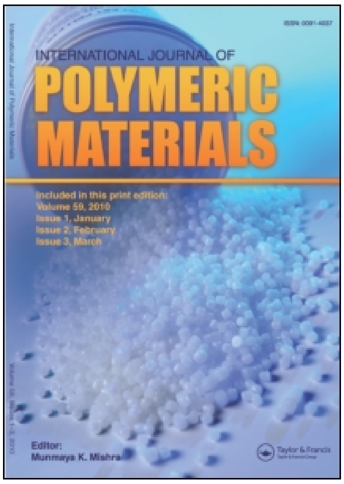


International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

EFFECT OF FIBER ORIENTATION ON THE MECHANICAL PROPERTIES AND FRACTURE CHARACTERISTICS OF DATE PALM FIBER REINFORCED COMPOSITES

A. A. Wazzan[a]
[a] Department of Chemical & Materials Engineering, King Abdulaziz University, Jeddah, Saudi Arabia

To cite this Article Wazzan, A. A.(2005) 'EFFECT OF FIBER ORIENTATION ON THE MECHANICAL PROPERTIES AND FRACTURE CHARACTERISTICS OF DATE PALM FIBER REINFORCED COMPOSITES', International Journal of Polymeric Materials, 54: 3, 213 — 225

To link to this Article: DOI: 10.1080/00914030390246379

URL: http://dx.doi.org/10.1080/00914030390246379

International Journal of Polymeric Materials, 54:213–225, 2005

ISSN: 0091-4037 print/1543-5253 online
DOI: 101080/00914030390246379

EFFECT OF FIBER ORIENTATION ON THE MECHANICAL PROPERTIES AND FRACTURE CHARACTERISTICS OF DATE PALM FIBER REINFORCED COMPOSITES

A. A. Wazzan
Department of Chemical & Materials Engineering,
King Abdulaziz University, Jeddah, Saudi Arabia

The mechanical properties and fracture surface morphology of date palm fiber (DPF) reinforced polyester resin composites were investigated. Laminates with different orientation and volume fraction of reinforcement were prepared using resin transferred molding (RTM) processing technique. The fracture surfaces and sections through the molded composites were examined by means of scanning electron microscopy (SEM). Mechanical properties such as tensile strength, tensile modulus, ultimate elongation, the critical stress intensity factor (K_I), and the crack fracture initiation energy (G_{IC}) of composites prepared with different volume fraction of unidirectional and woven DPF reinforcement were calculated. The average tensile strength ranged between 55.2 and 86.1 MPa for long unidirectional fibers and up to 76.9 MPa for woven fibers. Incorporate, 60% volume fraction of the date palm fiber decreased the impact toughness of the unreinforced polyester matrix by 10%. Close SEM inspection showed that fiber pull-out, inter-laminar failure, and delamination were the major features of reinforced composites failure.

Keywords: natural fiber, date palm fiber, polyester resin, RTM, mechanical properties, SEM

INTRODUCTION

Composite materials based on fibers of natural polymers, such as wood cellulose fibers, recently attracted much attention due to their remarkable environmental and economical advantages.

Received 12 June 2003; in final form 22 June 2003.
The author gratefully acknowledges provision of the polyester resin and hardener by Saudi Industrial Resins LTD (SIR).
Address correspondence to A. A. Wazzan, Department of Chemical & Materials Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah 21589, Saudi Arabia. E-mail: awazzan@kaau.edu.sa

