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Effect of Bio-Fiber Waste Addition on Specifications of Epoxy Composite

This study investigated the fabrication of composite from epoxy resin (EP) and waste short chicken feather fiber (CFF) at 5% volume fraction of fibers using hand lay-up method at room temperature. Some mechanical properties of the composite were determined including bending, shore D hardness and compressive strength. The process involved the treatment of the CFF with alkali solution, such as NaOH with 0.5 normality and then the effect of treatment on epoxy composite properties was studied. The results revealed that the addition of CFF to the epoxy resin has only a slight effect on the mechanical properties. It has shown that the values of Young modulus, compressive strength and hardness of EP/CFF composite were increased by the treatment of CFF with NaOH solution compared to pure epoxy and EP/CFF composite without treatment.

***Keywords*:** Chicken fiber waste, Epoxy, Composites, Shore D hardness

1. Introduction

Chicken feather is an important waste product of poultry industry. Poultry feather fiber is mainly keratin protein in α–helix structure with a crystalline melting point of about 240°C [1]. The feathers are commonly considered as waste by-product because their recent uses are economically very small and their disposal is difficult. Disposal methods of chicken feather are done either by burning or burying occasionally .Thus they are environmentally unfriendly. Burning feathers causes air pollution and a landfill feather decompose very slowly and requires a lot of land for decomposition [1].

The applications of composite reinforced with chicken feather fiber (CFF) are offering more successful way to solve environmental concerns compared to the traditional disposal methods. Castano et al. was found that the CFF keratin biofibers allows an even distribution within and adherence to polymers due to their hydro-phobic nature and they reported that CFF reinforced composites have good thermal stability and low energy dissipation. [2]. Biodegradable composites were used in biomedical composites for drug/gene delivery, cosmetic orthodontics and tissue engineering applications, they usually mimic the structures of the living materials involved in the process also to the strengthening properties of the matrix that was used but still providing bio compatibility [3].

The progress of bio-composites have been increasing in recent years so many researchers have been conducted to study the mechanical properties, particularly interfacial performances of the composites based on bio fibers due to the poor interfacial bonding between the hydrophilic bio fibers for example sisal, jute and palm fibers and the hydrophobic polymer matrices and the result are expected to be able to improve the worldwide waste problem [3].

The CFF has recently attracted the attention of scientists and engineering industries because of advantages of fibers which provide certain desirable properties including lightweight, high thermal insulation, acceptable specific strength, excellent acoustic properties, non-abrasive behavior and excellent hydrophobic nature, renewable, recyclability and bio-degradability. Also, they are readily available, low cost, the lowest density value, large aspect ratio, the thermal stability of these fibers and their specific properties are compared to other fibers used for reinforcements [2,3]. Despite these advantages, there are definite drawbacks such as incompatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing, and poor resistance to moisture limit the potential of bio-fibers to be used as reinforcement in polymers. CFF is consisting of two parts, the fibers and the quills (Fig. 1).

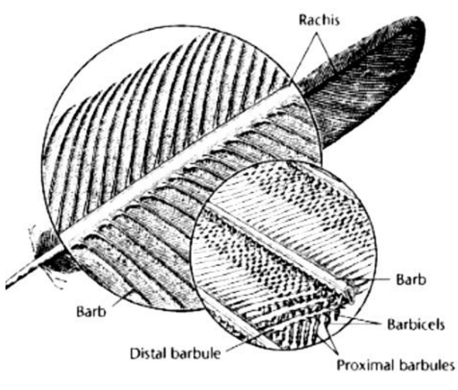

Fig. (1) Different parts of chicken feather [3]

The fiber is thin filamentous materials that merge from the middle core material called quills. The quill is hard, central axis off which soft, interlocking fibers branch [4,5]. The feather is basically made up of keratin which contains ordered α-helix or β-helix structure and some disordered structure. The feather fiber fraction has slightly more α-helix over β-helix structure. The outer quill has more β-helix than α-helix structure [4]. The barbs at the upper portion of the feather are firm, compact, and closely knit, while those at the lower portion are downy, i.e. soft, loose, and fluffy. The down feather provides insulation, and the flight feather provides an airfoil, protects the body from moisture, the skin from injury, and colors and shapes for displays. Figure (1) shows the cross-sectional views of the flight and down feather fibers. It is obvious that flight feather fiber exited in a hollow form while down fiber is in solid. In terms of the purpose of fiber-reinforcement, the use of down fiber appears much better than that the use of flight fiber [6]. The aim of this work is improving the mechanical properties such as (hardness, bending and compressive strength) for epoxy resin reinforced with CFF composite systems and comparison which system has optimum properties.

