Flexural studies on Basalt Fiber Reinforced Composite sandwich panel with profile sheet as core

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HIGHLIGHTS

- Basalt fiber & profile sheet are used in sandwich panel, studied as flexural member.
- Constructed adopting both prefabrication and cast-in-situ construction process.
- The panel has ultimate flexural strength of 26 kN exhibiting ductile behaviour.
- Compositeness, failure mechanism & debonding phenomenon was studied experimentally.
- Partial compositeness of the panel has been validated using numerical approach.

ABSTRACT

In this paper, the experimental behaviour of Basalt Fiber Reinforced Composite (BFRC) sandwich panel under flexural loading has been investigated. The BFRC sandwich panel investigated in this study comprises of top skin, bottom skin and core. Both top and bottom skin are composed of BFRC mix and flanges of profile sheet to act as composite in effectively resisting flexure where as the core is constituted by the web portion of profile sheet in resisting shear. The panel is constructed by adopting both prefabrication and cast-in-situ construction process exploiting the advantages of both the process. The panel has ultimate flexural strength of 26 kN, exhibiting ductile behaviour. The panel exhibited 200\% ductility over the deflection at the ultimate load with 10\% loss in the ultimate load making it an ideal for flooring units. Further, numerical study has been conducted to assess the integrity of the connection between skin and core and to find the effectiveness of connection on overall strength, stiffness of the panel. The results from the finite element analysis have been compared with the experimental results of BFRC sandwich panel and are found to be in good agreement. Finite element study also helped in concluding that with improved connection mechanism both strength and stiffness of panel can be enhanced.

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1. Introduction

Sandwich panel is an often sought out area of research in the field of civil engineering for its open bounds in arriving at a panel which is competent in terms of strength, stiffness and weight using new construction materials [1]. The present civil engineering industry demands ease and fast track construction probing research towards prefabrication and light weight structural element, thereby making sandwich panel as one of the main area of research [2]. Sandwich panel generally consists of two skins bonded together by a core to act as single integral system. Theoretically in a homogenous sandwich panel, all the components should be constrained against relative movement in order to ensure proper composite action without any relative slip due to interfacial shear. But in case of composite sandwich panel it is unlikely to achieve full composite action due to differential curvature attributed by stiffness variation of the materials used [3].

The mid 1940's, marked the use sandwich panel and the basic idea was to develop it for structural application was initiated after 1970 [4]. Generally composite panels were constructed of honeycomb core with different types of facing material like plywood, high density and medium density hard board, cement, asbestos, aluminium, etc. The inner core was classified broadly into cellular,
foam, polymer, honey comb and corrugated [5–8]. Thereafter down the line, the panels were constructed using light weight material [9] to be used as non load bearing component, but present scenario has once again encouraged the use of sandwich panel as load bearing component.

For the present study, sandwich panel of dimension 1500 × 650 × 70 mm is constructed using Basalt Fiber Reinforced Composite (BFRC) mix and profile sheet and studied as a flexural member. The BFRC sandwich panel will have top skin as a composite of BFRC and compression flange of profile sheet, the bottom skin as composite of BFRC, basalt mesh and tension flange of profile sheet and the core comprising of web of the profile sheet. Ease and fast track construction is achieved by attaching prefabricated bottom skin to the core using self tapping screws wherein the integrity of connection is obtained by dowel action. Economy is achieved by cast in situ concreting of top panel using profile sheet as construction platform; the integrity of connection is obtained by means of adhesion and shear interaction.

