Strength Analysis of HCS with BFRP sheet : A Composite Material Study

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Abstract - *The purpose of this paper is to analyse the behaviour of a column when it was wrapped with Basalt Fibre Reinforced Polymer(BFRP). The hollow circular section (HCS) columns were wrapped with basalt fibre. The application of fibre varied considering its orientation. The specimen was wrapped with fibre in the transverse direction. Even the wrapping varied in the number of layers. These columns experimented under a digital Universal Testing Machine for compression testing. The presentation of the result was done in terms of 1. Local Bucking, 2. Flexural Buckling, 3. Slenderness Ratio and 4. Stiffness. The column also showed enhancement in load-carrying capacity, increment in stiffness property of a column and thus proved to be a beneficial engineering material.*

Keywords: *Hollow circular section, Basalt Fibre Reinforced Polymer, Stiffness, Local buckling, compressive strength.*

1. Introduction:

Basalt Fibre Reinforced Polymer has been proving that it is very beneficial construction material. Its inherent properties help it in resisting various types of loads, chemical attacks, and even fireworks. This BFRP has versatile types such as basalt laminates, bar profile sheets, steel fibre composites, fibre steel wire plates and so on. The basalt fibre and its composites are very fruitful in having engineering properties. The main reason for its popularity is its cost-effectiveness and feasibility of its application in the field. There is a recent increase in the use of BFRP because it is also eco-friendly, light in weight and also offers exceptional properties over glass fibres. It also has high specific mechanical, physical, chemical properties[1]–[3]. Basalt yarns within composites provide tensile, compressive, flexural strength and also increases stiffness. Whereas polymer of basalt bares all adverse environmental conditions. BFRP laminates have upgraded mechanical properties as compared to GFRP laminates. Even the BFRP provides higher tensile strength and impact strength in an acidic environment. The properties of basalt fibre make it a recyclable product and have the main benefits for RCC structure strengthening as follows: (1). High strength to weight ratio than steel, (2). Concrete and basalt have the same thermal coefficient, (3). No extra coatings are required, (4). Resistant to salt, acidic and alkali attacks, (5) Non-heat conductor, (6). Also non-electrical conductor, (7). Manifested in various shapes by the regular tool as well[4], [5]. The construction having poor quality work, designing errors, can be strengthened by using various external jackets. This includes wrapping of steel-fibre, carbon-fibre, glass-fibres and basalt-fibre. Basalt fibre wrapping proves to be an economically effective alternative as compared to other fabric. This use resulted in axial strength increment[6]. To retrofit the structure, the BFRP and basalt fibre reinforced cementitious matrices (BFRCM) proves to be useful[7]. By using suitable design recommendations and design codes, the fabric material proves to be beneficial like strengthening the existing bridges and buildings in earthquake-prone areas [8]. Even the BFRP grids help in flexural strengthening of reinforced concrete beams. This was applied based on the type of thickness and examined the bond behaviour between basalt FRP grids and concrete and the flexural strength[9].

2. Methodology:

The main material required foe experimenting was basalt fibre, adhesive and steel tube. The fabric used had following specifications i.e. it was the unidirectional fabric of 420GSM with a yield tensile strength of 2100 MPa and ultimate strength of 4840 MPa with Young's Modulus of 86 GPa. The fabric configured a width of 600mm with a thickness of 0.415mm (fig 1.).

Fig 1. The unidirectional basalt fabric cloth

Furthermore, the column specimen consisted of bar diameter of 60mm with a height of 500mm and square plates at each end. After the column specimen fabrication, the columns were wrapped with fibre in transverse direction considering the column's longitudinal loading axis. While applying fibre material over the column surface, it was confirmed that the column steel surface remains rough to attain a perfect bond. The fabric was first to cut into various shapes as per adopted design (fig 2.). And it was stick using less toxic epoxy resin.

Fig 2. Specimens with various types of wrapping types

This resin consisted of a particular proportion of hardener i.e. 1 litre: 2-3 drops of hardener. This forms a layer which prevents the specimen from abrasion which can be further examined on the durability basis[10]. The high modulus CFRP laminates were used for strengthening the steel member and it was analysed based on the failure modes, bond strength, effective bond length, bond-slip relationship and so on[11].

BFRP has been manifested its relevancy in the concrete structural field, but its particular experimentation in steel structural field has not been specifically reviewed. But as per BFRP's properties, it can also be fruitful in other engineering fields. In this steel structural field, other fibres like glass, carbon and their composites have proved its versatility[12]. As a consequence, the carbon fibre reinforced polymer(CFRP) helps in axial strengthening when it was used as an external strengthening for hollow square section. The application of fibre was done on its thickness and orientation basis. It helped in effectively delaying the local buckling of a column. And also reduced external buckling. This experimental analysis was validated by using ANSYS12.0 A three-dimensional nonlinear finite element modelling[13]. The glass fibre reinforced plastic (GFRP) also significantly enhances the load-carrying capacity and stiffness when it was confined with a hollow tubular rectangular steel section[14].

