Effect of Banana fibers on the enhancement of compressive toughness of Reinforced Concrete Columns –A Review

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Abstract

Fibers have been used in concrete by different researches since a few decades. Natural fibers are widely used as additive material in concrete to enhance the strength and mechanical properties of concrete. It has been observed that by using fiber reinforced composite (FRC), the weight and manufacturing cost can be reduced. The purpose of this study is to find out the flaws in reinforced concrete (RC) columns regarding compressive toughness and their remedial measures. This paper includes the state of the art review of behavior of RC columns under compressive load, role of toughness and available measure to increase compressive toughness (CT). Analysis of chemical, mechanical and physical properties of banana fiber is done for choosing it as suitable fiber. Usage of banana fiber in different proportions in concrete and its effect towards enhancing the compressive toughness is also studied. The compressive strength of concrete by using FRC is reduced in most of the cases but ability to absorb energy is increased. There are a very less number of experimental studies present in literature regarding use of banana fiber in FRC so there is a need of a lot of work on it. Banana fibers can be used in future studies to enhance plasticity of concrete and its fire resistance.

Keywords: Banana fiber, Compressive toughness (CT), Fiber reinforced composites (FRC).

I. INTRODUCTION

Since past century, concrete has been used as primary engineering material in construction industry [1]. The concrete with combination of steel reinforcement is called reinforced concrete (RC) to withstand whole loads of structure. It is not necessary that the reinforced concrete structures having high strength always show a good structural performance. On the other hand, a material having higher energy absorption (toughness) provides higher structural performance when undergoes to failure due to certain reasons. Ductility is the count of a material that how much it deforms plastically before happening of fracture. The materials with low ductility and low strength have low energy absorption whereas the materials with high ductility and high strength have more ability to absorb energy. Hence, the materials with later described properties are more useful for structures [2]. In reinforced concrete structures, columns as compressive members transfers vertical load to foundation. Due to increase in axial stresses than capacity of column, it will fail in compression. There are many types of failures that can be minimized or controlled by enhancing ability of energy absorption (toughness) of columns. So there is need to study behavior of concrete under low toughness and techniques of enhancement of toughness to increase overall performance and durability of RC structures.

There are many reasons for applying natural fibers in concrete. Natural fibers are nature friendly and usually obtained from plants and trees. They are cheaper and have good mechanical properties i.e. tensile strength, flexural strength and compressive strength. The cost of replacement is very low as compared to other concrete materials. So, they have become popular among researchers. Many types of natural fibers are present and easily available. Coir, bamboo, rise husk, banana and jute fibers are some examples of natural fibers. Concrete columns when undergoes compressive load, a resistance is present to withstand this load and resist against cracking and failure. At a point, column starts cracking and then deforms completely. According to British standard BS EN 12390-3:2019, the concrete can withstand the strain of 0.0035 and the steel present in RC structures starts yielding at a strain of 0.002 that can increase than concrete. When axial stress value exceed the certain limit then it causes increase in strain limit of concrete. Hence, as a result of this, concrete will fail suddenly by sudden crushing of concrete. If this particular section is properly reinforced it will provide warning before failure phenomenon. Sometimes columns due to eccentric moments caused by unbalanced loads are subjected to bending moments along with axial forces. Axial compressive stress and bending stress act, by adding the effect resulting final stress in that particular section. Failure of column due to these additive stresses will happen as explained earlier. The designers should keep in mind the load combinations and possible alternative loading effects. We need to be alert while having deviations in span.

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The flaws of columns under compressive loads can be overcome by using appropriate fiber materials as additive for enhancing overall structural compressive member's strength and toughness [3]. Columns may take an extra time in fracture as fiber can take load while experiencing compressive load. The purpose of this study is to analyze the behavior of RC columns under axial loads and the available ways to increase compressive toughness by taking into count the state of the art literature. Chemical, physical and mechanical properties of banana fibers are studied to choose banana fiber as suitable fiber. The feasibility and existing studies related to the usage of banana fiber in RC columns and expected performance due to banana fiber reinforced RC columns and improved toughness is also discussed.

