EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES AND WATER OBSORPTION OF NATURAL FIBER- REINFORCED POLYSTER COMPOSITES

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الملخص

زاد الاهتمام حديثا باستخدام الألياف الطبيعية، سواء كانت نباتية أو حيوانية، في صناعة المواد المركبة الحديثة وفى مجالات البحوث الأكاديمية والصناعية، لما لها من خصائص مميزة مثل خفة الوزن ورخص الثمن والتوفر الدائم وسهولة التصنيع وإمكانية التدوير الصناعي وصداقتها للبيئة. من بين هذه الألياف نذكر ألياف القنب والنخيل والحلفاء وجوز الهند والتبن وقشور اللوز وقشور الموز وشعر الحيوانات والأخشاب. ومن أهم مجالات تطبيقاتها صناعة وسائل النقل والديكور والسلامة الصناعية مثل صفائح الأبواب والأسقف، الأرضيات ولوحات التحكم ولوحات الأسلاك الكهربائية والمقاعد والأغطية الخارجية وقبعات السلامة ومستلزماتها. هذه الاستخدامات المتعددة جعلتها مجالا للبحث ولمعرفة خواصها الطبيعية والميكانيكية تحت تأثير البيئة والأحمال والقوى المختلفة.

يقدم هذا البحث دراسة معملية على الخواص الميكانيكية وتأثير امتصاص الماء لهذه المواد. لهذا الغرض تم تصنيع نوعين من صفائح المواد المركبة بطريقة التصنيع اليدوي (أبعادهما:30 x 600 x 600 ملمتر). النوع الأول استخدمت فيه ألياف النخيل والنوع الثاني استخدمت فيه ألياف القنب مع خلط كل نوع بمادة رتانج البوليستر كمادة لاصقة للألياف. تم إعداد العينات من النوعين حسب المواصفات القياسية لغرض إجراء تجارب امتصاص الماء واجهادات الكلل والشد عليها. أجريت تجارب امتصاص الماء عند درجة حرارة 95 درجة مئوية وحددت كمية امتصاص الماء بطرح وزن العينة قبل وبعد امتصاص الماء. كما أجريت اختبارا ت اجهادات الكلل واجهادات الشد الاعتيادية عند درجة حرارة الغرفة. من أهم النتائج المتحصل عليها هي أن سلوك النوعين المصنعين لامتصاص الماء هو سلوك يعرف بسلوك فيكن. نسبة امتصاص الماء للمواد المركبة المصنعة من ألياف النخيل هي 2.8% وللمصنعة من ألياف القنب هي 2%. وكانت قيمة اجهادات الكلل 60 MPa للنوعين.

ABSTRACT

Natural fibers have recently become attractive in many of industrial applications as one of the alternative reinforcement for traditional fibers such as glass and carbon fibers. This attractive related to their mechanical properties, low cost, low density, renewability and recyclability. One of the major fields of application can be found in non structural components for automotive industry such as door rims, panels and safety helmets.

This paper presents an experimental study on mechanical properties and water absorption behavior of natural fiber-reinforced polymer composites. Two types of natural fibers composite laminates were manufactured; the first one is made from hemp fiber reinforced with polyester and the second is made from palm fiber reinforced with polyester resin. Both laminates have dimensions of 600×600×30 mm. In order to carry out the water absorption, fatigue and tensile tests several specimens were cut and

fabricated from hemp and palm laminates. In the water absorption test, the percentage of water absorption content was found from the change in mass of the samples before and after immersing them in water at 95°C. Fatigue tests were carried out at room temperature using Avery- Dension machine (Type 7305). The tensile tests were made using the Pivol Universal Tensile Testing Machine with a crosshead speed of 10 mm/min. The results indicated that the mechanism of water absorption of the two composite follows the Fickian behavior. The percentage of water absorption was 2.8% and 2% for hemp and palm fibers reinforced polyester composites respectively and the fatigue limit of both fibers composites were 60 MPa.

