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Biomechanics of Natural Fiber Green Composites as Internal Bone Plate rafted

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Abstract. The main purpose of this paper was to introduce a new series of green composites as a plate for bone fracture applications. These green composites offer many advantages over traditional composites and biocomposites based on synthetic polymers. In current work, the new green composites bone plate based on two types of biopolymers involves biopolymethylmethacrylate thermoplastic material and bioepoxy thermosetting material reinforced with randomly oriented corn natural fibers at different weight fractions (5, 10, 15, and 20%) were fabricated by hand lay–up technique. Four forms of green composites ; treated and untreated corn biopolymethylmethacrylate groups A and B respectively, treated and untreated corn bioepoxy groups C and D respectively were investigated. The mechanical properties were tested (tensile, compression, and compact tension) under a flow of phosphate buffered saline PBS at 37 $^{\circ}C$ has been reported. The experimental results showed that the green composites group A have the best mechanical properties than other groups under PBS condition while the green composites group D have the weak mechanical properties due to plastization by immersion in PBS solution. Also, the analysis of femur bone fracture plates carried out by applying finite element method FEM using the ANSYS 16 software package.

1 Introduction

Internal fixation is a surgical procedure in orthopedics that stabilizes and joints the ends of fractured (broken) bone by mechanical devices such as plates, pins, wires, and screws positioned entirely inside the skin. Plates for long bone fractures are a major element of internal fixation [1] and must be bear external loads for 1.5 to 2 years [2]. Various materials can be used as bone plates including metals, ceramics, and polymer based composites [3]. Metallic materials such as stainless steel, cobalt alloys, pure titanium, and titanium alloys are most widely used as internal fixation for long bone fractures because of their outstanding mechanical properties [4]. However, these devices are not suitable for use as internal fixation plates inside the skin for long time due to numerous limitations. The large difference in elasticity between metals and bone causes stress shielding results in osteopenia, osteoporosis, plate loosening, and delay the healing period [5] as well as metallic bone plates are incompatibility with living tissue, bioactive, magnates effect [6], lower fabricability and high cost [7]. Although ceramic materials such as Al_2O_3 and ZrO_2 have been considered bioinert, but the higher degree of brittleness, hardness, and high elastic modulus lead to stress shield effect and thus making its unsuitable for use as bone plates [3]. Composites based on polymers derived from petrochemical materials results in production of harmful by degradation products when used in orthopedic surgery [8]. To eliminate these serious limitations, friendly material consist of natural fiber and biodegradable polymers are becoming highly attractive for alternative material use as bone plates which should satisfy the conditions of fully biodegradability and biocompatibility.

Biocomposites made from natural fibers as the matrix material and biodegradable polymers as the reinforcing material are called “green composites” [9]. The word “green” affixed with materials which are “biodegradable” and “renewable” in same time [8]. Frequently, they are referred as biomedical materials [10].

The current work investigates using two types of biopolymers: bio based epoxy thermosetting resin and bio based

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polymethylmethacrylate thermoplastic resin reinforced with corn natural fiber at various weight fractions in order to manufacture green composite bone plates. The main purpose for using green composite as plate fixation for long bones fractures due to their mechanical characteristics are expected to be closer to those of long bones.

2 Materials and Methods

2.1 Matrix, Reinforcing and Composite Materials

Two matrix materials were investigated in this study. Polymethylmethacrylate (PMMA) wasproducedusing 617H55 resin and 617P37 hardener (Otto Bock Healthcare plc, Egham, Surrey, UK). SUPER SAP® 100/1000 high bio-epoxy system composed of SUPER SAP® 100 resin and SUPER SAP® 1000 hardener (Professional Epoxy Coating, Kendal, Cumbria, UK).

Corn cobs were obtained from local shops (Glasgow), the fibers were extracted from the cobs and then dried at 37 ˚C for 240 hours in an incubator (Sanyo MIR262, Japan) before surface treatment. All the natural fiber types were cut in length of 10 mm. The corn fibers were soaked in 1% NaOH solution at room temperature for 90 minutes. The fibers were then dried at 37 °C for 240 hours in an incubator.

A PTFE mold of dimensions 240 × 110 × 4 mm was used to cast the composite sheets. A hand lay-up technique was used to prepare the samples. Before reaching hardening, pressurized to 2 tons for 30 minutes, giving a pressure of 27.58 MPa. Non-filled PMMA and epoxy were manufactured in the same manner to provide 0% filler samples.

