HUMAN HAIR REINFORCED BIO-COMPOSITES ENVIRONMENT FRIENDLY ADVANCED LIGHT WEIGHT COMPOSITES

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Abstract—Bio-fibres have recently become eye-catching because of their immense potential, high aspect strength, fairly good mechanical properties, low cost and an effective reinforcement for fibre reinforced polymer (FRP).These bio-fibre composites can be used to substitute the traditional materials being used these days. The main component of hair is keratin which is tough, insoluble and incredibly strong. An important aspect is that a single strand of hair can withstand the strain of 100 -150 grams. Hair is elastic and it is capable of regaining its original position on the removal of the deformation load. The composite uses human hair as the dispersed phase. The composite was found to withstand a compressive load of 170KN and in terms of hardness measure, was stranger than copper and aluminium.

***Keywords*—Bio composite, human hair reinforced composite, Creep resistant composite.**

I. INTRODUCTION

A composite is made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The characteristics can even be more powerful than each of the individual constituent materials. The individual components remain separate and distinct within the finished structure. The components can be chemical or non-chemical. They may even be bio-materials.

The constituent in abundance is called as the matrix phase and the phase in meagre is called the dispersed phase. A theory on composites suggests that one of the components may be chemical and the other one may be biomaterial. The introduction of the dispersed phase acts as a re-inforcement to the matrix phase. In this composite, epoxy resin is the matrix phase.

II. THE MATRIX PHASE

Epoxy resin is used as the matrix phase. Epoxy is both the basic component and the cured end product of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins, also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide groups. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homopolymerisation, or with a wide range of co-reactants including polyfunctional amines, acids (and acid anhydrides), phenols, alcohols, and thiols. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing.

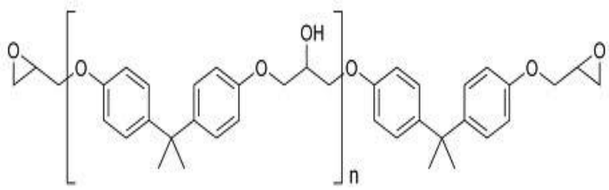

Fig. 1. The typical structure of epoxy

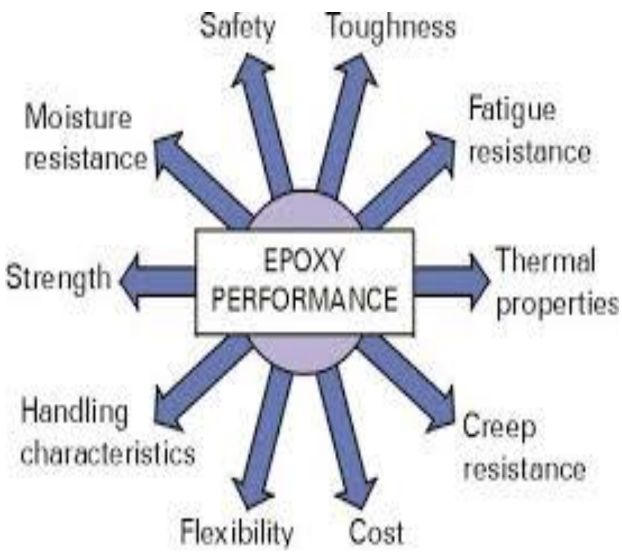

Fig. 2. Epoxy characteristics

III. THE DISPERSED PHASE

Hair has got excellent stiffness, tensile strength property and fairly good adhesive properties. Hair is capable of withstanding high loads, research has shown that a single strand of hair can withstand up to 125grams of load. Hair molecules are made up of polymer constituents.

- A hair strand is capable of elongation of up to 20% when dry and 50% when wet.

- On the application of a load, hair strands elongate elastically, but do not break and are capable of returning to their original position on removal of the deforming load.
- Hair strands are a SHAPE MEMORY ALLOY as they regain their original shape on the removal of the deforming load. Wet hair is heavier than dry hair. Thus, even in the case of mixing with a solution, hair molecules become heavier but do not become brittle as they are protected by the epoxy resin coating.
- Creep propagation is absent in case of hair, so they will not buckle or fail under heavy loads. Hair molecules are a fibre by themselves in nature and hence can effectively form a composite.
- Hair molecules are developed by a natural process and this enables better fibre properties to it.