KEYWORDS: Natural Fibers; Polyester; Water Absorption; Fatigue stress; laminates.

INTRODUCTION

The use of natural fiber for the reinforcement of the composites has received increasing attention both by the academic sector and the industry. Natural fibers including flax, hemp, jute straw, wood, rice husk, wheat, barley and oats have many significant advantages over synthetic fibers [1]. They are environmentally friendly, abundantly available, renewable and cheap and have low density. Plant fibers are light compared to glass, carbon and aramid fibers. The biodegradability of plant fibers can contribute to a healthy ecosystem while their low cost and high performance fulfils the economic interest of industry. Natural fiber composites are used in place of glass mostly in non-structural applications. Figure (1) shows some of applications of natural fibers reinforced-polymer composite materials in automotive components and safety helmets [2].

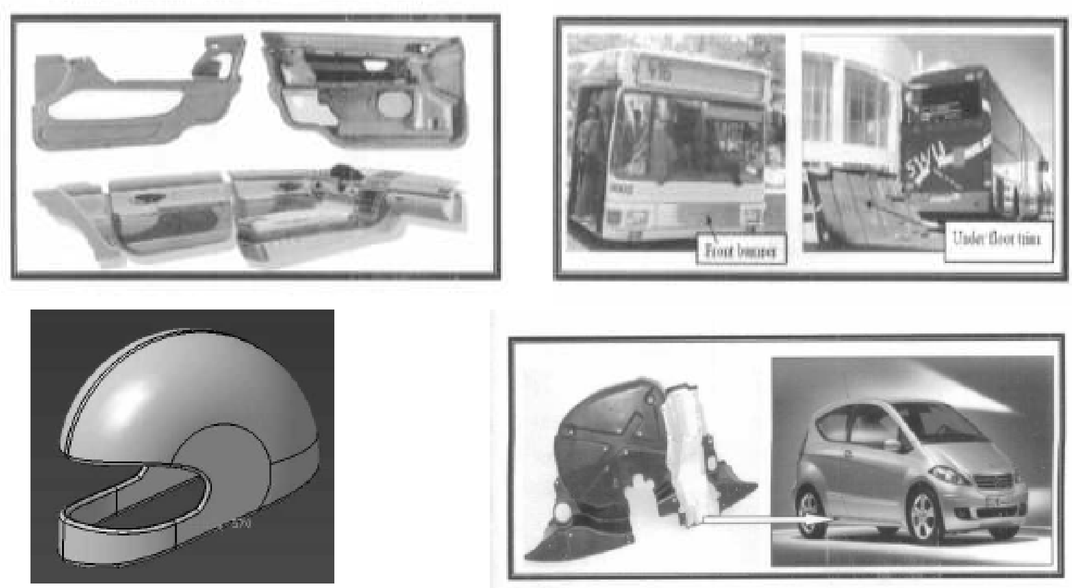


Figure 1: Applications of natural fibers reinforced-polymer composite materials

The mechanical and physical properties of natural fibers vary considerably, depending on the chemical and structural composition, fiber type and growth conditions [3]. Mechanical properties of plant fibers are much lower when compared to those of the most widely used competing reinforcing glass fibers. However, because of their low density, the specific properties (property-to-density ratio) such as strength and stiffness are comparable to the values of glass fibers [4]. Luo and Netravali demonstrated that the mechanical properties of natural fiber can be improved by surface treatment and compatibilizing agents prior to the fabrication of composite.

One of the main concern for the use of natural fiber reinforced composite materials is their susceptibility to water absorption and its effect on physical, mechanical and thermal properties [5]. Several studies have shown that the sensitivity of certain mechanical and thermal properties to the water uptake can be reduced by the use of coupling agents and fiber surface treatments [6, 7]. Dhakal et al [8] studied the effect of water absorption on the mechanical properties of natural-fiber-materials reinforced thermoplastics based on flax Fibres and polypropylene and they concluded that the tensile and flexural properties of specimens decreased with increase in percentage water uptake. Water induced degradation of composite samples was significant at elevated temperature. The water absorption mechanism of these composites at room temperature was found to follow Fickian behavior, whereas at elevated temperatures it exhibited non-Fickian.