Several researchers have investigated the potential of incorporating cellulosic fibers as cost-cutting fillers in polymer matrix [1–12]. Joseph et al. [1] studied the mechanical properties of sisal fiber–reinforced polymer composite. They reported a positive reinforcing effect of sisal fiber-LDPE compared to that of LDPE matrix. Zelanko and Karfakis [2] developed a polyester-based pumpable grout for civil and mining application. Cotton-kapok fabric-polyester composite has been prepared and tested by Mwaikambo and Bisanda [3]. They compared the specific strength of the prepared composite to that of other vegetable fiber–reinforced resins. The influence of fiber treatment using alkali, bleaching, and vinyl grafting on the performance of coir-polyester composite has been investigated by Rout et al. [4]. They reported that bleached coir-polyester composites show better flexural strength whereas 2% alkali-treated coir/polyester composites show significant improvement in tensile strength. Fiber/matrix adhesion also was reported to improve with surface modification. Aquino et al. [5] studied the mechanical behavior of cellulignin-based composites. They evaluated the effect of different polymer matrices. They found that urea-formaldehyde- and epoxy-based composites can be used as alternative materials for low cost and low strength application. The effect of banana fiber surface treatments on the reinforcement-matrix interaction was reported by Pothan et al. [6]. They found that simple alkali treatment with 1% NaOH is the most effective. Al-Sulaiman [7] evaluated the performance of date palm fibers, jute, and luffa as wetting pads in evaporative cooling.

The date palm tree continues to play a significant role in the economic life of the populace of the Arabian Peninsula today as it has done throughout the recorded history of the region. Apart from its highly nutritious fruit, which provides a basic diet for man from time immemorial, the tree itself with its trunk, branches, and leaves has served to satisfy essential human needs. The abundance of date palm fronds (DPF) and date palm leaves (DPL) in the Middle East and North Africa presents an exciting opportunity to develop a low cost construction material. Approximately 100,000 tons of DPF and 15,000 tons of DPL are produced annually in the Kingdom of Saudi Arabia alone. Worldwide, an estimated 1,130,000 tons of DPF are produced annually. Recently published research works by the author and others [8–12] have focused on the utilization of date palm waste. This article reports on the mechanical properties and morphology of different date palm fibers DPF orientations and volume fraction in polyester resin composites prepared by resin transfer molding.

EXPERIMENTAL

Materials

The composites were made using SIROPOL 8420-P polyester resin with MethylEthylKetonePeroxide (MEKP) as the hardener. Saudi Industrial Resins LTD, Jeddah, Saudi Arabia, supplied the polyester resin and the hardener. The components were used in the ratio 100 parts by weight resin to 1.0 part by weight hardener, according to the specification set by the manufacturer.

The reinforcements used in this study were unidirectional and woven date palm fiber, respectively. This fabric was manufactured and supplied from a local market. The orientations of the reinforced fibers are shown in Figures 1a and b.

Resin-Transfer Molding

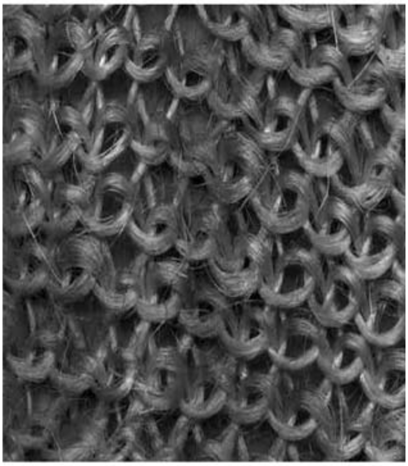
The composite was made using a Plastech Hypaject resin-transfer molding machine linked to a composite tool with a cavity that is rectangular in shape and of dimensions 250×350 mm. Prior to molding, the tool was prepared by treatment with a release agent (Frekote 44-NC) and the faces of the mold were wiped with a silicone fluid–based mold release agent. The edges of the mold were coated with high vacuum grease to aid ejection of the laminate. Once the mold was loaded with fiber it was turned such that the plane of the cavity was vertical. In this way, entrainment of air during mold filling was minimized. The resin was injected from the bottom and the air vent was positioned at the top. Prior to injection, the resin was drawn into the resin reservoir (commonly known as the homogenizer) under vacuum and the vacuum maintained until injection commenced so that degassing was possible. Injection took place with an initial pressure of 0.5 bar, which was increased toward the end of mold filling to 4 bar. A commercial resin sensor (AGC supplied by Plastech T. T.) was built into the top of the mold. Arrival of the resin at this point was indicated by a voltage signal from the sensor, which then decreased when the resin gelled. Resin was observed at the vent soon after the sensor indicated the presence of the resin. The molding was left in the mold for 3 h at 70°C for post-curing.