IV. COMPOSITION OF HAIR

Primary component of hair fibre is keratin. Keratins are proteins, long chains (polymers) of amino acids. Keratin proteins form the cytoskeleton (miniature skeleton within a cell) of all epidermal cells. Hair contains a high amount of sulphur because the amino acid cysteine is a key component of the keratin proteins in hair fibre.

The sulphur in cysteine molecules in adjacent keratin proteins link together in disulfide chemical bonds. These disulfide bonds are very strong and very difficult to break apart. These disulfide chemical bonds linking the keratins together are the key factor in the durability and resistance of hair fibre to degradation under environmental stress. They are largely resistant to the action of acids.

The organisation of keratin within its cortex allows it to resist a strain of up to about a hundred grams. A lock of 100 hairs can thus withstand a weight of 10 kilograms. As to the average head of hair, it could withstand 12 tons.

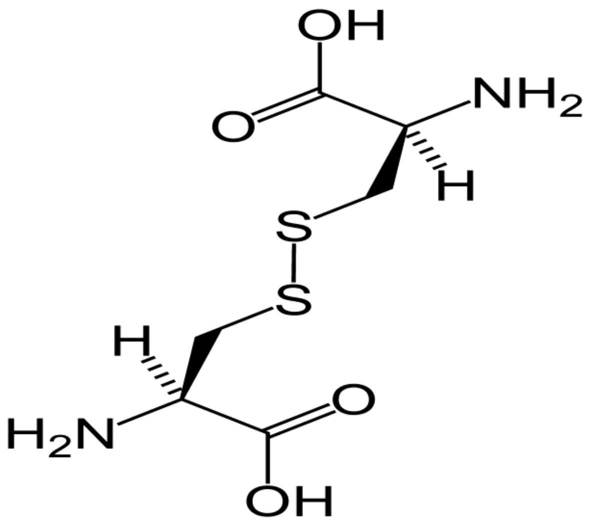

Fig. 3. Disulfide bond in keratin molecules

In chemistry, a **disulfide bond** is a single covalent bond derived from the coupling of thiol groups. The linkage is also called an SS-bond or disulfide bridge. The overall connectivity is therefore C-S-S-C. The terminology is almost exclusively used in biochemistry, bioinorganic and bioorganic chemistry. Formally the connection is called a persulfide.

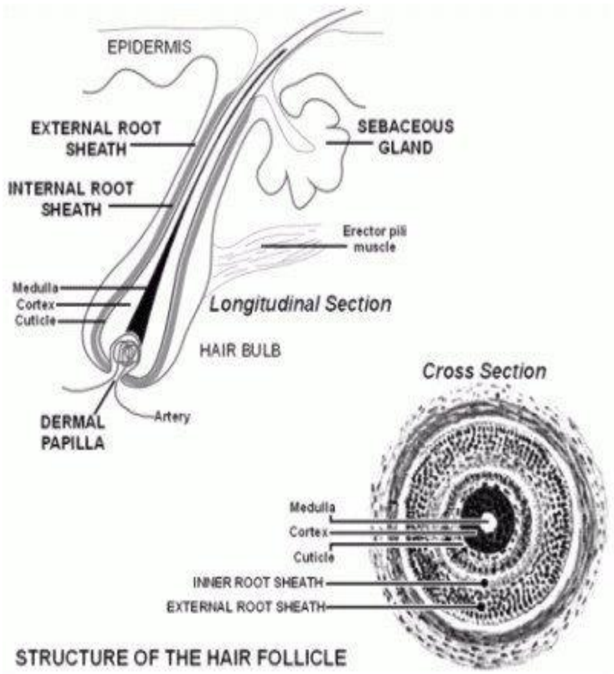

Fig. 4. Structure of human hair

V. ANALYSIS AND TESTING

The composite was formed in three different forms:

- Cross-linked polymer
- Random orientation polymer
- Mixed strand polymer

Cross linked polymer

Alternative layers of the matrix phase and the dispersed phase are laid one over the other. Each layer is 90 degrees orientation with the other.