EXPERIMENTS

Materials

Natural fibers used in this study are hemp and palm natural fibers as shown in Figure (2). The hemp fiber is also called cannabis sativa. The Hemp is an annual herbaceous plant native to Asia and widely cultivated in Europe. It is commercially available in local markets [9]. Whereas the palm fiber was collected manually from palm threes. The resin was based on commercially available unsaturated polyester; Trade Name is Scott-Bader, crystic 123 Pa (non-accelerated chemical isophthalic polyester resin). The resin was mixed with curing catalyst, methyl ethyl ketone peroxide at a concentration of 0.01 w/w of the resin for curing.

(a) **(b)**

Figure 2: Natural fibers (a): palm fibers and (b): hemp fibers

Manufacturing of Composite laminate

The hand- lay up technique was used to manufacture composite laminate. Two wooden smooth plates with dimension of 600x600x30 mm were fabricated to use as working plates as illustrated in Figure (3). The natural fibers were dried at 100 ^{o}C to remove the moisture in an electric oven. The first layer of fibers was stacked in the wood working plate, which was coated with wax as release agent and then wetted by a mixture of polyester resin and catalyst (hardener), ratio of (100:1). Carefully the wetted fibers were pressed to remove the trapped air by passing a small steel roller with smooth surface.

This procedure was repeated for next layers until obtain the required thickness (7 mm). Finally, the wetted laminate was covered with the top wooden plate and the whole assembly was clamped and lifted to cure at room temperature for 24 hours. Subsequently, the cured laminate plate was post-cured at 80 ^{o}C for three hours. Figure (4) shows the hemp and palm composite laminated plates after curing respectively.

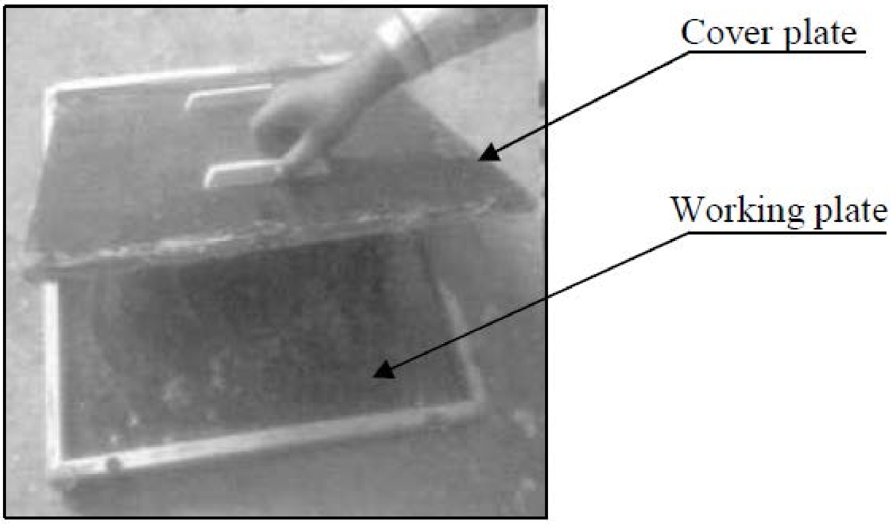


Figure 3: working wooden and cover plates for using to manufacturing the natural composite laminates.

