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Mechanical Properties of Polyvinylchloride (PVC) Reinforced Hemp Fibers Composites

الخصائص الميكانيكية لمؤلفات البولى فينيل كلورايد ونبات التيل كألياف طبيعية

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ملخص

تعتبر مادة البولي فينيل كلورايد من المواد البلاستيكية وتتميز برخصها، متانتها، ومرونتها و هى من أكثرها تنوعاً وتلعب دورا هاماً في صناعة البلاستيك. فى هذا البحث تم دراسة تأثير تقوية البولي فينيل كلورايد بإستخدام آلياف التيل لذا تم إضافة آلياف التيل بنسب ٤،٤٦٪، ٦،٢٪، ٧،٧٥٪، ٩٪، ١١٪ ، وقد تم دراسة تأتير وزن الآلياف المضافة على إجهاد الشد وإنفعال المؤلف وقد اظهرت النتائج أن أقصى إجهاد الشد كان عند إضافة الآلياف بنسبة ٦،٢٪ من الوزن الكلى للمؤلف حيث تحسن إجهاد الشد لمؤلفات البولي فينيل كلورايد ٧٥، ٥٥ وآلياف التيل بنسبة ٣٤،٩٣٪، ٥٤،٨٪ على الترتييب. تم وضع آلياف التيل عند نسبة ٦،٢٪ من الوزن الكلى للمؤلف طوليا، بزاويه ٤٥ درجة، أفقيا، عشوائيا وتم دراسة تأثير تغيير إتجاه ألياف التيل فى المؤلف على الإجهاد والإنفعال وقد بينت النتائج أن إجهاد الشد عند الوضع الطولى أكبر من إجهاد الشد عند أى إتجاه آخر. كذلك تحسن إجهاد الشد كثيراً عندما كانت الآلياف منسوجة وقد تم دراسة تأتير آلياف التيل على صلادة البولي فينيل كلورايد.

ABSTRACT

Polyvinyl-chloride (PVC) is inexpensive, durable, and flexible thermoplastic material. PVC is one of the most versatile thermoplastics, and plays an important role in the plastic industry. This paper investigated the mechanical properties of reinforcing PVC by hemp fibers. Hemp fibers were added at different weight fractions (4.46%, 6.2%, 7.75%, 9%, and 11% wt). Influence of fiber's content on composite tensile strength and strain were revealed and the results showed that, at 6.2% wt the tensile strength of PVC 75, PVC 55 with hemp fiber composites was improved by 34.93% and 54.8% respectively. At 6.2% wt, the fibers were longitudinally, at 45°, horizontally, and randomly oriented. The influences of fiber's orientation on both stress and strain of the composites were studied and the results showed that, when the fibers were longitudinally oriented, the tensile strength of the composites was higher than that of the other fiber's orientation. Also, the tensile strength of the composites at 6.2% wt was highly improved, when the fibers were weaved. The effect of hemp fiber on the hardness of PVC was deliberated.

Key wards: PVC, Hemp fibers, NFRPCs, Tensile strength (Ts), and Hardness number.

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1. INTRODUCTION

Generally natural fibers also give positive outcome to the stiffness of the composites while decreasing the density [1]. Increased environmental awareness and consciousness throughout the world has developed an increasing interest in natural fibers and its applications in various fields [2]. The main disadvantages of using lignocellulosic fibers in thermoplastics are their poor filler–matrix interaction [3]. Lignocellulosic fibers like, sisal, coconut fiber (coir), jute, palm, bamboo, and wood have many advantages, including that, they are biodegradable and renewable, with acceptable specific properties compared to glass fibers [4]. The main disadvantage of natural fibers is their hydrophilic nature, which results in incompatibility with hydrophobic polymeric matrices leading to poor composite mechanical properties [5]. Since the past few decades, research and engineering interest has been shifting from traditional monolithic materials to fiber reinforced polymer-based materials due to their unique advantages of high strength to weight ratio [6]. Natural fiber composites are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions [7]. Fiber composites can withstand higher stresses than either of their individual constituents because the fibres and matrix interact and redistribute the stresses [8]. The use of agro-based fibers in paper and composite products has increased in research in the fields of chemical and materials science [9]. Natural fiber composites can be mixed and molded using high intensity, high volume production machinery where the processing temperature is typically kept below 200 °C [10]. The use of natural polymers was superseded in the 20th century as a wide-range of synthetic polymers was developed based on raw materials from low cost petroleum [11]. The greatest growth potential for NFRPCs is in the building industries, and products known as "wood-plastic composites" include decking, industrial flooring, landscape timber, and molding [12]. Insufficient adhesion between hydrophobic polymers and hydrophilic fibres result in poor mechanical properties of NFRPCs [13]. The purpose of the present work is to evaluate the mechanical properties of the PVC and hemp composites at different fiber's content and investigates the effect of fiber's orientation.