Random orientation polymer

The matrix phase and the dispersed phase are laid layer by layer with the dispersed phase spread randomly over the matrix phase.

Mixed strand polymer

There is no layer by layer orientation. The matrix and dispersed phase are spread as a solution and allowed to solidify to form the composite. The load applied will be taken by the hair strands on the layer and thus, this is most suitable method.

Of all these, mixed strand polymer is the best which would withstand load without surface crack.

We fabricated a mixed strand composite. COMPRESSIVE TEST, ROCKWELL AND BRINELL HARDNESS TEST were conducted. COMPRESSIVE TEST showed that the composite withstood up to 170KN. TENSILE TEST showed that the composite withstood up to 480MPA or 48 Kg/mm2 .The ROCKWELL HARNESS NUMBER was 66 (and) the BRINELL hardness number was 131.This shows that the composite is more stronger than copper, aluminium and mild-steel. Mild steel has tensile strength of 410 MPA or 41Kg/mm2.

VI. ANALYSIS OF GEOMETRY OF LOAD APPLICATION

A single strand of hair was able to withstand a load of up to 125g.

$$\text{TENSILE STRENGTH} = \frac{\text{FORCE APPLIED}}{\text{CROSS-SECTIONAL AREA}}$$

The diameter of the hair strand = 0.00157 inches
= 0.004 cm
= 0.04 mm

Therefore, radius of hair strand = diameter/2
= 0.04/2
= 0.02mm

A single strand of human hair is fixed at its two ends and weights are suspended at its centre. Suitable weights are added and the weight suspended is increased. It is found that the hair strand breaks at weight above 125gms.

We apply **LAMI'S THEOREM** to find out the amount of load acting on each arm of the hair. Lami's theorem states that when three forces acting on a body keep the body in equilibrium, then each force is proportional to the sine of the angle between the other two forces.

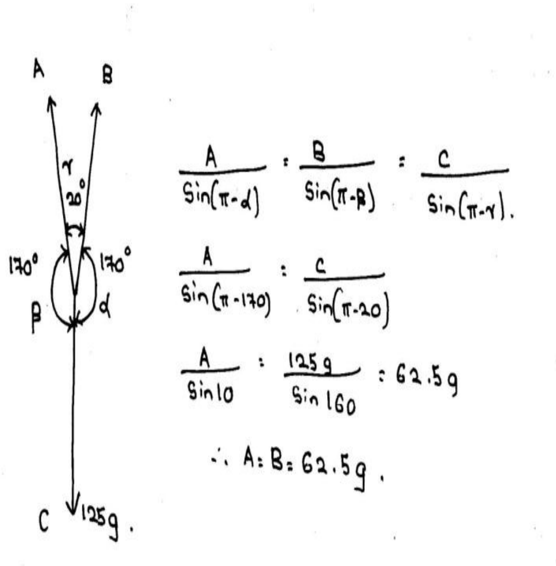

Fig. 5. Lami's theorem and geometry of load application

Thus, the amount of load to be considered = 62.5 gms

VII. EQUATIONS

Cross-sectional area = ∏*r*r
Radius r = 0.04 mm
Thus, the cross-sectional area = ∏*0.02*0.02
= 0.001256 mm^2

Force = 62.5 g
= 0.0625 Kg
= 0.6129 N

$$\text{TENSILE STRENGTH} = \frac{\text{FORCE APPLIED}}{\text{CROSS-SECTIONAL AREA}}$$

TENSILE STRENGTH = 487.79 N/mm^2
= 487,790,000 N/m^2
= 487,790,000 Pa
= 487.79 Mpa

Thus, the tensile strength of composite = 487.79 Mpa
Tensile strength of mild steel = 410 Mpa
Tensile strength of copper = 210 MPa
Tensile strength of aluminium = 180 Mpa

Thus, this composite has a tensile strength more than that of mild steel, copper and aluminium.