2.2 Single-Fiber Tensile Test

Individual fibers of the corn fibers were tensile tested to BS ISO 11566 [26]. Weibull distribution is a statistical tool used to characterize the failure mode of brittle fibers. In this study, Weibull two parameter analysis was performed. For each individual corn fiber the failure stresses were ranked from minimum to maximum, according to following equation [11]:

$$P\left(\sigma_f\right) = 1 - exp\left\{-\left(\frac{\sigma_f}{\sigma_\circ}\right)\right\}^{\beta} \quad \ldots(2)$$

Where P is the probability of failure of a fiber length L at a stress less than or equal to σ. The constants $\sigma_\circ$ and β are the scale parameter (characteristic strength of life) and the shape parameter, respectively. The scale parameter corresponding to the fracture stress of the fiber. m is the shape parameter, also called the Weibull modulus. $L_\circ$ is the reference length (the minimum length to find a flaw); usually it is considered as unity or as the same length as the scale parameter.

The probability of failure, P_i, the probability of failure of sample *i* of the *n* samples in the group, was calculated using Bernard's correction [12]:

$$P_i = \frac{i-0.3}{n+0.4} \quad \ldots(3)$$

From P_i the Weibull number, *Y*, was obtained using equation (4)

$$Y = ln\, ln\left[\frac{1}{1-P_i}\right] \quad \ldots(4)$$

and σ_y was plotted against the Weibull number and the gradient and intercept found.

2.3 Composite Testing

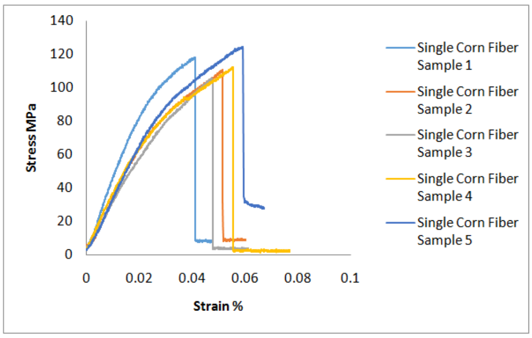
Before testing all samples were soaked in phosphate buffered saline (PBS) solution (Sigma-Aldrich, United Kingdom) at 37 °C for between 1 and 3 weeks. The composite systems were prepared are divided into 4 groups as follows: treated and untrated corn/PMMA composites (groups A and B), and treated and untrated corn/epoxy composites (groups C and D). The mecahnical testing (tensile, comppresion) were performed according to ASTM D638-02 ans to ASTM D695 – 02a standards respectively, using an MTS 850 Mini Bionix® II universal testing machine (MTS, Minneapolis, USA).

3 Results and Discussion

3.1 Strength of Individual Fibers and Wiebull Analysis

The typical load – displacement curves selected corn natural fiber are shown in Figure 1. The curve shows that the tensile load increased proportionally with increasing strain until the point of ultimate load, which is the maximum load on the stress – strain curve. At this point the corn fiber broke and exhibited brittle behavior with no apparent yielding for corn fiber.
The modulus of elasticity is the slop of the stress – strain curve was determined in the elastic region of the curve. The values of the Young's modulus varies from 2.38 to 4.50 GPa, the tensile strength from 83.12 to 124.47 MPa, and the strain to failure from 4.10 to 7.58 %.

Figure 1. Load – displacement curves of selected corn naturals fibers.



The Wiebull plot of tensile strength of corn natural fibers of 25 mm gauge length is shown in Figure 2. By applying the least squares method, the linear relationship between ln (σ_f) and ln (ln (1/(1-P))) is determined. From this figure, the R^2 coefficient of corn was 0.989. The values indicates a high degree of linearity.

For synthetic fibers, the Weibull modulus between 1-15, whereas in most common natural fibers types which intrinsically have more variation in properties lie in the range of 1-6 [13]. The Weibull modulus of corn fibers is β = 8.839, gives small variability in tensile strength. The little scatter in tensile strength and the lower variation (more regularity) in fiber diameter of randomly selected corn fiber (62 - 74 μm) as well as the distribution of flaws or defects on the corn fiber surface is less severe (more smoothness) results in higher value of Weibull modulus for corn fiber and exceed the normal range of most natural fibers.

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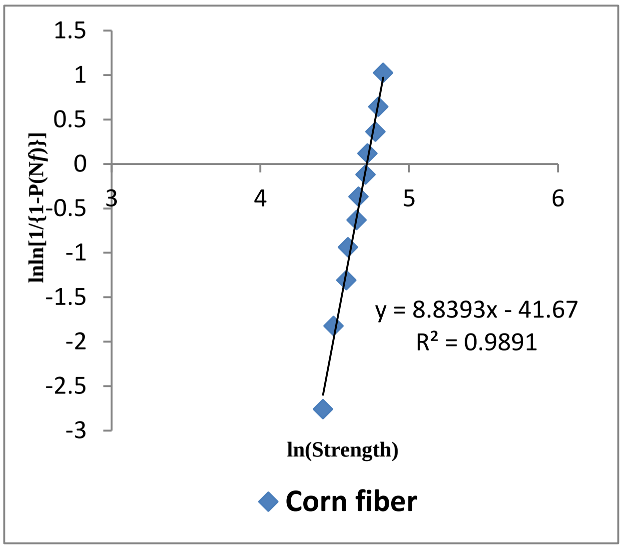

Figure 2. Weibull distribution of corn natural fibers tensile strength of 25 mm gauge length.