2. EXPERIMENTAL WORK

PVC sheet was formed by injection molding machine of type (HAITIAN 320 TON). Two types of PVC were used PVC 75 and PVC 55. PVC sheet was cut into layers of 50x15x3mm and weighted together using a sensitive balance of accuracy 0.001 gram. Pure PVC 75 was compacted at 1.8 MPa under steady heat source of 170 °C for 10 minutes. But PVC 55 was exposed to steady heat source of 160 °C for 10 minutes under compaction of 1.2 MPa.

Hemp fibers were used which cut into 50mm length. Hemp fibers were added at 4.46%, 6.2%, 7.75%, 9%, and 11% wt with different orientation.

The composites were prepared using the classical "contact method". The die was cleaned well and a foil of aluminum was placed inside the die to prevent the direct adhesion between the specimen and the lower part of the die. PVC layer was placed above the aluminum foil and the fibers were added at suitable fraction above PVC layer. The composite was completed by a second layer of PVC above the fibers then the aluminum foil was placed to prevent the direct contact between the punch and fibers.

Specimens with 15 mm width and 50 mm length were cut from the manufactured parts for tension test. The tensile test was performed on Computerized Universal Testing Machine (model WDW-300, serial no: 5126 EXW Date 2010 Y05M, China) with a 5KN load cell. The specimens were clamped by the machine jaws and the test was at constant strain rate of 2.5 mm/min. Three samples were tested at each fiber's content and the average results have been reported. Hardness test was done using shore. Scanning electronic microscope (SEM) was used to examine the fracture samples.

3. RESULTS AND DISCUSION

Figures 1 and 2 show the stress strain curves of bench mark values of both pure PVC 75 type and PVC 55 type.