2. Experiment

Epoxy resin (Quick-mast 105) was used in this research. It is a liquid with moderate viscosity and capable to be converted to solid state by adding the solution (Metaphenylene Diamine, MPDA) as hardener. This hardener is a light liquid with yellowish color, the ratio of this hardener to the epoxy is about (1:3). The characteristics of this epoxy can be briefed as follows: high adhesion to fibers, high electrical insulation, high chemical resistance, low shrinkage and high mechanical properties.

Waste feather were brought to laboratory from poultry farm in Baghdad with density of 0.89 g/cm^3 and washed several times with water mixed with sodium chlorite to remove blood, manure and extraneous materials and washed by polar solvent (ethanol), the clean feather were then spread on sheets and dried under the sun for three days. Short feather fibers (barbs) were obtained by manually cutting in small filaments by using scissors.

The poultry feathers (FPF) were immersed in sodium hydroxide solution of 0.5 normality for half an hour at room temperature. The fibers were then washed with distilled water until the NaOH was removed, after washing, the fiber was air dried for 2 days. Next, the fiber was kept in an oven at 80°C for 6 h immediately before use.

Hand lay-up molding was used for preparing the samples under test. First, a mold prepared in advance and made of vulcanized iron with dimension of 15x10x0.5 cm^3. The base of mold must be cleaned vet well before casting and must be covered with oiled material for getting the sample easily. Three samples were prepared as follows:

1- Pure epoxy: EP resin was mixed gradually by glass rod with its hardener at ratio of (3:1).
2- EP/CFF composite: Short chicken feathers were added gradually to the epoxy resin with continuous mixing to obtain 5% volume fraction of chicken feather fibers.
3- EP/treated CFF composite when chicken feathers were treated with NaOH solution. Volume fraction of fiber (V_f) is combined with the weight fraction (Ψ) by the relation [7]:

$$V_f = \frac{1}{1+\frac{1-\Psi}{\Psi}\times\frac{\rho_f}{\rho_m}} \qquad (1)$$

where ρ_f and ρ_m are the densities of the filler and the matrix, respectively

When the solidification process is finished, the mold was taken out of the mold. Then, the curing process is done at a temperature of 60°C for 2 hours. Finally, the sample was cut down into standard dimensions according to the standard qualities for fulfilling the specific tests in the work.

Fourier-transform infrared (FTIR) spectroscopy is an important analysis technique which detects various characteristic functional groups in molecules of any matter [8]. FTIR-8400S from Shimadzu was used in this investigation.

Hydraulic press supplied from Leybold-Heraeus 36110 was used to calculate compressive strength. In this process, the sample is fixed on a moving base, then the base is lifted up by a lever found in the instrument till the surface of the sample touches the upper surface of the instrument, then the pointer of the gauge is placed on zero level. The load is applied gradually to the longitudinally fixed sample, and then the reduction in the length of sample is determined via the fixed digital vernier, the increasing of the load continues till sample failure. The value of the maximum load represents the ultimate compressive strength of the sample**.** This three-points test apparatus is made by PHYWE Co., Germany. The bending tests were performed according to ASTM-D790 standard with dimensions of sample: length of 100mm, width of 10mm and height of 5mm. The main purpose of this test is to find Young's modulus (E) which can be calculated from the Eq. [9]:

$$E = \frac{MgL^3}{48IS} \qquad (2)$$

where (*M/S*) is the slope calculated from mass-deflection curve, g is the acceleration due to gravity (9.81 m /s^2) and I is the momentum of geometrical bending which could be calculated from the equation:

$$I = \frac{bd^3}{12} \qquad (3)$$

where b is the width of specimen (m), d is the thickness of specimen and L is the distance between supports

The hardness test was performed with instrument called Shore (D) Durometer made by Italian company type (TH210). This test was preformed according to ISO 9001 standard. The hardness test was carried by using pointed dibbing tool. The pointed dibbing tool penetrate the material surface by the pressure applied on the instrument where the dibbing tool head touching quite the surface of the samples then calculate the hardness value will appear on screen of instrument and the reading depends on the degree of penetration.