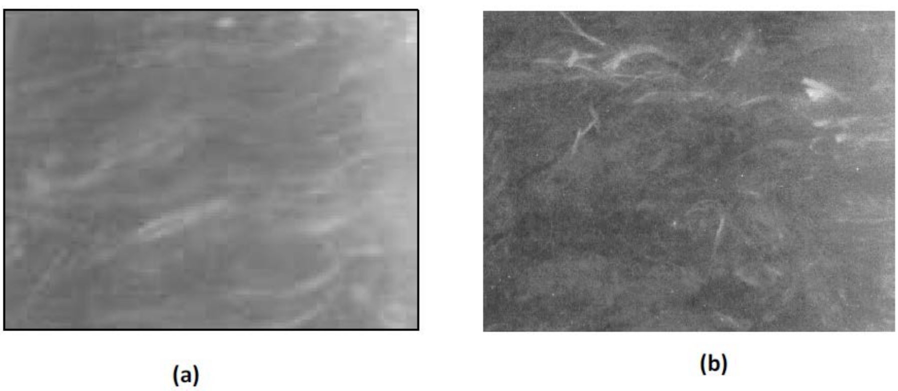


Figure 4: composite laminates after curing, (a) hemp fiber, (b) palm fiber.

Water Absorption Tests

Several specimens with dimension of 30×30mm were cut from each type of a composite laminate for water absorption test. Sea and fresh water were used. The test procedure was carried out in accordance with BS EN ISO 62:1999 [10]. All the specimens were conditioned by immersion in water at 95 ^{o}C, in a small stainless steel tank provided by an electric heater, until saturation time was achieved as indicated by no further change in weight. The use of this fairly high temperature enabled saturation to be achieved in a matter of days. Water absorption was measured by periodically removing specimens from the water tank, weighing, and returning them in the tank. To check whether any leaching of material had been take place, some additional samples were dried at 100 ^{o}C after weighing then reweighed to ensure whether there had been any weight change. No significant effects were observed. The percentage of water absorption content can be found from the change in mass of the samples before and after immersing in the water as:

$$\overline{M} = \frac{W_w - W_d}{W_d} \times 100 \quad (1)$$

Where: W_w and W_d are wet and dry weights of the specimen respectively.

Fatigue Tests

In order to carry out fatigue tests on the hemp fiber composite and palm fiber composite laminates, several specimens from each type were cut, fabricated and machined to their final shape (31 ×89 ×7 mm) as shown in Figure (5) [10].

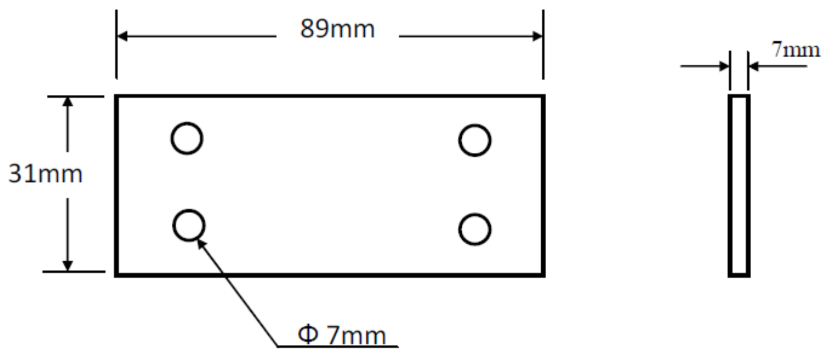


Figure 5: A schematic view of the fatigue specimen

All the specimens were fatigue testing using Avery- Dension machine (Type 7305). Figure (6) shows a photograph of this machine.