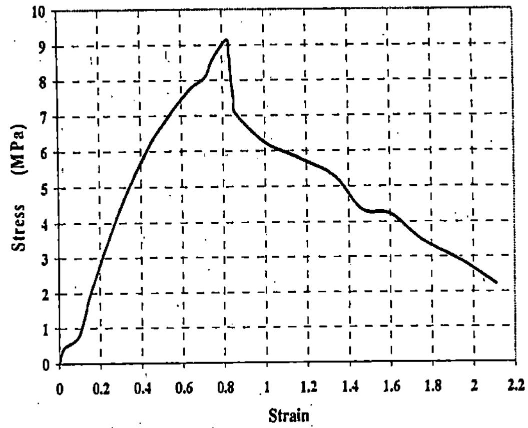


Fig.1 Stress and strain curve of pure PVC 75

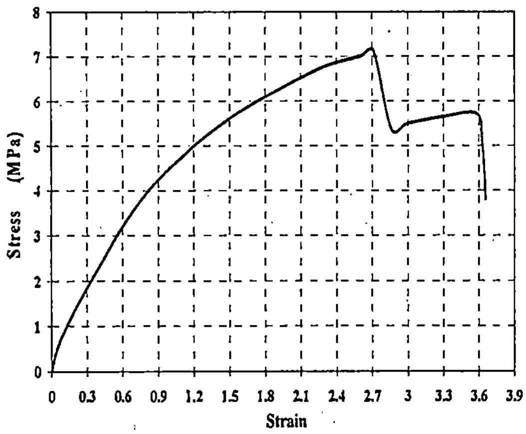


Fig.2 Stress and strain curve of pure PVC 55

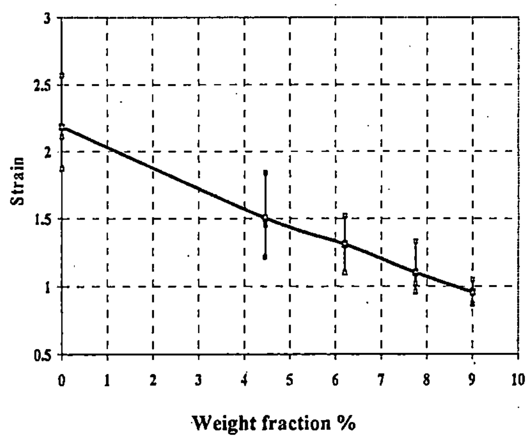


Fig.4 Strain of PVC 75/hemp fiber composites

It was found that at 11% wt of fiber PVC 75 layers were separated from hemp fibers as soon as the applied pressure was removed due to higher fiber's content.

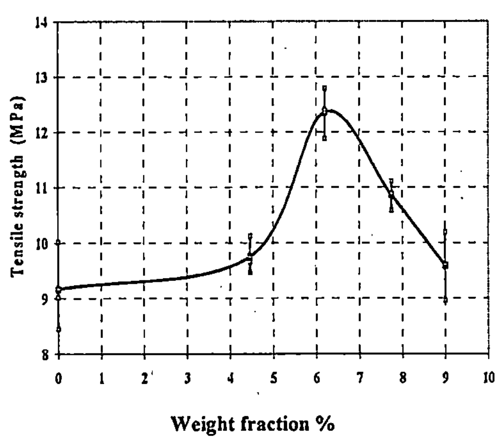


Fig.3 Ts of PVC 75/hemp fiber composites

Addition of hemp fibers to PVC 75 has a positive effect on the stress of the composite as shown in Figure 3. Hemp fibers improved the strength of the composite greater than that of pure PVC due to strong interface bonds, and improved interfacial adhesion.

The stress of the composite at 6.2% wt of fiber was greater than that of the other fiber's content where; the average tensile strength was increased by 34.93% greater than that of pure PVC 75. This ascribed to better coherent between the fibers and matrix. Increasing of the fiber's fraction decreased the tensile strength less than that at 6.2% where, the average tensile strength of the composites at 7.75% and 9% wt was only increased by 18.6%, 4.63% respectively. Because of greater fiber's content reduced the interfacial bonds, decreased the adhesion between the fibers and matrix, and weaken the filler–matrix interfacial adhesion, so, crack initiation and its propagation will be easier. Also, at 4.46% wt the average tensile strength was improved by only 6.44% higher than that of pure PVC 75 due to lower fiber's fraction, which reduced the composites resistance to carry the load. The strain of the composites was lower than that of pure PVC 75 due to increased stiffness and rigidity of the composite as illustrated in Figure 4. The strain of the composite was inversely proportional with the fiber loading where the ductility of the composites at 4.46% wt was higher than that at 6.2%, 7.75%, and 9% and reduced by 31.14%. But the ductility at 6.2%, 7.75%, and 9% of fiber was reduced by 40%, 49.47%, and 56% respectively.

At fiber loading of 9% wt, there was no connection between PVC 55 and hemp fibers due to higher fiber fraction, so the fibers were separated from the matrix.