3. Results and Discussions

The ability of a material to resist breaking under compression stress is also one of the most important and widely measured properties of materials used in various applications. The value of uniaxial compressive stress reached when the material fails completely is designated as the compressive strength of that material. The compressive strength is usually obtained experimentally by means of a compressive test [10]. It was shown from Fig. (2) that the compressive strength of composite was increased after reinforced epoxy with chicken feather fibers. The reason behind this strengthening was related to the role of chicken feather fibers which act to distribute the load on more volume of the sample under test. Short or longer fibers would highly affect the stress transferability as well as shear strength of the composites. The fibers, themselves also would be a barrier to the movement of polymer chains inside the composites and it may result in increasing their strength, but reduce their fracture toughness [3].

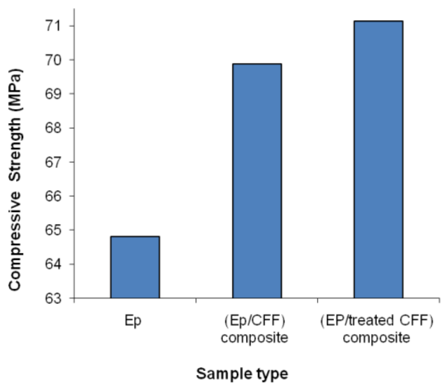

Fig. (2) Variation of compressive strength with sample type

The relation between mass and deflection was shown in figures (3-5). From the mechanical test results, the E value of epoxy resin to which treated CFF added was 2270.96 MPa compared with that to which untreated CFF added was 1742.11 MPa. Both samples showed higher E values than the epoxy resin 2252.03 MPa. It is known that chicken feather contains approximately 91% protein (keratin), 1% lipids and 8% water. The structures of keratin, the primary constitute of chicken feather affects the chemical durability. Because of extensive cross-linking and strong covalent bonding within its structure, keratin is responsible to provide high resistance to degradation [11].

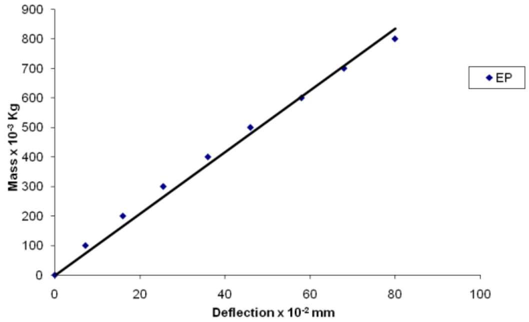

Fig. (3) The relation between mass and deflection of (EP)

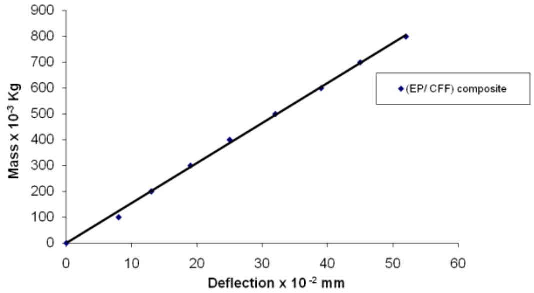

Fig. (4) The relation between mass and deflection of (EP/CFF) composite)

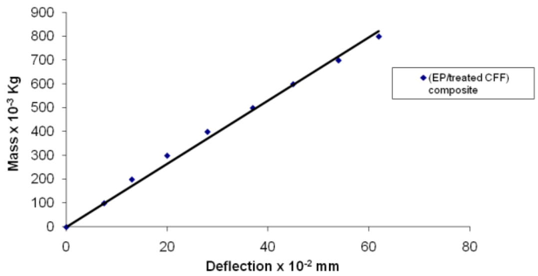

Fig. (5) The relation between mass and deflection of (EP/treated CFF) composite

The keratin in chicken feather, a polypeptide chain compound, when treated with alkali solution (NaOH) with 0.5 normality, it hydrolyzed to a peptide bond (at C–N bond site), and formed free amine and carboxylate ion. When mixed with epoxy resin, the free amine and carboxylate ion react with active epoxy group (present in epoxy resin) and forms an additional chain with epoxy matrix. It was concluded from this study that, when the feather is treated with (NaOH) solution before mixing with epoxy resin, chemical reaction between the matrix and reinforcement occurs (i.e. chicken feather) which gives rise to formation of ester and amine. This is the main reason for increase in young modulus of the composite, made with alkali treated chicken feather.