Fibre Volume Fraction Determination

The following composites were prepared:

1. Unidirectional composites containing 1, 2, and 3 layers of reinforcement. The composites prepared had a fiber-volume fraction of approximately 20%, 40%, and 60%, respectively.

(a)



(b)

FIGURE 1 Reinforcement patterns of the date palm fiber composites. a. Unidirectional alignment, b. woven pattern.

2. Woven composites containing 1, 2, and 3 layers of reinforcement. The composites prepared had a fiber-volume fraction of approximately 20%, 40%, and 60%, respectively. Spacers were used to change the diminutions of the mold, which had a large flexible seal, so that the volume fraction could be changed.

The fiber-volume fraction was determined using optical microscopy. Samples were taken from five different places in the laminate; they were cut with the fiber perpendicular to the surface and then polished. An area counting 100–150 fibers was selected under an optical microscope with 200× magnifications and the fiber counted. From knowledge of the average fiber diameter and the size of the selected region, the area fraction of fibers could be determined. This was then assumed to be the same as the volume fraction of fibers. The volume fraction of the woven samples was assessed in a similar manner.

Tensile Testing

Tensile testing was carried out using a computerized Instron 5568 universal testing machine. Rectangular samples with a width of 20 mm and a gauge length of 85 mm were cut from the cured laminates using a fine bandsaw and then smoothed using P1200 waterproof abrasive paper. The unidirectional composites were 1.5 mm thick, whereas those prepared with woven reinforcement structure were 3 mm thick. Clamping was achieved by wrapping a piece of emery cloth around the ends of the specimen. The measurements were carried out at $23 \pm 1^{\circ}C$ and with an extension rate of $0.5\,mm\,min^{-1}$. Results from samples that failed within the grips were excluded.

Impact Testing

Specimens cut from composites containing 0, 20, 40, and 60 vol% fibers were tested using a Charpy 6709 impact testing machine. The effects on impact properties of both reinforcement structures were investigated. Test pieces were sliced from the molded sheet using a fine bandsaw. To bring the specimens to the test dimensions, each sample was milled with a Clarkson deadlock-facing cutter and notched with $4'' \times 3/64 \times 1''$ roebuck metal slitting saw with an angle of 60°, using a Schaublin 53 milling machine. The width, thickness, and notch depth for the test specimen were 6 mm, 12 mm, and 5.5 mm, respectively. The striking velocity was set at $3.46\,m\,s^{-1}$.

Impact strength data were obtained using the linear elastic fracture mechanics (LEFM) standard for determining K_I and G_{IC} for plastics, created by the EGF task group on polymers and composites [13–14]. The test is designed to characterize the toughness of the prepared composites in terms of the critical stress intensity factor, K_I, and the energy per unit area of crack, G_{IC}, at fracture initiation using Eqs. 1 and 2.

$$K_I = \left[\frac{6Ma^{1/2}}{BW^2}\right](f\alpha) \quad (1)$$

$$M = \frac{PS}{4}$$

$$\alpha = \frac{a}{W}$$

$$f(\alpha) = 1.96 - 2.75\alpha + 13.66\alpha^2 - 23.98\alpha^3 + 25.22\alpha^4$$

where: K_I is critical stress intensity factor (MPa.m$^{1/2}$), M is bending moment, P is maximum load absorbed (N), S is support span of bend specimen (m), B is specimen thickness (m), W is specimen width (m), a is notch length (m), and $f(\alpha)$ is calibration factor.