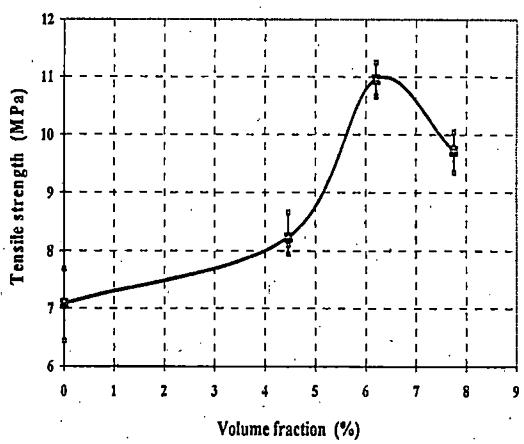


Fig.5 TS of PVC 55/hemp fiber composites

As expected, the strength of the PVC 55 was improved, when it reinforced with hemp fibers as represented in Figure 5 because of, the improving of interfacial bonds, and the improving of adhesion between PVC 55 and fibers which ascribed to favorable interactions and good contact between them. At fiber's content of 6.2% wt, the average tensile strength of the composite was improved by 54.8% greater than that of pure PVC 55 due to better adhesion between fiber and matrix. The average tensile strength was decreased as the fiber's content decreased below 6.2% wt this due to lower fiber's fraction, and bad transfer of loads from matrix to fiber. Therefore, the composite resistance to withstand loads is reduced, and the tensile strength at 4.46% wt was only improved by 16.29%.

Also, when the fiber's content increased to 7.75%, the average tensile strength of the composite was only increased by 37.43% greater than that of pure PVC 55 because of strong tendency for fiber–fiber interaction which caused poor fiber dispersion. In such systems the crack initiation and its propagation will be easier at higher loadings due to lower interfacial bonds.

As a general rule, reinforcing PVC 55 with hemp fibers reduced the strain of the composites below that of pure PVC 55 as shown in Figure 6. In this figure, the strain is inversely proportional to fiber's fractions. The strain of composites at 4.46% wt was greater than that at both 6.2% and 7.75% wt because of, as the fiber's content is increased, the rigidity and stiffness of the composites is increased, and also, as the fiber's content increased the micro voids presented in the composite due to hydrophilic nature of the fibers were increased. So, the composite's strain was decreased. The ductility of the composites at 4.46%wt, 6.2%wt, and 7.75%wt was reduced by 26.69%, 42.62%, and 51.09% respectively.

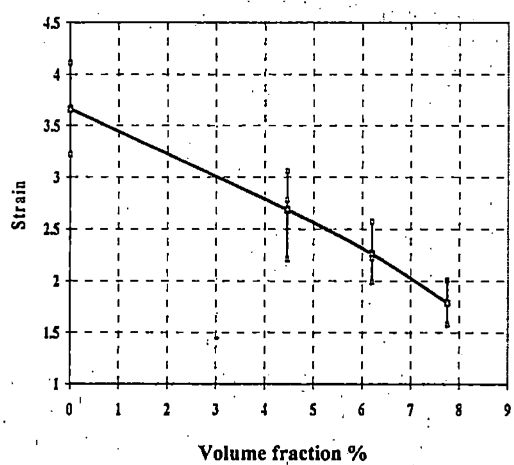


Fig.6 Strain of PVC 55/hemp fiber composites

The fibers at 6.2% wt were oriented longitudinally, randomly (the fibers were chopped into parts of 3mm length), at 45°, and horizontally. Also at 6.2% wt of fibers were weaved together to form a spin before the composite was fabricated and the composites were fabricated at the proper conditions.

The effect of varying the fiber's orientation on stress and strain of the composites is shown in Figures 7 and 8.