More recently though, advanced composite fibers and resins are being used to create skin material. The basalt fiber can also be thought of as a possible material for the sandwich panel due to the following economical and durability advantages such as low price, light weight, good adhesion and excellent corrosion resistance properties. From the literature review, basalt fiber is found to have good mechanical and chemical properties such as high elastic modulus, high elastic strength, and stability at high temperature, etc which will make it a viable construction material [10]. The bonding capability of basalt has been exploited by using

![Diagram of BFRC sandwich panel](image-url)
it as composite with different materials such as concrete, geopolymer concrete, polypropylene composites, polysiloxane based matrices, epoxy composites, inorganic binder like phosphate etc. [11–15]. It is reported that the usage of basalt fiber as a composite showed increase in compressive strength as well tensile strength [16,17]. Basalt sandwich panel are also being researched for their performance against impact and explosion loads. BFRP-ALC sandwich panel (Basalt Fiber Reinforced Polymer Aerated Lightweight Concrete) was proposed by [18]. As claimed by authors, this type of sandwich panel can find its application in fields of defense, bridge engineering, civil construction and other allied areas of necessity. A Patent has been filed for cementious panel with basalt fiber reinforced major surfaces [19]. This basalt fiber reinforced sandwich panel was developed as wall panel and it is mentioned that it has better performance in humid and wet area and also reported to have high impact resistance. Profile sheet has been sought as possible construction material for achieving high strength, stiffness and less weight for BFRC sandwich panel. Generally profile sheet are preferred as load bearing and cladding material. It has been widely studied for its usage as composite slab, wall and column [20–22]. The profile sheet with trapezoidal shape has the advantage of imparting additional stiffness by breaking the continuity in the plate at every bend. The flanges are provided with stiffeners in order to reduce the flat width to thickness ratio, thereby improving the local buckling strength. Use of profile sheet between two skins in BFRC sandwich panel increases the lever arm distance between tensile and compressive forces thereby increasing flexural resistance and reducing deflection by increased inertia. Shear embossment in profile sheet increases bonding of cast-in-situ concrete on the top side of panel.

From the studies conducted in field of basalt sandwich panel, it has been observed that the research is very limited. Hence, there is scope for further study on developing sandwich panel using Basalt Fiber Reinforced Composite with profile sheet and exploring its usage in the annals of civil engineering and allied engineering applications as flooring member.

A detailed view of the Basalt Fiber Reinforced Composite (BFRC) sandwich panel is shown in Fig. 1.

2. Materials and characterisation studies used in BFRC sandwich panel

2.1. Basalt Fiber Reinforced Composite (BFRC) mix

The ingredients for BFRC mix along with mix design are given in Table 1. Mix design so arrived to attain maximum compressive strength of more than 50 MPa. Study on formulating the mix design for BFRC mix along with volume fraction of basalt fiber used has been elaborated [23].

The property of basalt fiber used for the study as provided by the supplier is reported in Table 2.

The properties of basalt mesh as provided by the supplier is reported in Table 3. The property of basalt fiber used for the study as provided by the supplier is reported in Table 3.

The stress–strain behaviour of cold formed sheet is well known but yield stress varies with the thickness of sheet. Uniaxial tensile test has been conducted on 1.2 mm thick cold worked profile sheet as per ASTM E-8 [27]. The stress–strain data obtained has been plotted in Fig. 4. The elastic modulus value obtained from the graph is 200 GPa and the Poisson ratio is 0.3.

From uniaxial tensile test, average tensile stress is found to be 5.8 MPa for an average 140 micro strains as shown in Fig. 4.

2.2. Profile sheet

The profile used for the core is cold formed steel of grade Fe250 conforming to IS: 2062-1999 [26] has been used. The general geometry of the profile sheet used for this study is given in Fig. 5. The thickness of the profile sheet used was 1.2 mm. Although stress strain behaviour of cold formed sheet is well known but yield strength varies with the thickness of sheet. Uniaxial tensile test has been conducted on tension coupons of 1.2 mm thick cold worked profile sheet as per ASTM E-8 [27]. The stress–strain data obtained has been plotted in Fig. 6. The elastic modulus value obtained from the graph is 200 GPa and the Poisson ratio is 0.3.