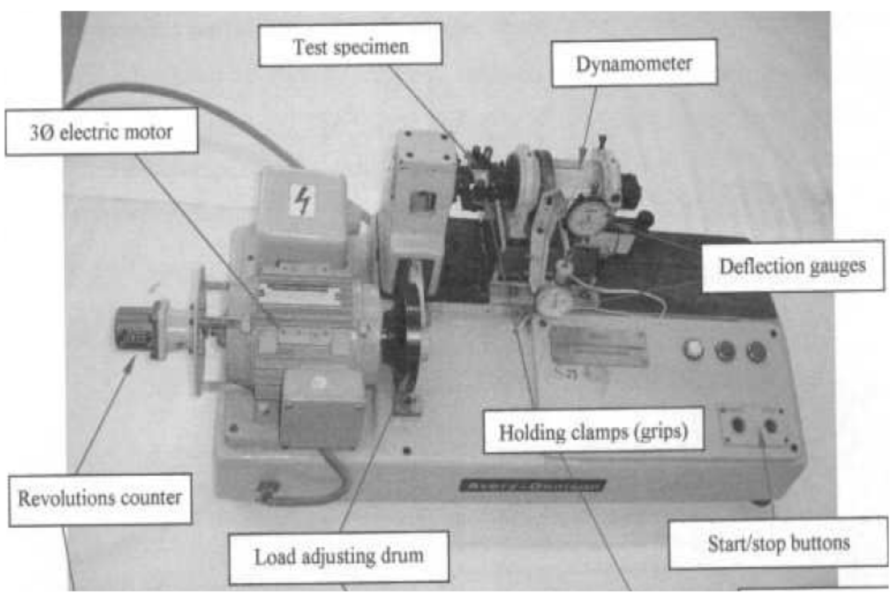


Figure 6: Photograph of the Avery-Denison Fatigue Testing Machine (type 7305).

The fatigue tests were accomplished at unit stress ratio ($R = \frac{\sigma_{\min}}{\sigma_{\max}} = -1$) on pure bending loading condition [9]. The fatigue stress of each tested specimen can be calculated by known bending equation [9] as follows:

$$\sigma_B = \pm \frac{M\,y}{I} \tag{2}$$

Where:
$\boldsymbol{\sigma_{max}}$, and $\boldsymbol{\sigma_{min}}$ are the maximum and minimum working stresses (MPa), $\boldsymbol{\sigma_B}$ is the bending stress (MPa), ***I*** is the moment of inertia of the specimen (mm^4), ***Y*** is the distance above the centroid of the specimen (mm). ***M*** is the bending moment of the specimen (N-m) and can be calculated in term of deflection of the dynamometer of the machine as:

$$M = K\,\Delta \tag{3}$$

Where ***K*** is a constant which can be determined by using the deflection equation of a beam under pure loading. The manufacturer of the machine determined the value of the ***K*** **as 18.372** with negligible error. ***Δ*** is the deflection of the dynamometer (mm). The corresponding number of cycles (***N***) can be recorded directly from the revolution counter of the machine for each tested specimen. Finally, the performance curve of tested specimens can be obtained by plotting fatigue stresses versus number of the cycles to failure.

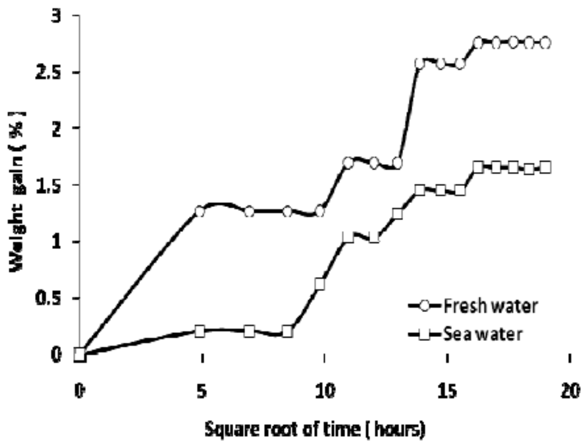
Tensile Tests

In-plane axial tensile tests were curried out to determine the strength and Young's modulus of the hemp fiber and palm reinforced composites. Three specimens from each type of composite laminate plate were individually cut and prepared to their final dimensions (300× 25×7 mm) according to the British Standard 2782: part 10: method 1003: 1977 [10]. The tensile tests were carried out using the Pivol Universal Tensile Testing Machine with a crosshead speed of 10 mm/min in [10].