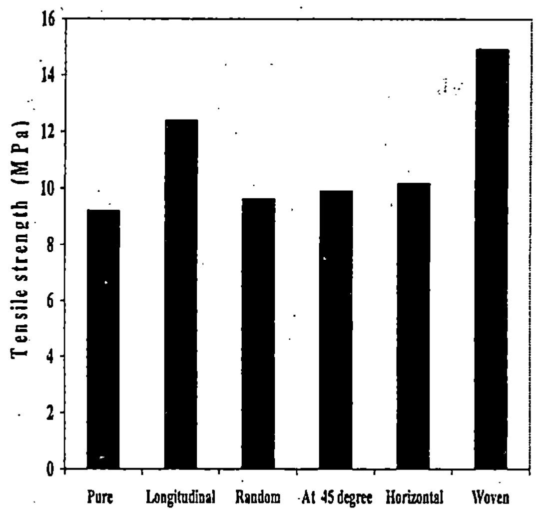


Fig.7 Ts of PVC 75/hemp fiber composites at different fiber's orientations

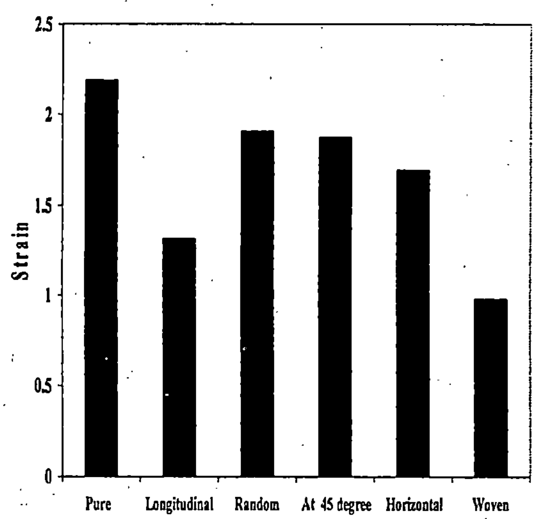


Fig.8 Strain of PVC 75/hemp fiber composites at different fiber's orientations

The average tensile strength of the composite when the fibers were placed longitudinally was greater than that of the other fiber's orientations and increased by

34.93% when compared to the pure PVC 75, because the fibers were perfectly aligned, so the load was uniformly distributed on the fibers and matrix, and better interactions between them.

When the fibers were oriented at 45° and randomly, the average tensile strength was improved by only 7.64%, and 4.59% respectively. This attributed to the separation of fibers from PVC 75 layers during testing, lower interfacial bond, lower adhesion between the matrix and fibers, and weak interfacial interactions as results of free spaces between the matrix and the fibers. When the fibers were placed horizontally, the average tensile strength of the composite was improved by 10.59% because of better coherent between PVC 75 and fibers during fabrication and better distribution of fiber. When the fibers were weaved like spin, the average tensile strength was improved by 62.44%, because of very strong bonds, penetration of melted PVC 75 into the fiber spin, and better adhesion.

As expected, the strain of the composites was much decreased when the fiber oriented longitudinally. At random, horizontal, and 45° orientation the ductility was reduced by 12.83%, 22.58%, and 14.34% respectively lower than that of pure PVC 75. On the other hand when fibers were weaved the strain was highly decreased and the ductility was reduced by 55.56% less than that of pure PVC 75.

Varying the fiber's orientation affected the stress and strain of the composites shown in Figures 9 and 10. The average tensile strength of the composite at longitudinal orientation was improved by 54.8% greater than that of pure PVC 55 because of the fiber were perfectly aligned so the load was uniform distributed between the fibers and matrix, favorable interactions, and good adhesion between the matrix and fiber.

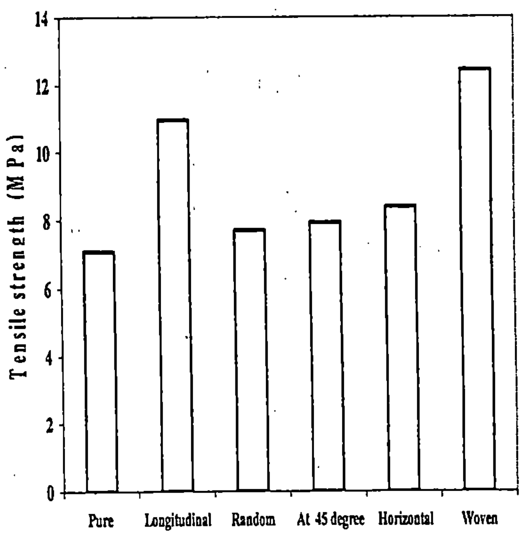


Fig.9 Ts of PVC 55/hemp fiber composites at different fiber orientations

On the other hand, when the fibers were randomly oriented, the average tensile strength of the composite was improved by only 8.76% due to poor fiber dispersion. Also, the average tensile strength of the composite was slightly increased when the fibers were horizontally oriented, at 45° and increased by 18.5%, and 12% respectively due to separation of fibers during the test. When, the fiber were weaved like spin the average tensile strength of the composites was highly improved and increased by 75.56% due to penetration of molten PVC 55 into the fiber's spin, very highly strong bonds, and improved adhesion.

