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Experimental study for mechanical properties of composite material reinforced by human hair fiber

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***Abstract* - In this experimental article, bio-composites based on human hair fiber, produced by mixing the epoxy (Sikadur-52) with hair fibers, hand mixing technique at room temperature and applied pressure (10 N) on upper part of mold to producing main sheets of composite reinforced by human hair fiber.**

Specimens of epoxy composite reinforced by hair fibers manufactured with different weight ratios of hair as 0%, 5%, 10% and 15% respectively. All tensile specimens performed according to ASTM standards aspect and tested by Universal tensile machine, then the result analyzed and considered.

The aims of our task in this article are to investigate the mechanical characteristics of stress-strain tensile tests such as, ductility, modulus of elasticity (Elastic coefficient) (E), Elastic limit (yield point) (σ_y), Ultimate tensile stress and transverse stiffness (K) for four specimens of each three weight ratios.

The results indicate that different values for weight ratios of randomly oriented reinforced hair fiber have an effect and gave results well on many mechanical properties through its effect on the properties of epoxy materials (Matrix).

Index Terms - Bio-composites, Epoxy resin, Polyester-Human Hair composite).

INTRODUCTION

Main specification of composite material achieved to increase property of stiffness to weight ratio for the major material and rising the strength of its. The practical utilization of composite material started at first in applications of producing materials of manufacturing the aircrafts, in the substance of parts that involve low density and high strength. Thousands of examinations done to discover the significant characteristics of the composite material, in addition to that performing the appropriate feature of composite substance properties (D. Senthilnathan et.al, 2014 Feb-Mar).

Recently, biological fibers became eye-catching for scientists, researchers and engineers as reinforced replacement substance for traditional fiber reinforced polymer (FRP) since that adequately improved mechanical characteristics such as high strength consideration and low cost. Human hair represents type of clean biological eco-friendly fibres. There are (3- 4) tons of human hair fibres wasted in overall republic of India yearly; for this reason, it creates challenges on an environment (Akarsh Verma et.al. 2016).

With the intention find profitable of manufacturing and utilizing the wasted human hair fiber, presently positioning its utilization in scope of composite material knowledge.

Hair of human is broadly present a nano bio- friendly composite with perfectly significant microstructures. Various equipment and methodology have been utilizing to investigate several properties of human hair to verify it a bio-friendly composite fibre (Akarsh Verma et.al. 2016).

Day after day, Using and production of natural fibers still more offer an eco-friendly world, these fibers are a reuse able substance's source and difficult degradable, that they can be repeatable without difficulty and in addition ensure that don't contaminate or generate non-eco-friendly environmentally gases. Bio-friendly fiber composites have many favorably properties compared with that of synthetic fiber Glass (Paul Wambua, Jan Ivens, et.al. 2003 February).

Human hair fiber considers as difficult recyclable trash on hand and plentiful mass round the planet, while it is not discovered completely for utilizing in engineering domain. The magnitude of tensile stress for a human hair is variety between 150 to 220 MPa. This feature of human hair fiber might be making employment in the domain of usage bio friendly composites (P. Divakara Rao1, et.al. 2017).

In recent days, Natural fibers, which produced from Plants and animals are utilize in manufacturing polymer composites as reinforcement.

Natural hair is a raw bio fiber that can locate widely in most places of the universe. It is a proteinous and robust chain of keratinous fiber. The fundamental element recognized of hair fiber known as keratin. The keratin contains proteins composed from extended strings (polymers) of amino acids. The bond of desulphated chemical jointing the keratins together represent the key factor in the robustness and resistance of hair fiber to erosion by atmospheric effects. They are highly resistant to the acids affected on its (Jayachandran, Hari Arjun and Lilly Mercy J., 2016). Human hair contains also lipids, water, trace elements and pigments (C.R. Robbins 2012).