3. Experimental investigation of BFRC panel

Casting of sandwich panel was done in three steps as shown in Fig. 7. First, the bottom panel was cast and was water cured under room temperature for 7 days. The BFRC mix has got 0.5% volume fraction of basalt fibers in the composite mix and 0.2% volume fraction of basalt mesh. Workability of the BFRC mix was...
measured through flow table test as per BS EN 12350-5:2009 [28] and slump of the mix was in the range of 85–95%. The normal water curing of precast bottom panel has been done under room temperature for 7 days. In the second step, the 7 days old prefabricated bottom skin is attached to profile sheet along with hat section using self tapping screws. The screw is directly drilled in binding both bottom skin and profile sheet. The connection is to ensure dowel action rather than hold up type connection. In the third and final step, after fixing of profile sheet and hat section with prefabricated bottom skin, BFRC mix with volume fraction of 0.5% has been cast-in-situ in the top part of BFRC sandwich panel.

In order to avoid corrosion of the profile sheet, special curing scheme has been used for 28 days under room temperature. Moist sand bed has been prepared over which BFRC sandwich panel has been kept which will cure the prefabricated bottom part of panel and moist gunny bag has been used on the top part of BFRC panel. In order to maintain saturated moisture level in the sand bed and gunny bag, proper watering has been done for 28 days.

4. Test set-up of the sandwich panel

In order to study the composite and debonding behaviour for BFRC sandwich panel, strain gauges and rosette has been used at different location and at different level inside panel other than on the outer top and bottom skin of sandwich panel. The instrumentation implemented of the panels is elaborated in the Figs. 8(a)–(d).

As seen in the Fig. 8(a), the BFRC mesh is instrumented with two rosettes (RM1 and RM2) to measure the stress in the shear zone and one strain gauge (SM1) in the middle to measure the bending strains. The profile sheet is instrumented with 6 strain gauges (Sp11, Sp12, Sp13, Sp21, Sp22 and Sp23) attached to lead foils connected to the profile sheet and embedded in the concrete in order to measure both debonding and bending stress as shown in Fig. 8(b). Since the web of the profile sheet is the main shear carrying member, rosettes (Rp11, Rp12, Rp21 and Rp22) are placed in the shear zone. The entire panel is instrumented with three linear variable displacement transducer (LVDT) (two at L/3 distance from both supports and one at the middle of the panel) to measure the deflection behaviour of the entire panel as shown in Fig. 8(c). The panel also has two strain gauges (Tp and Bp), each in middle of top skin and bottom skin in order to measure the surface strain of the panel as shown in Fig. 8(d). A schematic figure exhibiting the position of strain gauges and rosettes in the corresponding bending and shear zone is shown in Fig. 9.

BFRC sandwich panel was tested experimentally under four point bending test with the simply supported condition. The test was conducted on a UTM of 250 tons capacity. The load was applied by means of jack through I beam to two similar roller mounted at a third point of the supporting span i.e. spaced at 390 mm centre to centre. The load has been applied using displacement control method at the rate of 0.5 mm/min. Experimental set up which is complying with all the aforementioned details is shown in Fig. 10.

5. Results and observations

From the experimental studies, it was observed that the ultimate load for the BFRC panel is 25 kN for a deflection of 10 mm. In the post peak region of the ultimate load, the panel exhibited 200% more deflection than the deflection observed at ultimate load with less than 10% reduction in the ultimate load. The first crack was observed in bottom region of BFRC sandwich panel in the range of 4.75 kN for a deflection of 0.27 mm. The crack was through–through crack bridging across the entire width of the section. After first crack, there is significant loss in the stiffness of the panel and with increasing the load; multiple crack started forming in the bottom skin which shows the redistribution of stresses along the length of basalt mesh. Crack widening was increasing as load transferred from bottom BFRC to flange of profile sheet. On later stage of loading i.e., after post peak, the top flange of profile sheet started debonding from BFRC mix implicating that the capacity of shear embossment in resisting longitudinal shear has been exceeded. In the final stage of failure of BFRC panel, cracks propagated in compression region, the final failure was governed by crushing top compression skin as shown in Fig. 11.

