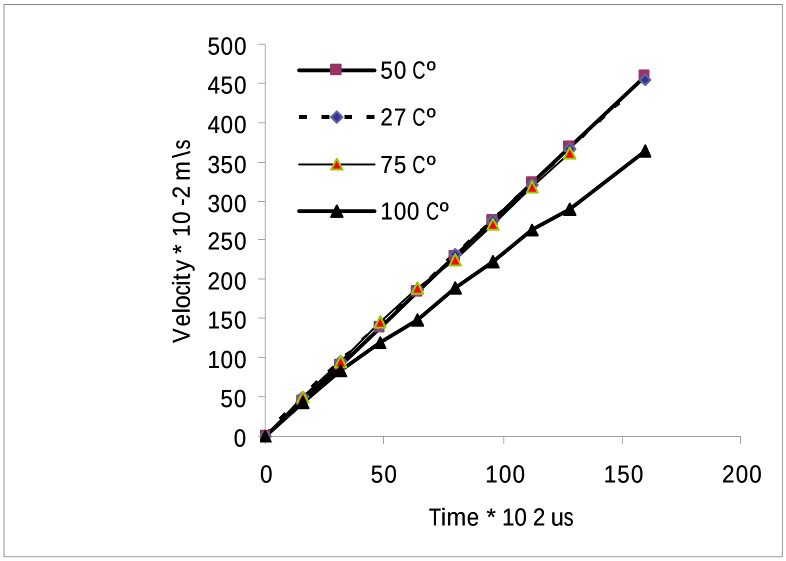

Figure (5) **Displacement - time**

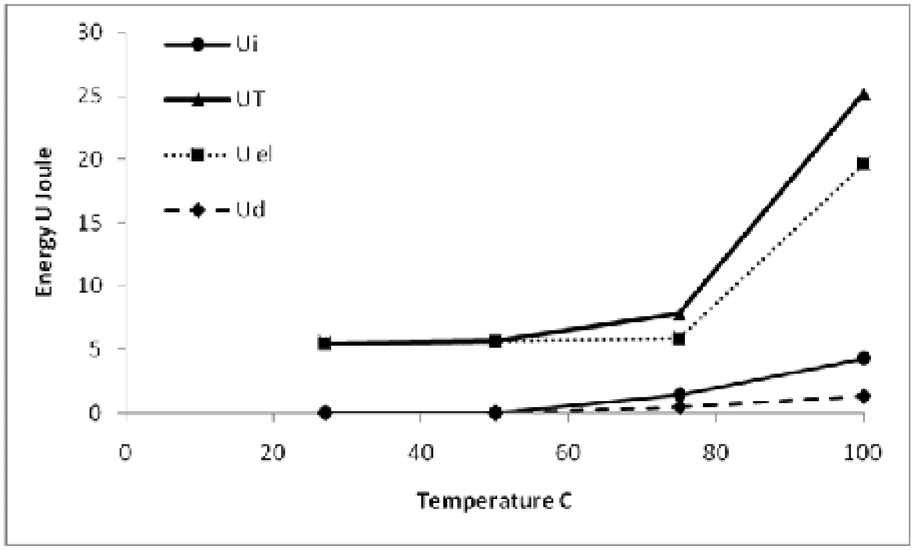

Figure (6) **Plastic's deformation energies- test temperature**

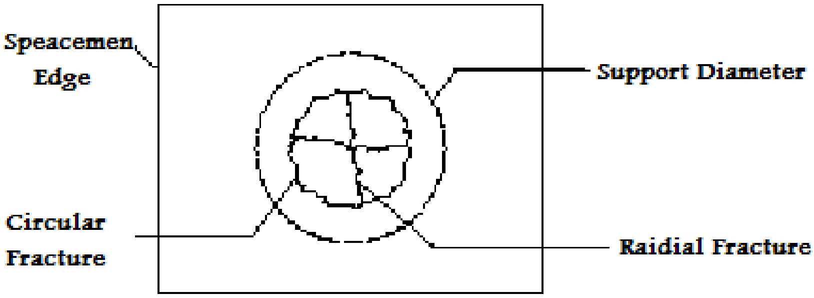