LITERATURE SURVEY

Elanchezhian et. al. mention to the composite material was made from eco-friendly natural fiber practically were similar to the industrial silk fiber composite material which were expensive in comparison with hair fiber (Elanchezhian C. 2017).
Barone (Barone JR et.al. 2005) and Ahmad (Ahmad S. 2014) formulated a suitable composite of human hair fibers with polymer as a matrix, concerned that human hair fibers can be used as a renewable engineering composites fiber. They approved by the conclusion that tensile and flexural characteristics reduced when the percent of fiber loading rise. Using aggregate fibers, not only supply excellent features, but will also exclude necessity to treating the fiber advantageous to reduce the costs and improvement the properties. The tensile features could be improved with increasing the percentage of the human hair fibers for different matrix amount.
Babu et al. investigated and decided that the biodegradable substantiated by polymers had significantly intensified the consideration and awareness due to ambient dangerous concerns that worldwide oil supplies would be vanished (Babu RP, et.al. 2013).
Most recently, studies on bio-fiber of hair using the nano-indenting procedure then found out modulus of elasticity for human hair fiber and the hardness reduced as the indenting intensity raised. In addition, they concluded the behavior of mechanical features for the hair's surface that reduced from root to the head (Ray SS and Okamoto M. 2013).

THEORETICAL ASPECT

From the tensile test results and stress –strain data, specific terms and measurements can find as the following:
The ultimate tensile stress represents the maximum stress that appears in the stress-strain diagram. We can get the magnitude of force (F) and the elongation (ΔL) in the specimen directly from the universal tensile machine. Corresponding to this date, the stress and strain can be calculated from equations (1) and (2) while (A, L) represent the section of area and the initial length of specimen respectively.

$$\sigma = F/A \quad (1)$$

$$\varepsilon = \Delta L/L \quad (2)$$

The ductility is an important property because it measures the ability of a composite material to absorb overloads and how much strain is given by producing stress. Ductility prosperity presents the same value of percentage elongation which found by the equation (3). The value of tabulated elongation (ΔL) measured directly from the tensile test machine. Ductility indicates how much the cold worked can be executed and represents the amount of plastic deformation which material has it's before breaks. Ductile material can exhibit a significant strain before fracturing while a brittle martial frequently have very little strain (Joseph Edward Shigley et.al., 2011).

$$\text{Ductility } \% = \Delta L/L \times 100\ \% \quad (3)$$

The elastic limit describes a composite material's resistance to fracture under impact loading in the elastic region and is often expressed in terms of the summation magnitude of energy that a material able to absorb before failure. The elastic limit is not a single characteristic while rather a mixed from strength and ductility.
After the elastic cutoff edge, constant malformation will produce. The elastic limit represents the minimum value of strength magnitudes at which fixed malformation able to be calculated. This need a manual loading process; the precision is essentially based on the device requirements that used and skills of the user. For elastomer, like as rubber and composite material, the limitation of elasticity expands more than the linear limit of proportion. In addition, accurate strain measurements appear that plastic strain starts at quite small stresses (Flinn, et.al.1975), (Barnes and Howard, 1999).
The elastic limit represented by yield strength (σy), this Yield limit in stress-strain curves at which the curvature elevation off and plastic malformation starts to produce (Ross C., 1999).
Modulus of elasticity (Elastic coefficient) is mathematical description for quantity that measures the resistance of an object (composite) material to start elastic deformation when a stress is implemented to it. Modulus of elasticity for the matter is known as the tendency or slope of its stress-strain diagram in the elastic malformation area (Askeland et.al., 2006). A hardened matter will own a larger value for modulus of elasticity. A modulus of elasticity will be wright in the equation configuration:

$$E = \sigma/\varepsilon\ . \quad (4)$$

Stress (σ) represent the relationship between the applied force producing the malformation and the cross sectional area to which the affected load is applied and strain (ε) represent the proportion between the changing in some parameters item required to cause the malformation to the original magnitude value of the same parameter (Beer et.al. 2009).
Ultimate Modulus of Elasticity represent the maximum magnitude value in the elasticity of the composite material.
Transverse stiffness (K) which have a unit (N/m) or bending stiffness is termed as the flexural rigidity of the composite specimen and also termed as the capacity of structural members to resist bending, represent the ratio of transverse load (F) to deflection (δ) as shown in equation (5):

$$k = F/\delta \quad (5)$$

The composite material is widely used due to its proportion of significant stuffiness to the weight as compared to traditional material (Ghasemnejad et.al. 2010).