The load deflection graph has been plotted for all the data recorded through load cell and LVDTs located at middle and at one third of length for BFRC sandwich panel. The load deflection behaviour of the panel is shown in Fig. 12. The maximum deflection recorded was 43 mm before the experiment was stopped due to too much uplift at the support, creating loss of contact between the roller and the base plate.

The strain variation across cross section of the panel is plotted as shown in Fig. 13. It can be seen from the graph that the panel acted more like a over reinforced system till the maximum load is reached.

From Fig. 14, it can be seen that, the longitudinal stress is constant in the mesh indicated by RM1 and RM2 pasted near the two ends of the panel, inferring the full participation of the mesh. As evident from the load deflection graph, first crack occurred at 4.5 kN (1.62 MPa) but it can be seen in the Fig. 14, the mesh was taking a maximum stress value of 5.2 MPa (12.16 kN) indicating the load carrying ability of the mesh after cracking of the BFRC mix.

The flexural stress is taken by the second crest compared to the first crest of the profile sheet. It can be seen that the Rosette Rp11and Rp12 failed taking load in the range of 1.5–2 MPa (4–5.5 kN) indicating the first crack zone and possible debonding between the BFRC mix and the profile sheet. The majority of the load thereafter is taking by the bonding between the second crest of the profile sheet and the BFRC mix. In the second crest also, possible debonding initiated near the hinge zone (Fig. 15) where lateral movement is restricted and then spread to the roller region of the second crest.

The debonding phenomenon as indicated by the rosette is also studied with the help of strain gauge data as shown in Fig. 16. The Fig. 16 indicates the possible debonding between the profile sheet and the BFRC mix from the strain gauge data. It can be seen...
that the strain gauges Sp11, Sp12 and Sp13 stopped taking strain on reaching the maximum load indicating a possible debonding between the BFRC mix and the profile sheet in the first crest region of the profile sheet as seen in Fig. 16. From the Strain gauges in the second crest of the profile sheet (Sp21 and Sp23), it can be seen that they were in contact with BFRC mix till failure indication no debonding occurring in that region.

Because of composite nature of sandwich panel due to use of different material such as BFRC mix, profile sheet, basalt mesh and basalt fiber, there were many slips as shown through sudden increase and decrease in stress after elastic limit. Since the BFRC skin is connected to profile sheet by both adhesion and discrete self tapping screws acting as shear connectors, the loss of load after post peak may be due to loss of adhesion and again increase in load might be due to active participation of self tapping screws in load transfer mechanism.

The basalt mesh underwent plate stress action where it derived stiffness from the other direction as indicated from the transverse stress recorded by the rosettes as shown in Fig. 17.
Fig. 8(c). LVDT position under the panel.

Fig. 8(d). Strain gauge position on the panel.

Fig. 9. Schematic position of strain gauge and Rosettes.

Fig. 10. Experimental testing of BFRC sandwich.

Fig. 11. Crushing of top skin in BFRC panel.
Hence it can be seen the mesh was stressed in both directions and it has 50% less strength and ductility compared to the longitudinal direction even though it possesses the same load carrying capacity in both directions as given by the supplier. This reduction in strength can be attributed to the lack of stiffness in the transverse direction since support is provided only in the longitudinal direction. The same reason can be said for the profile sheet for lack of strength. The effect of debonding is also pronounced here from the difference in behaviour of rosettes in the first crest and second crest.