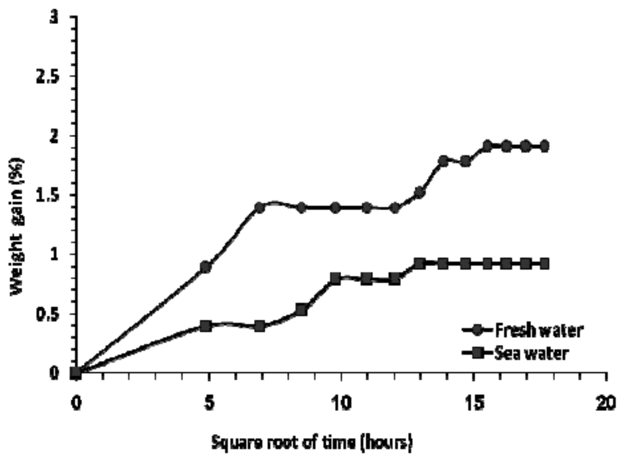
RESULTS AND DISCUSION

Water Absorption Test

Figure (7) shows the variation in weight gain, as percentage of original dried specimen weight versus square root of time for both fresh water and sea water at 95^{o}C for a period of 264 hours. The choice of the square root of time as the abscissa was made as Fickian behavior predicts an initial linear relationship between the weight gain and time [11]. It can be noted that the initial part of curves was linear which indicated that the weight gain increases with time due to effect of temperature. The curves become increase in manner of steps. The first step or flatten indicated that the first saturated time was reached and after that the curves increased gradually to reached the second step and so on until reached to saturated time in which no change in weight gain was observed. The increase of the curves suggested that the volume of specimen increased due to swelling phenomena and therefore allows absorbing more water to compensate the change in volume. Swelling phenomena in composite materials has been observed by many researchers such as Adamson [12] who stated that composite materials swelling due to effect of water absorption and elevated temperature leads to induce thermal stresses and micro cracks. The water gain percentage of sea water in both types of composites was lower than in the fresh water. A possible reason for such behavior related to the presence of salt particles in sea water, which probably reduce the diffusion of water into the specimens. Furthermore, the hemps fibers composites exhibited higher water absorption than the palm fibers reinforced composites which probably related to the nature of the hemp fibers.



(a)



(b)

Figure 7: Weight gain versus square root of time for (a): hemp fibers reinforced polyester composites and (b): palm fibers reinforced polyester composites

Fatigue Tests

Figure (8) shows the fatigue stress versus number of cycles for hemp and palm fibers reinforced composite laminates. The both curves follow the traditional curves of fatigue behavior in the most of engineering materials. The curves started with high values of fatigue stress about 104 MPa for both materials. At low number of cycles, the palm fiber composites exhibited higher values of fatigue stress than the hemp fiber composite.

In both curves, the fatigue stresses decreased as the number of cycles increases until reached to the fatigue limit, in which the fatigue stress becomes approximately constant with increase of number of cycles. The fatigue limits of both fibers composites is 60 MPa.