EXPERIMENTAL ASPECT

- Materials and methods: The materials can be divided into two basic parts, the matrix and the reinforcement. The investigation on the focal points concept, presenting in the practical part by selecting the materials and by using hand mixing process of laying-up then pour it's in the designed mold at room temperature with (10 N) pressure applied on the upper part of glass mold to producing epoxy composite material sheets reinforced by human hair fiber. The composite materials are made of randomly oriented chopped with various fiber length and different combinations as 0%, 5%, 10%, and 15% weight ratio fraction of human hair, then cutting the sheets by electrical saw to produce the specimens as shown in the fig. (1).
The properties of materials are mentioned below;

FIGURE 1:

HUMAN HAIR REINFORCED COMPOSITE MATERIALS AND SPECIMENS

- **Reinforcement material**: Human hair is the Reinforced material of this study. This raw fibre constituted from keratin, which represents the basic content of human hair fiber, and represent have weight 65-95% from the total weight of hair fibers, the keratin consisting from proteins and polymers of amino acids. i.e., the protein includes significant concentration of Sulphur. The physical features of human hair represent strong fiber, smoothness, elastic and softness. Cortex keratin is not degradable in water, highly resistant to proteolytic enzymes and affected by this feature and its extended chains pressed to be forming a systematic structure that additionally being strong and flexible. This characteristic present main reason for making the human hair composite material more flexible (Fuchs E., 1995).
A uniform singular hair able to resist a load about 70 grams. Different specifications of human hair fibre illustrated in the table (1) (Zhenxing Hu et al., 2010).

TABLE 1.
STANDARD HUMAN HAIR FIBER SPECIFICATIONS.

Density [g./cm3]	Tensile Stress [MPa.]	Modulus of Young's [GPa.]	Poisson's Ratio [-]
1.34	200	1.74 – 4.39	0.37

Matrix: The Resin of SIKADUR -52 LP manufactured by SIKA Gulf Company in Bahrain kingdom used as matrix to produce of specimens. This resin consists of two components (A+B) as shown in Fig. (2), component (A) is an epoxy resin contains of reaction product bisphenol A (epichlorohydrin) oxirane, mono [(C-12-14 alkyloxy) methyl] derives, and component (B) is the hardener which contain 3-aminomethlyl -3,5,5- trimethyl cyclohexylamine 3,6-dizaoctanethylene diamine. Hardener (B) mixed with (A) as (1.33 gram) with each (2.67 gram) from epoxy (B).
The epoxy resin is a high mechanical and adhesive strength, low-viscosity injection liquid, used at low temperature and Shrinkage free hardening. The specifications of epoxy resin listed in table (2) (Sika Egypt for Construction Chemicals, 2015).

TABLE 2.
THE SPECIFICATIONS OF RESIN USED IN THIS RESEARCH AND TECHNICAL DATA SPECIFIED AT 20° C.

Specifications	Typical Results
Flexural Stress	50 (N/mm2)
Compressive Stress	53 (N/mm2)
Tensile Stress	25 (N/mm2)
Modulus of Elasticity	1060 (N/mm2)

FIGURE 2:

Matrix Resin & Hardener (A+B)

- **Preparation of specimens:** Specimens were produced by procedure was known as handled lay-up technique that is really simple procedure for batch fabrication and little amount manufacturing. This production method is suitable for making a model like as pattern or specimen and small bulk manufacturing composite material components. The process of handle lay-up can be separated into four fundamental processes like as fabricating and arranging the mold, covering and coat the surface by gel, mixing lay-up and completing. Fabricating and arranging the mold is one of steps that essential and the very significant in the lay-up steps. The Molds might be fabricated from woods, plastic, glass, composites or metal rely upon on the quantity of material, solidification degree, atmospheric pressures and etc. The design of mold depends on the volume, bonding and material matrix etc. In our investigation the mold consists of plastic frame with two glass sheets and coated the inner mold surfaces by gel in order to separate the mold easily after solidification time period (48) hours for composite. The handle lay-up is the process that the shredded filament mesh implemented on the mold by hand. The Human hair Composite stratified Fabrication is cured completely within the surrounding circumstances and with assisting of applied external load (10 N) on the upper mold glass part. Finally, the machining processes done to manufacturing and produce the specimens as demanded dimensions specified in ASTM criterions in order to be ready for tensile test process for composite materials as show in the figure (3), (4), (5) and (6) as respectively.