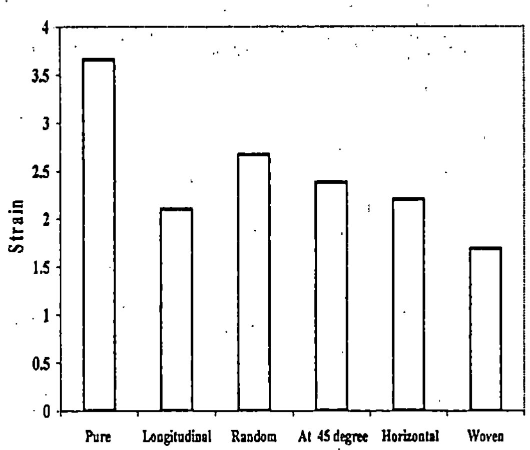


Fig.10 Strain of PVC 55/hemp fiber composites at different fiber's orientations

The strain was affected as the fiber's orientation was altered. When the fibers placed randomly, the ductility of the composites was reduced by 27.05%. But, at longitudinal, horizontal, and at 45° orientation, the ductility of the composites was reduced by 42.62%, 38.52%, and 34.97% respectively. When the fibers were weaved, the ductility was decreased by 53.83% due to very strong interfacial bonds and better adhesion.

The hardness of the composites was measured using a hardness tester "shore A" of accuracy "0.2 HA". The hardness number was the average of five measures taken at the surface of the composites. Figure 11 show the average hardness number of pure PVC.

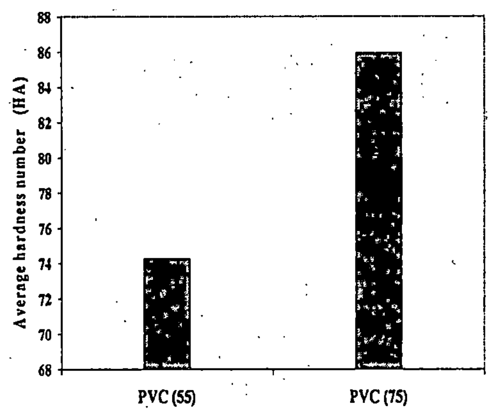


Fig.11 Average hardness number of PVC after compaction at the appropriate conditions

Addition of hemp fiber to PVC increased the hardness of the composites better than that of pure PVC this due to good interaction between fibers and matrix, and stronger interfacial adhesion which increased the stiffness of the composites. The average hardness number of PVC 75, PVC 55 with hemp fibers composite was improved by 4.19%, 6.33% respectively as shown in Figure 12.

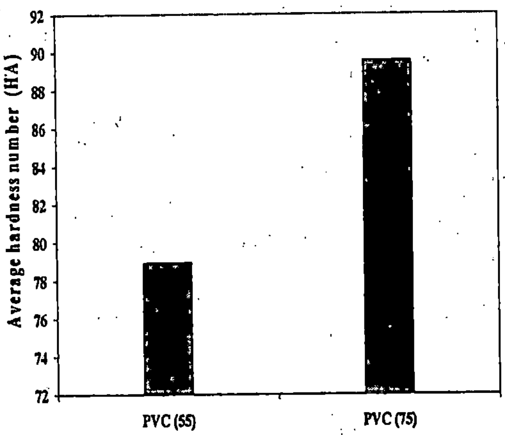


Fig.12 The average hardness number of PVC/hemp fiber composites

The fracture mechanism was viewed using a scanning electron microscope (JSM-5500LV) supplied by JEOL Company Limited, Japan. The samples were placed perpendicular to the electron beam. Different portions of the fractured surface from each sample were examined. Figure 13, SEM showed the surface morphology of hemp fibers.

A high degree of adhesion between hemp fibers and the PVC is desired, in order to obtain the optimum mechanical properties and higher interfacial bonding. As shown in Figure 14 by the arrows, the fibrillation phenomenon can be attributed to improve and increase the effective contact area between the fiber and the matrix, and hence the interfacial was improved