$$G_{IC} = \frac{U}{BW\phi} \tag{2}$$

where: G_{IC} is crack fracture initiation energy per unit area (J.m^{-2}), U is energy absorbed at fracture (J), B is specimen thickness (m), W is specimen width (m), ϕ is energy calibration factor, which can be expressed as:

$$\phi = \frac{A + 18.64}{dA/d\alpha}$$

$$A = \frac{16\alpha^2}{(1-\alpha)^2}[8.9 - 33.717\alpha + 79.616\alpha^2 - 112.952\alpha^3 + 84.815\alpha^4 - 25.672\alpha^5]$$

$$dA/d\alpha = \frac{16\alpha^2}{(1-\alpha)^2}[-33.717 + 159.232\alpha - 338.856\alpha^2 + 339.26\alpha^3 - 128.36\alpha^4] + 16[8.9 - 33.717\alpha + 79.616\alpha^2 - 112.952\alpha^3 + 84.815\alpha^4 - 25.672\alpha^5]\left[\frac{2\alpha(1-\alpha) + 2\alpha^2}{(1-\alpha)^3}\right]$$

RESULTS AND DISCUSSION

Tensile Testing

Figure 2 shows the ultimate tensile strength (UTS) for the composites as a function of structure and volume fraction percentage of date palm fiber reinforcement. There is a gradual increase in the UTS with increasing reinforcement phase volume fraction for both unidirectional and woven structure. But, the UTS of the composite prepared

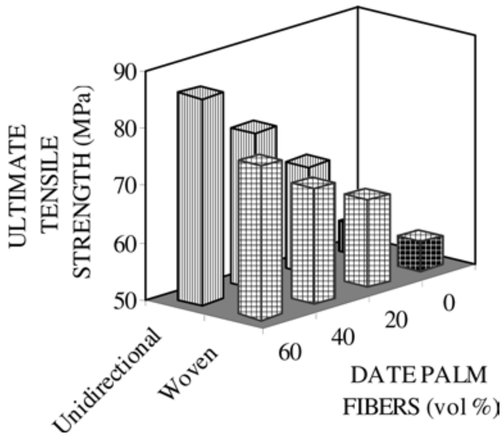


FIGURE 2 The effect of date palm fiber vol% on the ultimate tensile strength of composites prepared by resin transfer molding.

with woven reinforcement structure has lower value comparing to the unidirectional reinforcement composites.

The ultimate elongation for the date palm/polyester composites with different structure and volume fraction are shown in Figure 3. For the composites with woven structure of reinforcement, increasing the volume fraction from 0 to 60 vol% leads to a continuous increase in the ultimate elongation. The order of increase in ductility is high as was observed for unidirectional composite specimens.

Figure 4 shows the effect of the presence of date palm fibers on the Young's modulus for both unidirectional and woven composites. The Young's moduli measured for the unidirectional composite of 0, 20, 40, and 60 vol% were 3.8, 3.91, 4.05, and 4.17 GPa, respectively. For the woven structure reinforcement specimens the Young's moduli measured for the composites of 0, 20, 40, and 60 vol% were 3.8, 3.84, 3.96, and 4.08 GPa, respectively. These data are in good agreement with the values of 3.8, 3.94, 4.08, and 4.22 GPa, respectively, calculated using the simple rule of mixtures.

The variation in the tensile testing results between unidirectional and woven reinforcement structure is expected, because in the woven structure half of the reinforcement volume fraction percentage is in the transverse position and therefore, it will not transfer load as much as the unidirectional composites specimens.

Scanning electron micrographs of some of the tensile fracture surfaces for unreinforced and reinforced polyester composites prepared by resin transfer molding are shown in Figures 5 and 6, respectively.