II. FLAWS IN RC COLUMNS REGARDING COMPRESSIVE TOUGHNESS

Concrete is a brittle material and have lower ductility in comparison with steel [4]. Column is compression member of RC structure which transfers load to foundation. Axial load of structure is applied on column, eccentric moments also join and transformation of combined effect happens [5]. Corrosion in RC columns results in reduction of performance degradation in member strength and ductility. The un-retrofitted eroded columns failure mode is converted from flexure failure to shear compression failure [6]. When column experiences compression load the concrete cover spalls out resulting in reduction of durability and toughness [7]. By the consequences of this phenomenon, durability and performance is compromised in long terms in worse conditions [8] [9] [10]. Concrete and reinforcement withstands stresses when columns are axially loaded. In unfortunate conditions, if the area of cross-section of column is less as compared to the loads, the column can be failed without going any lateral deformation. As steel of column and concrete has reached the yield stress. This failure is due to the crushing effect of material.

Vertical elements like columns are subjected to cyclic loading. In the compression members, the higher stresses are generated near connections. The lack of links in the areas where shear stresses are high cause failure of columns. If toughness of the column which is under cyclic load is less, then it will suddenly collapse. Columns are usually designed against considering the effect of shear, axial and bending forces but sometimes due to irregularities in structure, effect of torque can be observed. Columns have reinforcement around the section and considered as rigid. However, if torsional effect crosses the limits then columns can collapse. Low toughness will cause sudden deformation while collapsing. The engineered cementious composites (ECC) behavior was determine under pure compression load by testing. Results were combined in terms of load deformation curves, ductility and toughness. It was observed that the failure mode was sudden due to low toughness but toughness can be increased by using ECC skin [11].

III. AVAILABLE MEASURES TO ENHANCE COMPRESSIVE TOUGHNESS

The effect of content of fiber on flexural and compressive strength by appropriate tests was found. It was observed that the mechanical properties were enhanced along with first crack and failure strength by enhancing the amount of fiber in concrete mixture. Concrete has brittle nature and this nature induces micro cracking, due to penetration of intruding agents the service live of concrete may be reduced causing durability issues. Carbon nanotubes result in reduction of micro cracking by enhancing cement paste matrix. Hence it increases the toughness and durability resistance [12]. Recycled aggregate has been used along with fibers by researchers to check the properties of concrete made by recycled aggregate. For this purpose recycled aggregate (RA) was used from 0% to 100% and fiber 0% to 1%. Results revealed that the hardened properties of this concrete were somehow less than the conventional concrete that can be due to presence of old mortar in RA. On the other hand, compressive strength increased marginally but the split tensile strength increased by 43-52% and flexural strength 35-44%. There was a considerable increase in compressive toughness of concrete [15].

The stress-strain graph by varying content of RA and fibers is shown in figure 1. It was observed that the failure in graph for the concrete without fibers is sudden and post-peak toughness is little. However, the failure in concrete that has fiber content is gradual with significant amount of toughness [14] [15]. It was concluded that the addition of fibers enhanced the peak stress ration from 1.091 to 1.112 and peak strain ratio from 1.49 to 1.56. The overall value of peak strain ratio was increased by 50-60% and peak stress ratio is increased by 9-11%. It is clear from table 1 that the compressive toughness (total energy absorbed) is considerably increased [13]. This Toughness can be increased by using fibers in concrete. So, the structure will show gradual failure pattern instead of sudden failure. [16] Conducted a

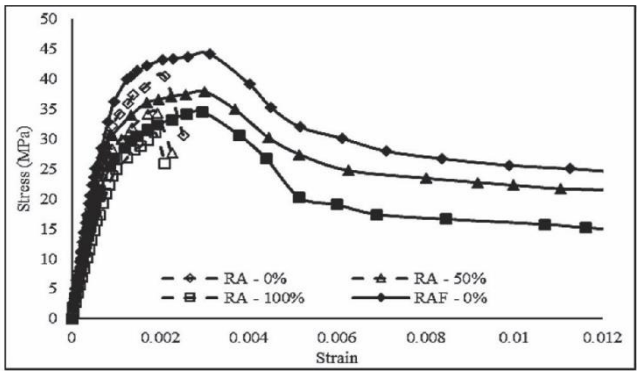

Figure 1. Stress-strain graph of recycled aggregate (RA) with and without fiber [13].

study one the effects of fiber towards the enhancement of compressive toughness. This study concluded that by the addition of fibers there was a slight increase in compressive load but post-peak compressive ductility was greatly enhanced. The compressive toughness values were calculated for 0.5% and 0.75% addition of fibers. Compressive toughness increased by three to six times. The increased compressive toughness was due to the bridging effect of fibers towards micro-cracking. Due to the bridging effect of fibers, propagation of micro-cracking to macro-cracking reduced. Hence, material withstand more load instead of sudden deformation and ability to absorb energy and toughness increased.