Table (1) FTIR peaks of different functional groups present in chicken feather

The functional groups present	I.R Peaks
N-H stretching H -bonding	3298 cm^{-1}
C-N stretching in amide groups	1649 cm^{-1}
N-H bending vibration	1541 cm^{-1}
C-S stretching vibration	700 cm^{-1}

Table (2) FTIR peaks of different functional groups present in (Ep /treated CFF) composite

The functional groups present	I.R Peaks
N-H stretching H -bonding	3377 cm^{-1}
C-H stretching vibration in methyl group	2924 cm^{-1}
C-H stretching vibration in benzene	3000-3030 cm^{-1}
N-H bending vibration	1510 cm^{-1}
O-H stretching vibration in free alcohol	3473 cm^{-1}
C-N stretching vibration in feather	1643 cm^{-1}
C–S bending vibration in feather	717 cm^{-1}
C–S stretching vibration	829 cm^{-1}
C=C stretching in benzene	1610 cm^{-1}
C=C bending in epoxy	1460 cm^{-1}
C-O-C stretching vibration in epoxy	1242 cm^{-1}
C-O-C stretching vibration in benzo-feather	1039 cm^{-1}

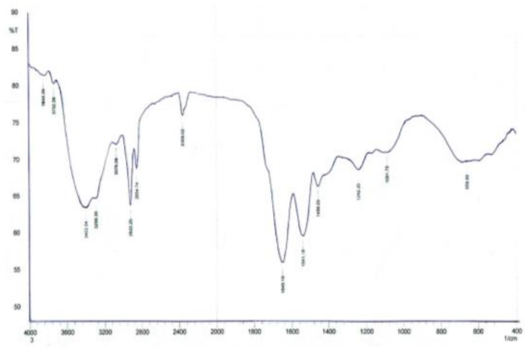
Fig. (6) FTIR peaks of chicken feather

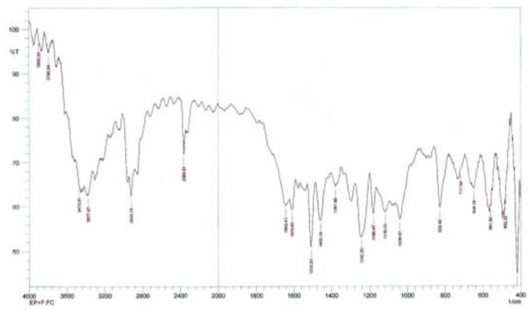
Fig. (7) FTIR peaks of (EP/treated CFF) composite

The results in Fig. (8) show that Hardness values were increased for samples strengthened by Chicken fiber, due to increased crosslinking and stacking (which reduces the movement of polymer molecules). This led to an increased resistance to scratching material and cutting. Becoming more and more resistance to plastic deformation where the material hardness depends on the type of forces between atoms or molecules in the material the more the stronger linkage between matrix and reinforced material, which increases the value of hardness [12].

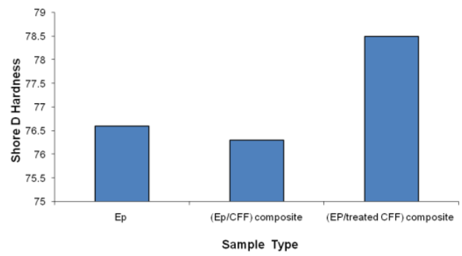

Fig. (8) Variation of shore D hardness values with sample type

4. Conclusions

The treatment of chicken fiber with (0.5 normality of NaOH) was slightly improved mechanical properties of epoxy composite which compared to the epoxy with untreated fibers due to good interfacial adhesion of the fiber with the matrix as a result of the formation of ester and amine groups, which is evident from FTIR observations. The presences of these functional groups are responsible for increasing of elastic modulus, hardness and compressive strength of these composites.

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