3.2 Tensile Test

The 1% NaOH alkali corn fiber treated have the major effect on both tensile strength and tensile modulus at degradation medium (groups A and C) as shown in Figures 3 and 4 respectively.

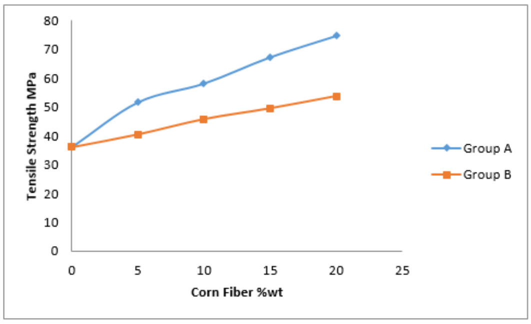

Figure 3. Effect of immersion in PBS at 37°*C* for 7 days on tensile strength of treated and untreated corn/PMMA green composites (Groups A and B).

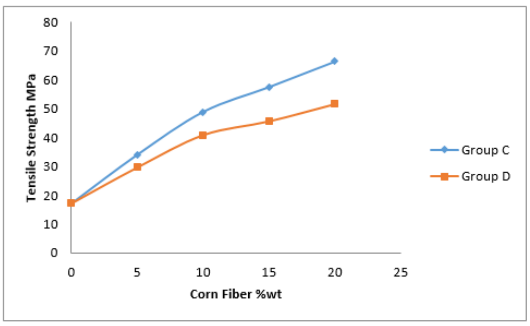

Figure 4. Effect of immersion in PBS at 37°*C* for 7 days on tensile strength of treated and untreated corn/ epoxy green composites (Groups C and D).

It was found that both tensile strength and tensile modulus increased as fiber concentrations increased. The tensile strength and tensile modulus were enhanced by 31%, 17.8%, 39%, and 18.6% of 20corn/80PMMA green composites in each groups from 53.68 MPa (group B) to 74.7 MPa (group A), and from 3.39 GPa (group B) to 4.02 GPa (group A) respectively. Immersio of treated and untreated fiber green composites (groups C and D) in PBS at 37°*C* for 7 days decreased the values of tensile strength and tensile modulus due to higher degree of plasticity for bioepoxy based resin. The largest results were found in group C of 66.23 MPa and 3.68 GPa respectively, while the lowest results in group D of 29.64 MPa and 2.79 GPa respectively.

3.3 Compression Test

The influence of both alkali treatment and immersion in PBS solution at 37 °*C* on compressive characteristics of corn/PMMA and corn/epoxy green composites are shown in Figure 5 and 6 respectively.

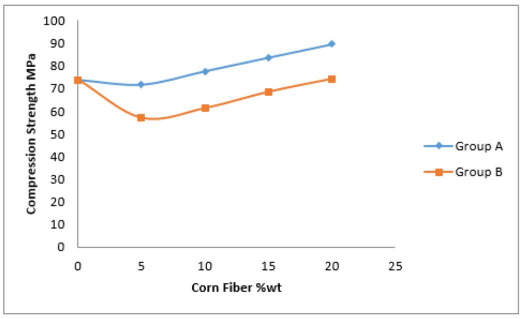

Figure 5. Effect on immersion in PBS at 37°*C* for 7 days on compression strength of treated and untreated corn/PMMA green composites (Groups A and B).

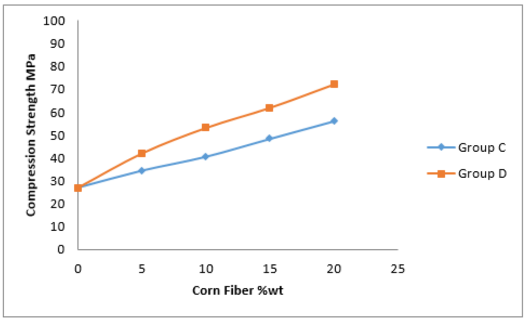

Figure 6. Effect on immersion in PBS at 37°*C* for 7 days on compression strength of treated and untreated corn/epoxy green composites (Groups C and D).