Table 1. Toughness index with and without fibers [13]

Specimen ID	Total Energy (KJ/m^3)	Toughness index
RA-0%	76.23	5.04
RAF-0%	384.34	-
RA-50%	57.52	5.74
RAF-50%	330.17	-
RA-100%	44.85	5.73
RAF-100%	257.10	-

IV. SELECTION OF SUITABLE FIBER

Many kind of natural and artificial fibers are present for use during construction. Each fiber has own characteristics. Fibers are usually use to enhance the properties of concrete. At one side if fibers enhance properties of concrete, it's not necessary to enhance all properties. Some properties remains same and some properties are enhanced considerably to take desired results. Natural fibers increase tensile and flexural strength of concrete. It has been observed that compressive strength is reduced by usage of natural fibers in most of the cases. There is an important factor of absorbing

energy is increased by natural fibers [16]. As a result of this the plasticity of concrete is enhanced. Concrete takes more fracture time as compared to the normal concrete made by simple mixture of cement, sand, aggregates and water. The Mechanical properties of Banana Fiber-reinforced virgin and recycled High-Density Poly Ethylene (HDPE) were determine in terms of tensile and flexure properties. During this study results concluded that the improvement occurred in tensile modulus and reduction in tensile strength. Furthermore, the reasonable increase in flexural strength and flexural modulus was observed [17].

Natural fibers are divided into two major categories the one is animal fibers and other is plant fibers. Chicken feathers, cocoon silk, spider silk and wool are some examples of animal fibers and used for biomedical applications. Composites prepared by natural fibers are eco-friendly, light in weight with considerable strength. The important factors that make natural fibers superior to artificial fibers are minimal health hazards during preparation, low cost, good thermal and acoustic insulation, biodegradable, good specific strength and modulus and ease of availability. Fibers are sometimes treated with different chemicals to obtain better strength results [18]. Plant fibers contain jute, coir, banana, bamboo and coconut etc. Banana fiber is natural fiber with good mechanical properties [19]. It has good thermal conductivity and thermal resistance [20]. It has strong moisture absorption and light in weight. Table 2 contains the chemical properties of banana fiber. Table 3 shows the mechanical and physical properties of banana fiber [22] . It has been observed that the treatment of banana fibers with 6% NaOH concentration for optimum treatment and immersion time is 2 hours. This process yields the 12.45 GPa tensile modulus whereas 371 MPa tensile strength and 3.96 MPa interfacial shear strength. As concentration of NaOH increases the tensile strain also increases. Mechanical properties of banana fiber deteriorate significantly when concentration of NaOH increases beyond 6% [22].

Table 2. Chemical properties of banana fiber [22]

Sr. No	Constituents	Banana Fiber
1	Cellulose (%)	63-64
2	Hemi cellulose (%)	6-9
3	Lignin (%)	5-10

Table 3. Mechanical and physical properties of banana fiber [22]

Sr. No	Mechanical and Physical Properties	Banana Fiber
1	Density (g/m^3)	1.25-1.35
2	Tensile Strength (MPa)	529-914
3	Tensile Modulus (GPa)	24-32
4	Elongation (mm)	2-2.5
5	Fiber Diameter (m^{-4})	50-250

Different natural fibers and their properties are present in Table 4. The low density and higher tensile strength of banana fiber make it superior than other described fibers. Because concrete is weak in tension and strong in compression. The usage of banana fiber may provide better strength properties as well as compressive toughness.