FIGURE (3)

Hand Lay-up

FIGURE (4)

The glass cover and plastic mold

FIGURE (5)

Pure Matrix sheet

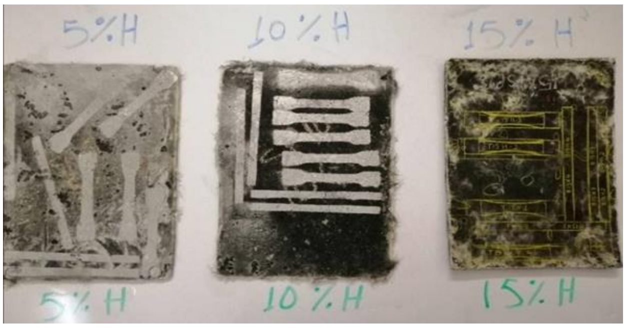

FIGURE (5)

The 5%, 10% and 15% weight ratios of human hair composite sheets

- **Tensile test investigation:** The experimental tests done by electrical universal testing machine type HOYTOM model DI- 922 FL; the apparatus has a maximum load of (200 KN.) with constant rate of crosshead movement of the applied load (10mm/min) as shown in fig. (7) to investigate the tensile properties of the material particularly composites.

FIGURE7.

Electrical universal testing machine

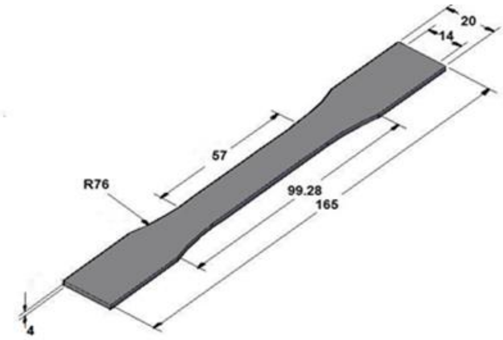

FIGURE8.

Dimensions of tensile specimen

The specimens of tensile test were prepared depending on specifications of international standards which developed by (American Society for testing and materials organization) (ASTM – D638-02a) with specimen's dimensions (165mm x 20mm x 14mm) as appear in dimensions drawing Fig. (8), the process of cutting fabrication for specimens shown in Fig. (9). The load of tensile machine proportion with elongation as appeared through the screen test and continued until specimen was broken as shown in fig. (10). Then stresses and strains curves are calculated, plotted and previewed.

FIGURE 9**.**

Specimen Machining Process

FIGURE 10.

Specimens of tensile after test

RESULTS AND DISCUSSION

From the mechanical tensile test, which are important to perform the suitability of a composite material and from this present investigation, we determined many characteristics such as ultimate stress, ductility, elastic Toughness, the ultimate modulus of elasticity and average of transverse stiffness (K).

The results appear high specific properties for polymerized natural human hair fiber composite that allowed the manufacturers to use its without restrict for cost instead of synthetic fibers (such as carbon or fiberglass) in many industrial mechanical applications such as product of boxes, car dashboard and disposable containers etc.

Fig. (11) Shows the tensile load test (Stress- Strain Curve) behavior for four specimens of pure matrix without hair fiber, which can be represent the reference stress - strain characteristics for other weight ratios investigated human hair composite material specimens.

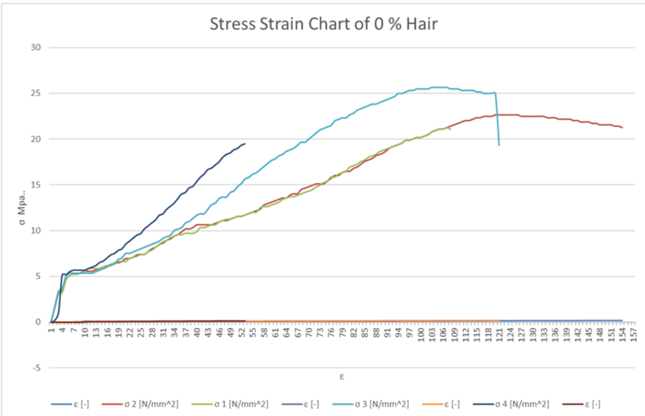

FIGURE 11.