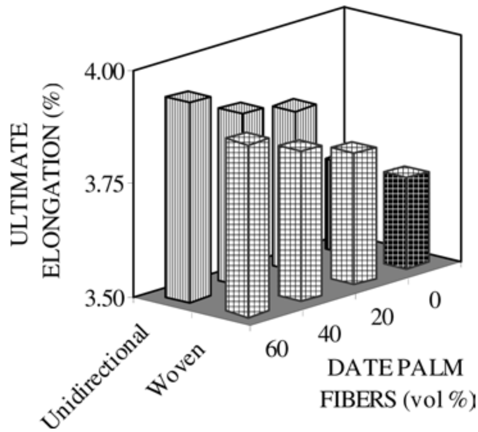


FIGURE 3 The effect of date palm fiber vol% on the ultimate elongation of composites prepared by resin transfer molding.

The fracture surface of the unreinforced specimen appears as expected for such a thermoset resin with a typical brittle fracture pattern, which is very similar to the brittle river pattern found in the cleavage fracture of metal. Observing the river pattern in Figure 5 several fracture paths can be seen. All of them initiate from the right toward the left of the micrograph. The fractures intersect each other in the top left

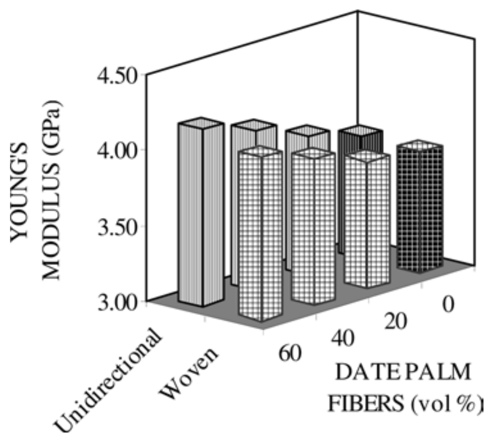


FIGURE 4 The effect of date palm fiber vol% on the Young's modulus of composites prepared by resin transfer molding.

FIGURE 5 SEM micrograph showing the fracture surface of unreinforced polyester resin specimen. A typical river pattern brittle fracture is noticeable.

corner of the micrograph, which appears as a bright line. Figure 6 shows the fracture surface of 20% date palm fiber−reinforced composite specimen, from which fiber pullout and delamination can be

FIGURE 6 SEM micrograph showing fracture surface of 20% volume fraction unidirectional date palm fiber composite. Fiber pull-out is evidently clear.

seen to be the major features. Closer inspection shows that there is little matrix material adhered to the fibers, indicating a comparatively weak interface despite the roughness of the date palm fiber surface. Interfacial failure is suggested by the micrograph of the date palm fiber composite specimen, as there is little trace of matrix material around the reinforcing fiber.

Impact Testing

Rectangular beam specimens were cut from the cured resin transferred molding plates and notches of up to 50% of the width were machined. Before testing, a razor was employed to introduce a sharp notch into the tip of each specimen. A thin layer of pure petroleum jelly (Vaseline) was applied on the central portion of the specimen to avoid hammer oscillation and specimen vibration. The results for the crack fracture initiation energy (G_{IC}) and the critical stress intensity factor (K_I) determined using Eqs. 1 and 2 are given, respectively, in Figures 7 and 8. The obtained data show a clear dependence on both the structure and volume fraction of the reinforcement phase. Both properties decrease with the volume fraction of reinforcement, regardless of structure. It can clearly be seen from this plot that the value of the fracture energy decreases as date palm volume fraction increases from 0.22 KJ.m^{-2} for the unreinforced polyester resin to $\cong$0.2 KJ.m^{-2} for the 60% unidirectional date palm fiber reinforced composite. The

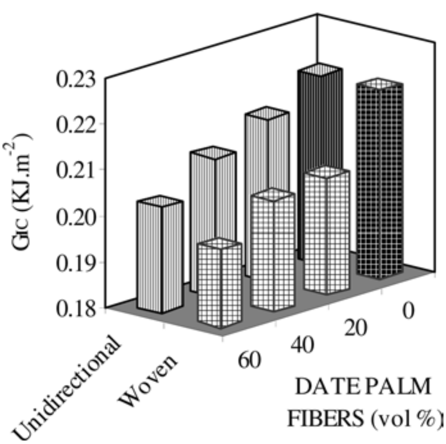


FIGURE 7 The effect of date palm fiber vol% on the crack fracture initiation energy of composites prepared by resin transfer molding.