MATERIAL	**RHN**
COPPER	49
ALUMINIUM	31
MILD STEEL	65
HAIR COMPOSITE	66

Table. 1. Comparison in terms of Rockwell hardness number

MATERIAL	BHN
COPPER	100
ALUMINIUM	66.55
MILD STEEL	120
HAIR COMPOSITE	131

Table-2 comparison in terms of brinell hardness number

Triethylenetetramine, abbreviated TETA, is an organic compound with the formula $[CH_2NHCH_2CH_2NH_2]_2$. This oily liquid is colorless but, like many amines, assumes a yellowish color due to impurities resulting from air-oxidation. It is soluble in polar solvents and exhibits the reactivity typical for amines. The branched isomer $N(CH_2CH_2NH_2)_3$ and piperazine derivatives also comprise commercial samples of TETA.

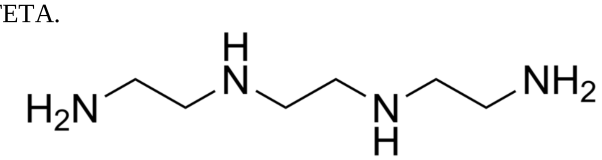

Fig. 6. TETA

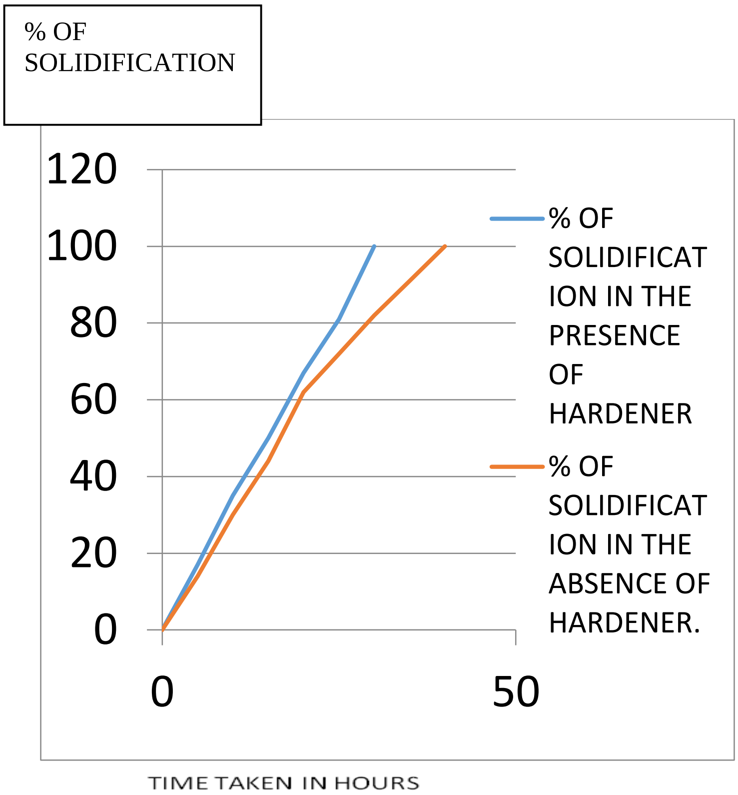

Fig. 7. Time taken for composite formation with and without hardener(i.e. time taken for the solidification of epoxy with and without hardener)

- A sample that we prepared with 100% full of epoxy and no hair did not form a composite and the result was a flexible sample that had no hardness at all and was easily bendable.
- When the percentage of the hair in the composite exceeded 50%, the composite no longer was formed as the basic principle for the formation of composite is that the matrix phase must be more than the dispersed phase.
- The time taken for formation of the composite and solidification of the entire composite with the presence of a hardener took time lesser than the time taken for formation of the composite without hardener.
- Increasing the percentage of hardener in the epoxy resin was found to make the composite weaker during tests. Thus the best optimum ratio for the presence of the hardener must be 10% of the total weight of the epoxy resin.
- Example: If the total amount of epoxy was 20g, then that amount of the hardener must be 2g.
- A hair strand of about 10mm extended to up to 12 mm during the application of load.