The Stress-Strain Curve of 0% human hair composite material

Fig. (12), (13) and (14) appears the tensile load tests (Stress-Strain Curves) behavior for four specimens of 5%, 10%, 15% human hair composite material respectively. Many mechanical parameters were observed from these curves then compared with pure matrix curves. Fig. (13) appears that max. tensile strength ranged from (18-23) MPa. cause the length of hair fibers are different collected that will increase the interference between the fibers, then rising the strength, while (Avinash Kuhar, 2014) found that max. tensile strength increased from (5-12) MPa. and when the percent of hair fiber increased to 20% from composite, the tensile strength reaches to (17) MPa. depending on the length of hair fiber around (0.5-2) cm. Jayachandran et.al. (2016) investigate that when hair fibers are 10% from composite, the tensile strength is (9) MPa.

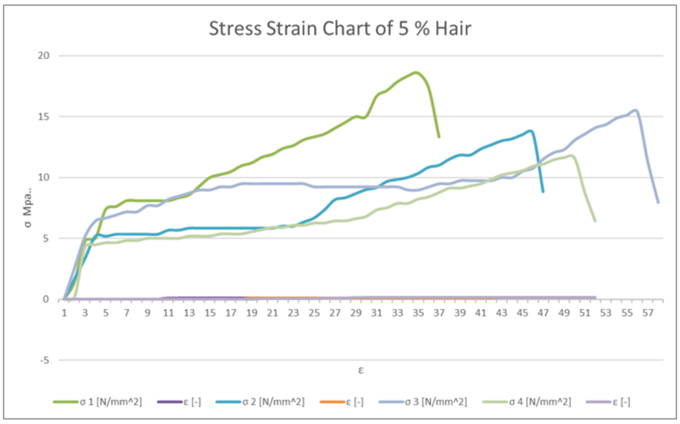

FIGURE 12.

The Stress-Strain Curve of 5% human hair composite material specimens

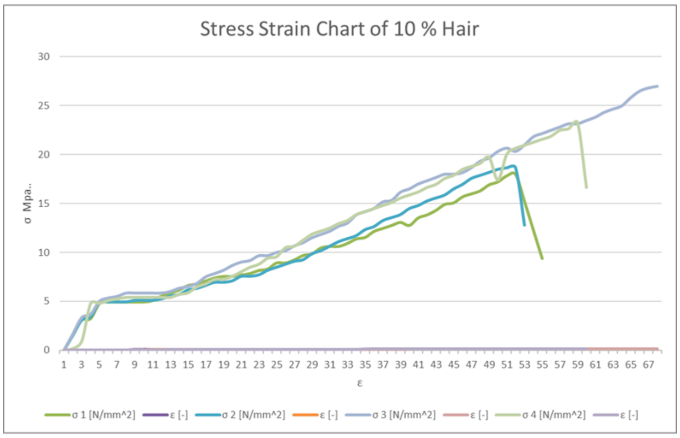

FIGURE 13.

The Stress-Strain Curve of 10% human hair composite material specimens

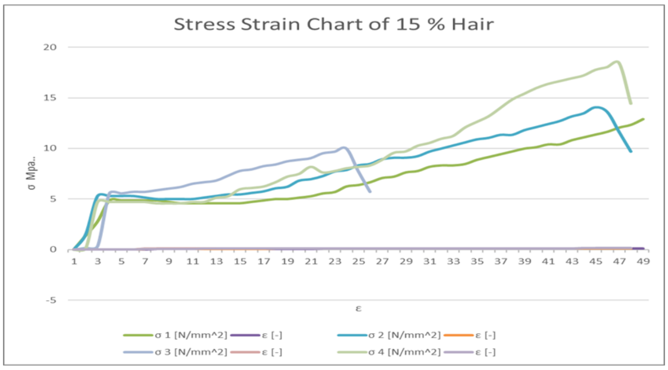

FIGURE 14.

The Stress-Strain Curve of 15% human hair composite material specimens

THE ULTIMATE STRESS

In (fig. 15) the vertical axis of chart represents the ultimate strength in unit of (MPa.), while the horizontal axis represents the weight ratios for 4 specimens of human hair reinforced composite. This figure indicates that the values of ultimate strength for 5% human hair composite material specimens are less than the values of pure matrix specimens, because the hair fibers are low strength than epoxy. While the values of ultimate strength for 10% human hair composite material are more effect than pure matrix, because the keratin protein is composed of large strings (polymers) of amino acids that increase the ability of human hair material of specimen to undergo the stress without failure. The values of 15% human hair composite material appear the lowest magnitudes of ultimate strength than pure matrix cause the epoxy polymer have been poor strength compared with high content of hair.