Table 4. Comparison of mechanical properties of different plant fibers [30]

Sr. No	Natural Fibers	Density (g/cm^3)	Tensile Strength (MPa)
1	Jute	1.35-1.45	393-773
2	Pineapple	1.44-1.56	170-727
3	Banana	1.30-1.35	503-790
4	Cotton	1.50-1.60	287-587

V. EXPECTED FEASIBILITY, USABILITY AND PERFORMANCE

Due to the increase of environmental, social and economic issues, there is need for sustainable and low cost construction. Dumping of agricultural waste like banana fiber is a matter of concern and it may cover large part of agricultural land. The other way which is often adopted is burning of agricultural waste, which is also not a healthy practice [24]. It causes global warming. The utilization of this agricultural waste (banana fiber) can enhance the properties of concrete and ability to absorb energy is also increased. Banana fiber is feasible to be used in concrete because it has no impacts on human and environment. Hence, it is a sustainable light weigh material for cleaner production and sustainable development. Banana fibers can be used in reinforced concrete columns to enhance their compressive toughness and other properties [25]. It changes the brittle nature of concrete to ductile behavior [26]. Micro-cracking is one of the major flaw in concrete [26]. Micro-cracks under the application of loads are converted to macro-cracks. So, the structure fails. Micro-cracking can be bridge by usage of banana fibers in concrete. Varied

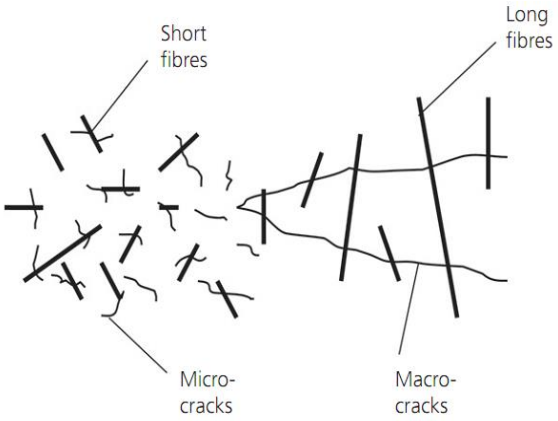

Figure 1. Crack bridging mechanism of natural fibers used in concrete [28].

length banana fibers can be used to bridge micro as well as macro-cracking in concrete as shown in figure 2. Due to addition of fibers in concrete, the stresses may transfer to upper and lower portion of crack surface in concrete. So, there can be reduction of stress in cracks tip. By this phenomenon, the cracks propagation to macro-cracking can be controlled up to some extent. Concrete will withstand more load [27]. Hence, the ability to absorb energy and finally the toughness will increase.

Concrete spalls out under the effect of elevated temperatures and failure of concrete columns may happen. Usage of fibers in concrete RC columns may lead to decrease in spalling phenomenon up to some extent [29]. The overall performance of concrete depends upon the compressive, tensile and flexural strengths of concrete. It has been observed that utilization of natural banana fibers lead to increase in all strength parameters with reduction of cement content which is not environment friendly. Performance of concrete is also

enhanced by fibers and adverse ecological effects are also minimized. This is the need with the growing age to find out new materials which are sustainable, enhance performance without compromising strength properties. Natural fibers are more feasible than artificial fibers like steel fiber because they are easy to mix and handle. Natural fibers are fire resistant and found useful to earthquake prone area. Because they have good response under seismic loadings. Concrete columns made up of reinforced concrete and banana fiber may provide better properties than simple RC columns with less ecological effects and cleaner production.

VI. CONCLUSIONS

Fibers have great influence on the properties of concrete columns. Flaws in concrete and ways of improvement are studied. Analysis of banana fiber's mechanical chemical properties is done for choosing it as a suitable fiber in this study. The expected feasibility of RC columns made up of fibers and their expected performance is also taken into count. By conducting this study following conclusions can be drawn:

- By addition of fibers, compressive strength may be compromised but considerable increase in compressive toughness is observed.
- The specimen without fiber content showed sudden failure with small value of post-peak toughness. On the other hand, specimen of concrete with fiber exhibited a significant post-peak toughness and a gradual failure.
- The overall value of peak strain ratio is increased by 50-60% and peak stress ratio is increased by 9-11% by addition of fiber.
- Due to the use of banana fibers in concrete columns, micro-cracking can be reduced along with propagation of micro-cracks towards macro-cracks, toughness can be increased and material can continue to withstand load.
- Toughness can be increased by using ECC skin.

The above outcome is favorable indicating the enhancement of performance of concrete columns. Banana fibers can be used to increase the toughness of RC columns and as a result of this overall durability can be enhanced.

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