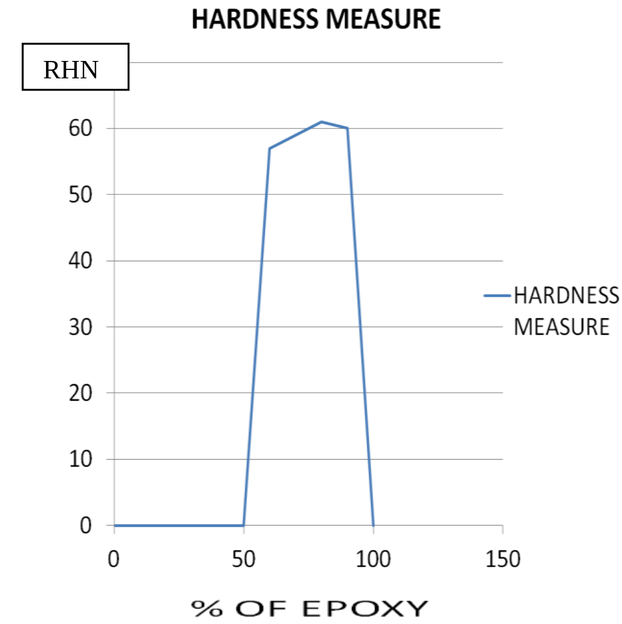

Fig. 8. Comparison between % of epoxy and rockwell harness number

Fig. 9. Material

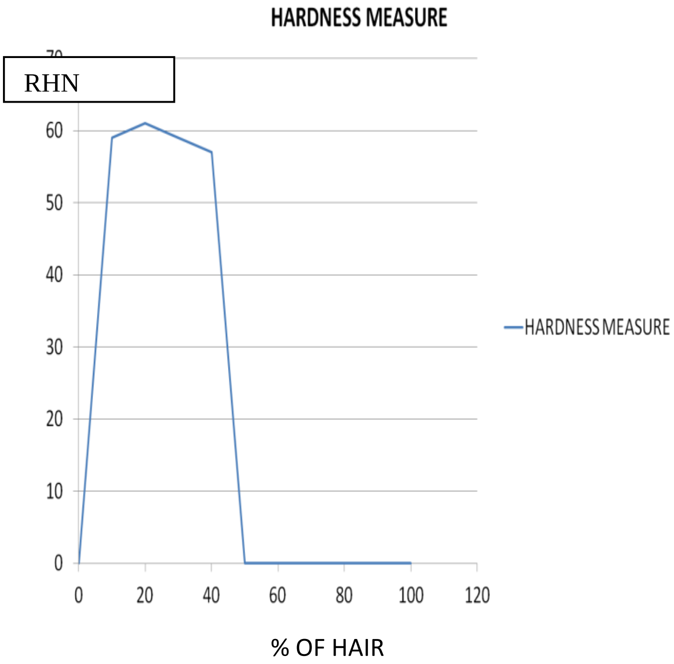

Fig. 10. Comparison between % of hair and rockwell harness number

VIII. ABSENCE OF CREEP PROPAGATION

Creep is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long term exposure to high levels of stress. Creep is a deformation mechanism that may constitute a failure and cause the solid to buckle. Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Creep is a "time-dependent" deformation. The amount of surface crack is dependent on the creep, both are directly proportional.

Creep propagation is absent in our composite as the loads applied are not stored but they are released once the applied load is removed. This happens because the hair strands are capable of elongation and they regain their shape on load removal. When they regain their shape, the accumulated stress is released. As creep propagation is absent, the amount of surface cracks that occur is greatly reduced.

Creep formation is absent in this composite since accumulated stresses will be absent. (Since hair is elastic).

IX. ADVANTAGES

This composite is prepared by an environmental friendly manner in comparison with the manufacture of copper and aluminium which require mining, smelting, and concentration which cause pollution to the environment.

- Creep propagation is absent in our composite. So our composite will not fail or buckle under heavy loads.
- Our composite is capable of elongation by up to 50% on application of loads.
- On removal of applied load, our composite will come back to its original position, thus, ours is a shape memory composite.
- Ours is a composite in which the constituent hair is a bio-fibre and a fibre by itself. Thus, the formation of the composite will be easier.
- Our composite can be fabricated in all possible shapes. The constituents are available in plenty in nature.
- Hair strands react efficiently to any dye applied. Thus any color can be coated on the hair strands. Thus, the composite can be fabricated in all possible colors.
- Can be fabricated in rod shape also.
- The composite can be used in critical as well as non-critical zones.
- The composite can take up compressive loads of up to 170KN.

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