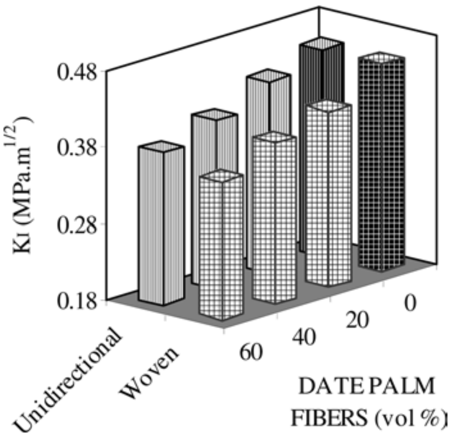


FIGURE 8 The effect of date palm fiber vol% on the critical stress intensity factor of composites prepared by resin transfer molding.

effect of increasing the reinforcement volume fraction on the impact properties is opposite to that observed on the tensile properties. This can be attributed to the fact that natural fibers are not capable of transferring the load to the matrix at a high rate. On the other hand, the change of reinforcing phase orientation has the same effect on the nature of the variation in the tensile and impact properties. The fracture toughness K_I of unidirectional and woven composites as a function of date palm fiber volume fraction is shown in Figure 8. The data, as expected shows the same behavior as the fracture energy. It is found that fracture toughness for 20% unidirectional reinforced composite has a higher value ($0.43\,MPa.m^{1/2}$) than that of the composite reinforced with 20% woven structure ($0.41\,MPa.m^{1/2}$). A similar observation was also reported by Mwaikambo and Bisanda [3] in their study of the performance of cotton-kapok fiber-polyester composite. They reported a decrease in the impact strength with increase in fiber volume fractions for both treated and untreated prepared composites.

Representative Scanning electron micrographs of the composite impact fracture surface are presented in Figures 9 and 10 for unreinforced and reinforced date palm fiber composites, respectively. The fracture mode was purely brittle for both unreinforced and date palm fiber reinforced composites. Figure 10 also shows clearly the surface roughness of the date palm fiber reinforcement. Despite the rough nature of the fiber surface this does not contribute positively to the fiber/matrix adhesion.

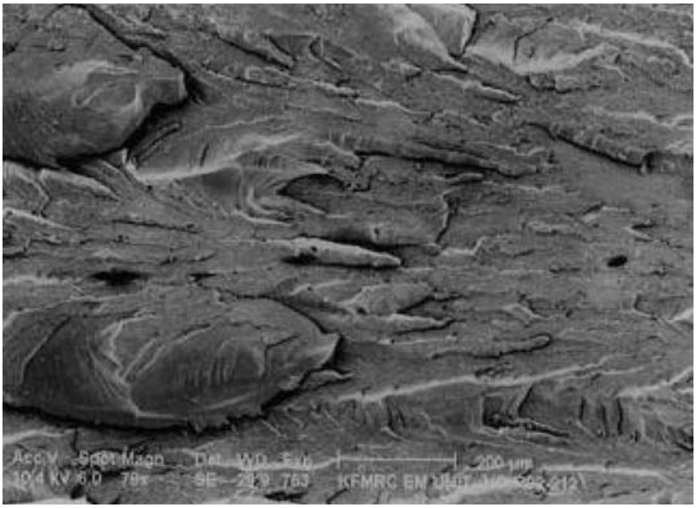


FIGURE 9 SEM micrograph showing impact fracture surface of unreinforced polyester resin specimen.