2.1 Experimental Setup:

The specimen consisted of a hollow circular steel tube with a square plate at each end. The square plates of 74 x 74 mm were welded for the equal distribution of load while experimenting. The tube consisted of a diameter of 60mm and a height of 500mm.

Fig 3. A specimen tested under UTM

As per calculation[15],

$$= \frac{leff}{LLD} = \frac{1000}{60} = 16.667 > 12$$

Therefore, the column was termed as long column. The failure of a column was failed in buckling. The columns are wrapped in the transverse direction with various wrapping details like singly wrapped layer and doubly wrapped layer. These wrapping consisted of 50mm, 100mm strips and even full wrapping in a single and double layer. The strips of BFRP vary with the width but the spacing between them did not vary i.e. 25mm spacing for both 50mm and 100mm width strip. The experiment setup consisted of the specimen with a particular design of wrapping. These specimens were further tested on a digital UTM of 100 tonnes capacity (fig 3.). And a graph of load vs displacement was obtained by the machine with accuracy.

3. Result and Discussion:

As the experiment consisted of a compression member, it was a long column. There are types of failure modes that would occur. The failure modes of an axially loaded column are (1). Local Buckling, (2). Squashing, (3). Overall flexure Buckling, (4). Torsional Buckling. But during this experimentation, the column witnessed maximum local buckling and flexure buckling.

3.1 Local Buckling:

Local buckling is mostly affected by very thin elements. Generally, such thin elements are part of structural steel members. When these structural members are subjected to critical loading, these thin elements buckle invariably. This occurs before yielding. For such type of buckling, the thickness of the plate constitutes the most. The thinner the plate, earlier it buckles. Therefore, the plates were welded at each end of the column faced such local buckling. The plain column witnessed larger local buckling. But the wrapped column faced local buckling after resisting a certain amount of load. This states that the local buckling occurs at an earlier stage of loading for plain column than wrapped columns. Therefore, it seemed that wrapping of fibre delays the local buckling of a specimen.

Fig 4. Column after application of load

The local buckling of the plate was visible while experimenting. But there were not any detachments between the welded plate and hollow column while the application of load(fig 4.). The plates were relatively bent from the edges.

3.2 Flexural Buckling:

The buckling occurs when the member is subjected to compression testing. Even these members are subjected to deflection due to bending action (fig 5.). This type of buckling occurs along about the axis having the largest slenderness ratio and smallest radius of gyration.

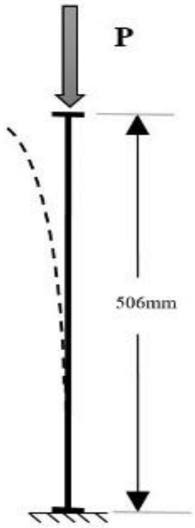

Fig 5. The failure mode of the column with end conditions

The buckling of the plain column was larger while the wrapped column resists the buckling action. The wrapped column manifested in resisting outward buckling, but in turn, provoked inward buckling. The wrapped portion of column restricted the buckling. Because the yarns in fabric resisted the load. But the inner portion of the column was not subjected to any restriction, therefore, it developed inward buckling.

3.3 Slenderness Ratio:

Slenderness is the measure of the column property to buckle. Thus the slenderness ratio is inversely proportional to the strength of the column.

$\lambda = \frac{l_{eff}}{\kappa}$

Where,

λ = Slenderness Ratio

l_{eff} = Effective length of column (mm)

= 2 x actual length

κ = Radius of gyration (mm)

$\kappa = \sqrt{\frac{I}{A}}$

Where,

I = Moment of Inertia (mm^4)

$I = \frac{\pi}{64}(D^4 - d^4)$

D = Diameter of an outer edge

d = Diameter of an inner edge

A = Area of a hollow circular section (mm^2)