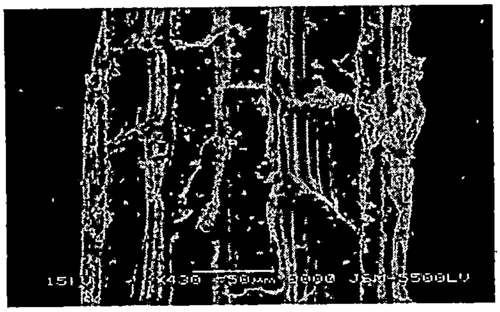


Fig.13 SEM observation of the surface morphology of hemp fibers

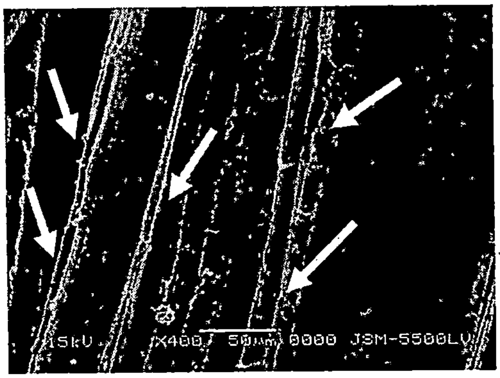


Fig. 14 SEM photo of the induced adhesion between the fibers and matrix

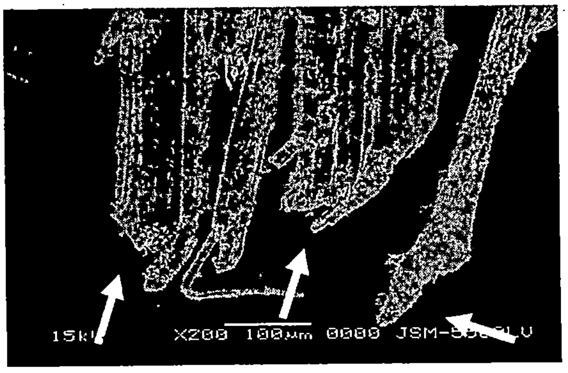
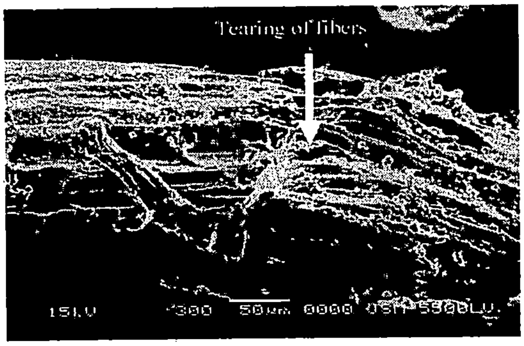


Fig.15 (a) SEM photo with X200 shows the tearing of fibers

The scanning electron microscope photographs of the samples showed that, the fibers were failed by tearing as shown by the arrows in Figure 15 (a) and (b). This is an indication that the adhesion between fiber and matrix was not lost and the failure of the composites was caused by the matrix material properties.



(b) SEM photo shows the fracture of the samples due to tearing of fibers with X300

SEM micrographs also showing separation of fibers as indicated by arrows in Figure 16 so that the load on the composites was not distributed evenly from the fiber to matrix, and a catastrophic failure of the composites was observed.

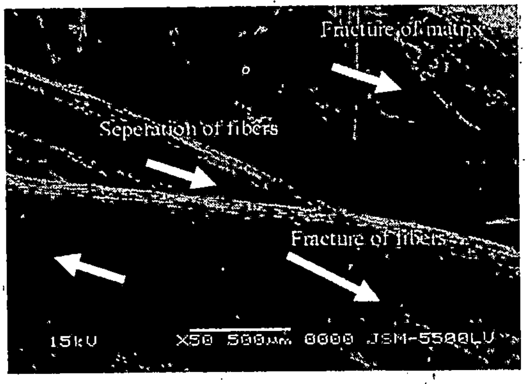


Fig.16 SEM photo shows the separation of fibers and fracture of matrix

4. CONCLUSION

Reinforcing PVC with hemp fiber has a positive effect on the stress of the composites and affected badly the strain. At 6.2% wt of fiber, the tensile strength of PVC 75, PVC 55 with hemp fiber composites was improved by 34.93% and 54.8% respectively but the ductility was reduced. The hardness was improved and the average hardness number of PVC 75, PVC 55 with hemp fibers composite was improved by 4.19%, 6.33% respectively.

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