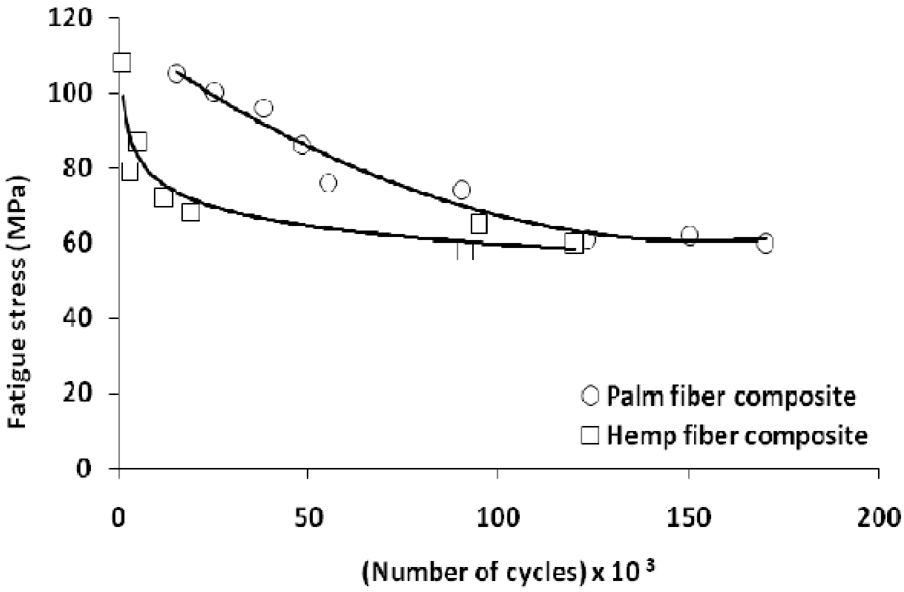


Figure 8: Fatigue stress vs. number of cycles for palm and hemp fiber composites Fracture Modes of the Fatigue Specimens

Figure (9) shows two tested specimens of hemp and palm reinforced polymer composites. The both specimens exhibited similar transverse cracks through the thickness near the ends.

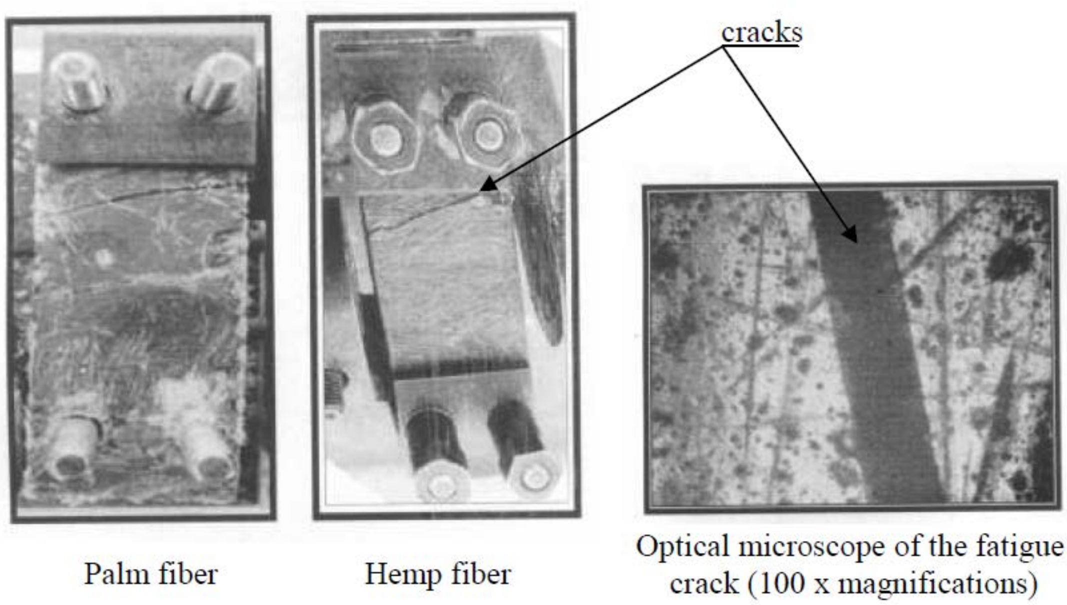


Figure 9: Fracture modes of tested specimens under fatigue loading

CONCLUSIONS

On the bases of the results obtained in this study, the following conclusion can be drawn:

- The hemps fibers composites exhibited higher water absorption than the palm fibers reinforced composites. This difference in water absorption is probably caused by the nature of the fibers.
- The absorption of sea water by both composites was found to be lower than the absorption of fresh water.
- The fatigue limit of both fibers composites was 60 MPa
- The fracture mode of tested specimens under fatigue loading is a transverse crack near one of its ends.

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NUMENCLATURES

M bending moment (m-N)
$\bar{M}$ Percent of water absorption
I moment of inertia (m^4)
K constant
R stress ratio
Y distance above the centroid of specimen.
W_w wet weights of the specimen.
W_d dry weights of the specimen.
σ_{max}, maximum working stresses (MPa).

σ_{min} minimum working stresses (MPa).

σ_B the bending stress (MPa).

Δ deflection of the dynamometer (mm).