$A = \frac{\pi}{4}(D^2 - d^2)$

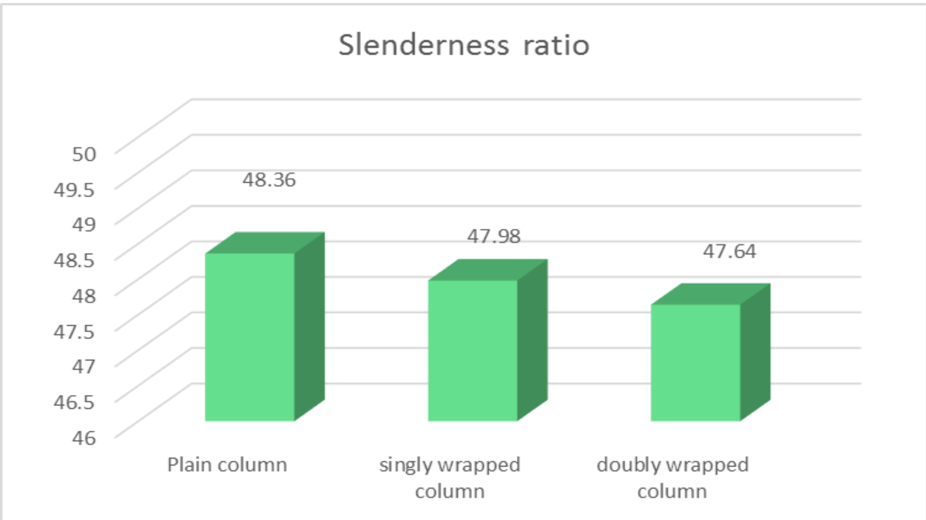

Fig 6. A comparative analysis of the slenderness ratio of a column which was wrapped in the transverse direction

As shown in fig 6; the plain column had a slenderness ratio larger than singly and doubly wrapped fibre. It seems that wrapping of fibre increases the diameter of a column and thus area. The more number of layers, the lesser was slenderness ratio. But inversely, it results in increment in load-carrying capacity. There is nearly decrement in slenderness ratio of 0.78% and 1.47% for singly and doubly wrapped column when compared to an unwrapped column.

3.4 Stiffness of Column:

Stiffness is defined as resistance to deformation. It is a measure offered by an elastic body to deformation. It is also dependent on various physical dimensions.

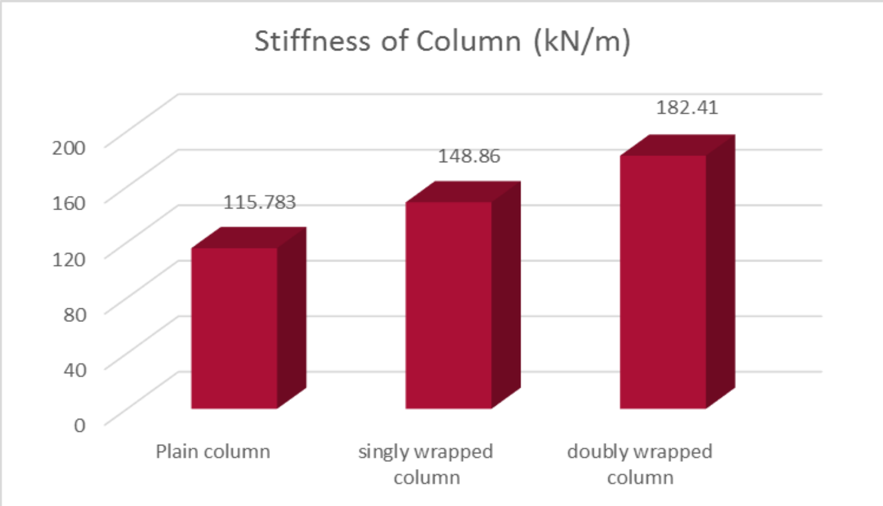

Fig 7. A comparative analysis of stiffness of a column which was wrapped in the transverse direction

In this experimentation, the layer of fibre affected the stiffness to a great extent(fig 7.). As the number of fibre layer increases, stiffness also increases. The increment showed 28.57% and 57.54% in singly and doubly wrapped fibre column when compared to a plain column. The increment in stiffness proved beneficial because stiffness is directly proportional to the strength of the column.

4. Conclusion:

The experiment states that the use of 0.415mm fibre has its effect on the slenderness ratio as well as on stiffness. It relates that the ordinary section can be stiffened and enhanced in terms of strength by using a thin layer of fibre i.e. basalt fibre, which also a cost-effective product. Even the failure modes can be controlled like restricting external buckling, delaying local bucking, thus can further prove to be a feasible composite structural material. As a result, delaying in failure modes results in larger structural stability and also reduces the danger of collapse at the site. This type of composite can also be be used in earthquake-prone areas. As compared to column strengthening by increasing sections, external strengthening by using BFRP proved beneficial as an engineering material.

5. Future Scope:

The application of basalt fibre in terms of its various products are now forthcoming in the market. One of the product was fabric cloth i.e. BFRP cloth/sheet. The material weighing 420GSM can be useful for retrofitting of an existing structure, enhancing the strength of the section, reducing the danger of stability and collapse. Therefore, its inherent properties can also prove fruitful for the proposed structure as well. And even the statistical analysis and modelling can add to its feasibility and serviceability design of an application. And thus, productive use can be geared in the market, in the civil engineering field and even other fields to a great extent.

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