Figure (7) **Fracture features of impacted specimens (not to scale).**

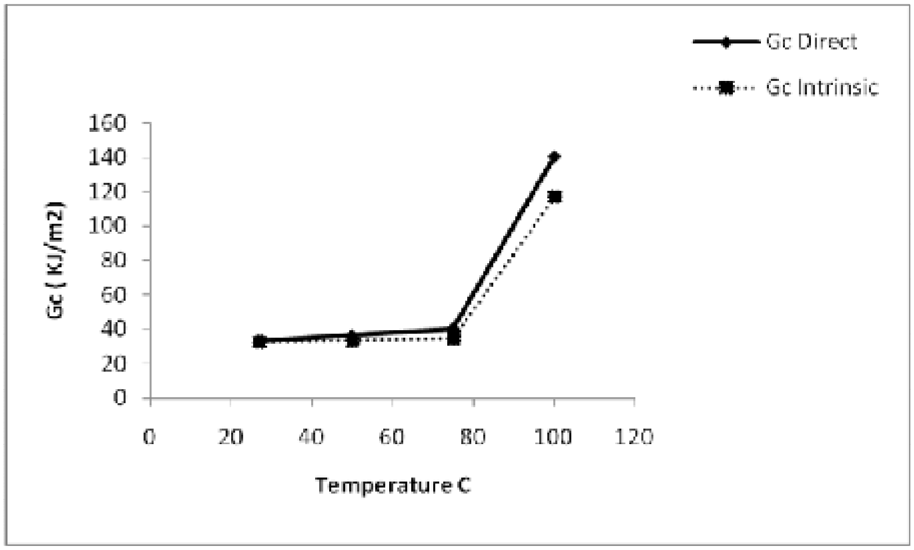

Figure (8) G_c – temperature relation.

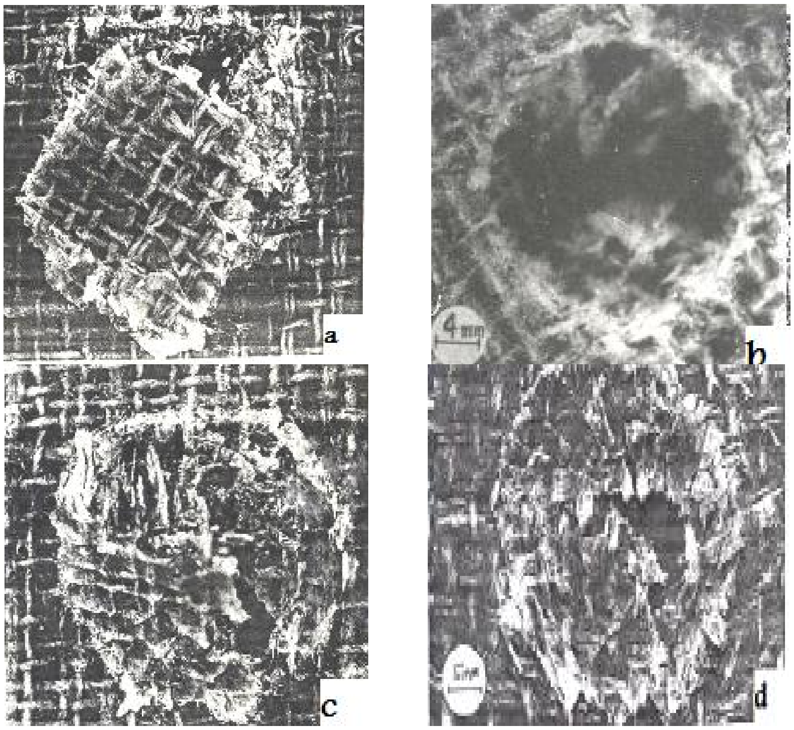

Figure (9) Morphology of impact fracture
tested at, a – 27 C°, b -50 C°, c- 75 C° and d-100C°