In both groups A and B, observed that there is a drop in flexural modulus of 5% wt corn fibers and then increased with increasing in fiber content. The drops in flexural modulus of both groups were not significantly. The largest increased in compressive strength of 89.7 MPa were occurs in PMMA based green composites containing 20% wt treated corn fiber (group A) compared to those of untreated fiber composites of same composition (group B) of 74.2 MPa.

The immersion in PBS solution at 37 °*C* led to higher drops in compressive strength for all samples of both treated and untreated corn epoxy composites (groups C and D). The results showed that the maximum compressive strengths were 56.12 MPa and 72.2 MPa of 20 % weight fraction of untreated and treated corn epoxy biocomposites respectively, which are lower than the value of the dry pure epoxy of MPa.

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4 Numerical Results

The von Mises stress of femur-bone plate system has been calculated. The results are shown in Figure 7 for 20corn/80bioPMMA green composites bone plate, and Figure 8 for 20corn/80bioepoxy green composites bone plate, green composites bone plate that are prepared in this study. Also, the von Mises stress of femur-bone plate system has been calculated for stainless steel type 316 L and Ti6Al4V titanium alloy as shown in Figure 9 and 10 respectively. It is having been observed from this figure that maximum equivalent stresses at femur bone plate decreased significantly when using any group of the natural fiber green composites groups that are prepared in current study instead of traditional bone plates made from stainless steel type 316L or Ti6Al4V titanium alloy. This is related to the flexibility of natural fiber green composite plates compared to other metallic bone plates

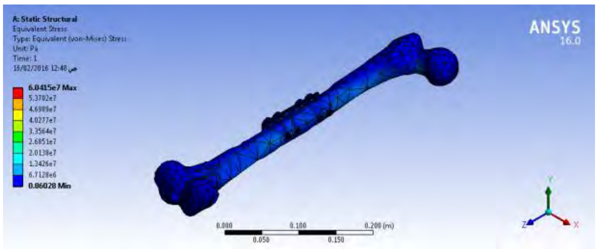

Figure 7 Contour plot for the maximum von Mises stresses for 20corn/80bioPMMA green composites.

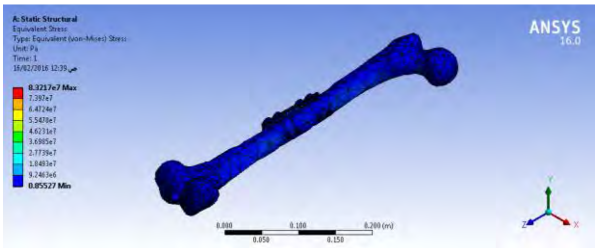

Figure 8 Contour plot for the maximum von Mises stresses of 20corn/80bioepoxy green composites.

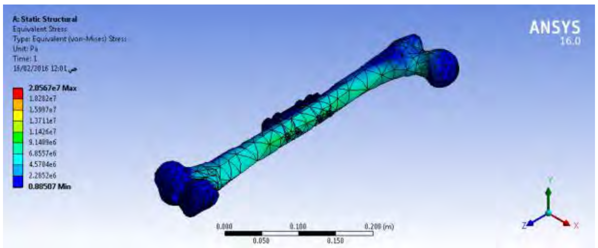

Figure 9 Contour plot for the maximum von Mises stresses of stainless steel type 316L.

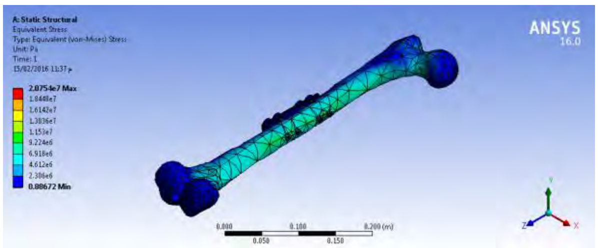

Figure 10 Contour plot for the maximum von Mises stresses of Ti6Al4V titanium alloy.

5 Conclusions

1- The tensile properties of corn natural fiber have been studies using Weibull analysis. The experimental data indicates that the corn natural fiber have a good tensile strength and modulus of elasticity.

2- The mechanical properties of biopolymethylmethacrylate resin are not affected by immersion in PBS at 37°*C*., whereas in case of bioepoxy resin larger drops where occurred due to plastization of the material.

3- The alkali treatment by 1% NaOH of corn natural fibers reinforced polymethylmethacrylate green composites give better mechanical properties in PBS conditions than in case of bioepoxy based resin.

4- The experimental results showed that the alkali treatment of corn natural fiber with 1% NaOH increased the values of pH of green composites of both groups in all compositions.

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