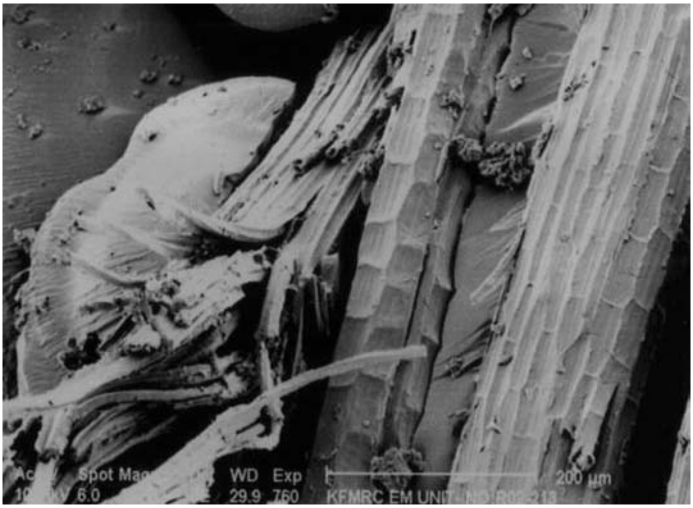


FIGURE 10 SEM micrograph showing the fracture surface of composite with 40% volume fraction woven date palm fiber. Fiber roughness and delamination is clearly observed.

CONCLUSIONS

As a result of the research work carried out the following conclusions are made:

1. Unidirectional and woven structures of date palm–reinforced composites were prepared successfully by resin transfer molding technique.
2. The tensile and impact properties of the reinforced composites with different volume fraction of reinforcement were investigated.
3. The tensile properties of the unidirectional and woven structure were improved by the addition of reinforcing phase. Conversely, the critical stress intensity factor (K_I) and the crack fracture initiation energy (G_{IC}) were adversely affected by the presence of the date palm fibers for both structures.
4. Investigations of fracture surface morphology using scanning electron microscopy show that inter-laminar failure and delamination always occurred along the fiber/matrix interface.

REFERENCES

[1] Joseph, K., Varghese, S., Kalaprasad, G., Thomas, S., Prasannakumari, L., Koshy, P., and Pavithran, C. *European Polymer Journal*, **32**, 1243 (1996).

[2] Zelanko, J. C. and Karfakis, M. G. *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstract*, **34**, 595 (1997).

[3] Mwaikambo, L. Y. and Bisanda, E. T. N. *Composites* **18**, 181 (1999).

[4] Rout, J., Misra, M., Tripathy, S. S., Nayak, S. K., and Mohanty, A. K. *Composites Science and Technology*, **61**, 1303 (2001).

[5] Aquino, R. C. M. P., D'Almeida, J. R. M., and Monteiro, S. N. *Journal of Materials Science*, **36**, 231 (2001).

[6] Pothan, L. A., George, J., and Thomas, S. *Composite Interfaces*, **9**, 335 (2002).

[7] Al-Sulaiman F. *Energy Conversion and Management*, **43**, 2267 (2002).

[8] Wazzan, A. A., Iskanderani, F. I., and Alp, T. (2001). Proceedings of 6th Arab International Conference on Polymer Science and Technology, Egypt, p. 447.

[9] Alp, T., Wazzan, A. A., and Iskanderani, F. I. (2001). Proceedings of 6th Arab International Conference on Polymer Science and Technology, Egypt, p. 491.

[10] Iskanderani, F. I., Alp, T., and Wazzan, A. A. (2001). Proceedings of 6th Arab International Conference on Polymer Science and Technology, Egypt, p. 465.

[11] Al-Sulaiman, F. *Applied Composite Materials*, **9**, 369 (2002).

[12] Abdul-Rahman, H. H., Al-Juruf, R., Ahmad, F., and Alam, I. *International Journal of Cement Composites and Lighweight Concrete*, **10**, 175 (1988).

[13] Williams, J. G. European Testing Protocol, Imperial College, U.K. (1990).

[14] William, F. B., Jr., and Srawley, J. E. (1966). *Plane Strain Crack Toughness Testing of High Strength Metallic Materials*, (American Society for Testing and Materials, Philadelphia, PA), 13.