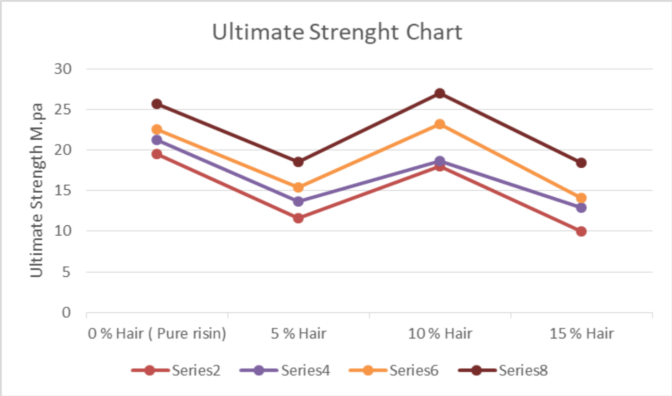

FIGURE 15.

Chart of ultimate strength for human hair composite material specimens

The Ductility: In fig. (16) The vertical axis of chart presents the ductility with (MPa.) unit, while the horizontal axis represents the weight ratios for 4 specimens of human hair reinforced composite. This chart indicates that the value of ductility for ratios 5%, 10% and 15% of human hair composite material specimens decreased more than the pure matrix specimens cause hair fiber ductile matter.

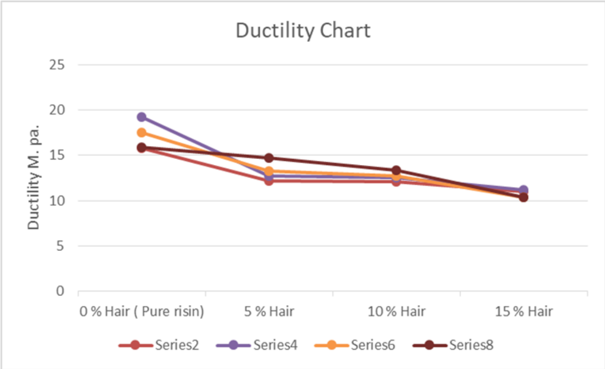

FIGURE 16.

The ductility of human hair composite material specimen's specimens

The Elastic limit: The vertical axis of chart in figure (17) Presents the elastic limit (or yield stress point) in unit of (MPa.). The yield stress point represents the separation limit between elastic and plastic region in the material. The horizontal axis represents the weight ratios of 4 specimens for human hair reinforced composite. This exhibit chart indicates that all specimens of human hair composite material for weight ratios 5%, 10% and 15% have values of elastic limit less than from the pure matrix specimens with approximately same behavior for all of this weight ratios.

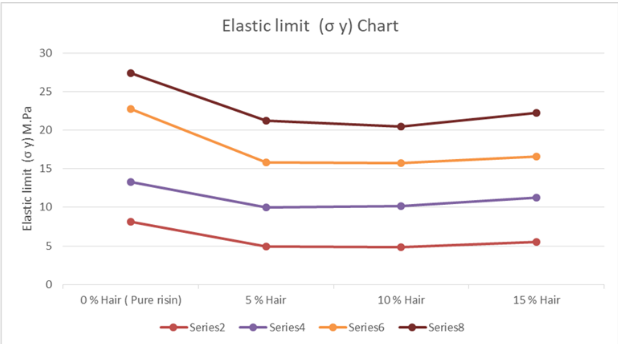

FIGURE 17.

Elastic limit (yield stress point)

CONCLUSIONS:

In this investigation we are studied the human hair reinforced composite material and we are deduced that;

- The weight ratio of 10% human hair composite material acquired the highest ultimate strength.
- All weight ratios of human hair composite material exhibit lowest values of ductility than the pure matrix specimens.
- The chart of elastic limit indicates that most weight ratios of 5%, 10% and 15% human hair composite material specimens laying in the same range values of elastic limit or little bit less than compared with the values of the pure matrix specimens.
- The behavior of the modulus of elasticity improved in most weight ratios of human hair composite material specimens compared with the weight ratio 0% of human hair specimens.
- The 5% weight ratio of human hair composite material specimens have best values of transverse stiffness compared with weight ratio of 10% and 15% human hair composite material specimens than pure matrix.

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