6. Numerical modelling of BFRC panel

The present numerical study is towards assessing the integrity of connection between skin and core (internal bonding at top skin by cast-in-situ and external bonding in the bottom skin through self tapping screws) in order to depict the flexural behaviour of the BFRC Sandwich panel and to study effectiveness of connection mechanism on the overall strength, stiffness of the panel. Numerical study has been conducted using Finite Element Analysis (FEA) software ABAQUS version 6.10 in which 3-Dimensional 8 noded brick element (C3D8R) are used to model the individual components of the panel. The constitutive relation towards material behaviour of the panel is obtained by means of experimental studies conducted on the individual component of the material as mentioned earlier is given in Table 4.
In the Finite element studies, integrity between the core and skins has been modelled as full composite by giving rigid connection in terms of tie constraints and partial composite by giving semi rigid connection as combination of tie constraint with cohesion and adhesion between connecting surfaces. The numerical FE model is reflecting both the geometrical and material properties of the individual components, interaction between individual components, proper loading arrangement and boundary condition depicting the experimental set-up is shown in Fig. 18.

Non-linear solution technique based on direct method "Full Newton Solution Technique" is used to get the desired results. For this study, the full numerical model has a total of 61061 C3D8R elements with aspect ratio in the range of 5–10.

The Interaction property studies are shown Table 5.

### 7. Results and observations

The FEA was conducted for the different interaction between skin and core. The load deflection profile obtained for each interaction is compared with experimental results and presented in the Fig. 20.

From the Fig. 20, it can be observed that, the FE model with the top and bottom skin tied with the core (no slip condition), the panel takes 52 kN for a deflection of 1.96 mm indicating a very stiff

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Experimental data</th>
</tr>
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<tbody>
<tr>
<td>Uniaxial compressive strength of BFRC mix</td>
<td>$\sigma_c$</td>
<td>56 MPa at 2000 micro strain</td>
</tr>
<tr>
<td></td>
<td>$\epsilon_c$</td>
<td></td>
</tr>
<tr>
<td>Uniaxial tensile strength of BFRC mix</td>
<td>$\sigma_t$</td>
<td>5.8 MPa at 140 micro strain</td>
</tr>
<tr>
<td></td>
<td>$\epsilon_t$</td>
<td></td>
</tr>
<tr>
<td>Chord modulus of elasticity of BFRC mix</td>
<td>$E_{BFRC}$</td>
<td>28 GPa</td>
</tr>
<tr>
<td>under uniaxial compression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chord modulus of elasticity of BFRC mix</td>
<td>$E_t$</td>
<td>29 GPa</td>
</tr>
<tr>
<td>under uniaxial tension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield strength of profile sheet</td>
<td>$f_y$</td>
<td>279.25 MPa at 2000 micro strain</td>
</tr>
<tr>
<td></td>
<td>$\epsilon_f$</td>
<td></td>
</tr>
<tr>
<td>Modulus of elasticity of profile sheet</td>
<td>$E_{steel}$</td>
<td>200 GPa</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>$\nu$</td>
<td>0.2 for BFRC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.3 for Steel</td>
</tr>
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</table>

Fig. 18. Experimental and numerical model for the BFRC panel.

Fig. 19. Interaction between the skin and core of the profile sheet.
Interaction used to study integrity between the skin and core shown in Fig. 19.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>Name of FE model</th>
<th>Connection used in FE model</th>
<th>Interaction property</th>
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<td>Partial composite</td>
<td>Top skin tied</td>
<td>Semi rigid connection</td>
<td>Tie constraint 4 MPa [29] 0.7</td>
</tr>
<tr>
<td>Partial composite</td>
<td>Bottom skin tied</td>
<td>Semi rigid connection</td>
<td>Tie constraint 4 MPa 0.7</td>
</tr>
<tr>
<td>Partial composite</td>
<td>Top and bottom partially tied</td>
<td>Semi rigid connection</td>
<td>Tie constraint 4 MPa [29] 0.7</td>
</tr>
</tbody>
</table>

Both strength and stiffness are decreasing consecutively. Under flexural load, rigid connection in the bottom skin (FE model bottom skin tied) will have more strength and stiffness as compared to rigid connection in the top skin (FE model top skin tied) as it is observed in the numerical model. Finite element study also helped in concluding that with improved connection mechanism between skin and core, both strength and stiffness of panel can be enhanced.

8. Summary and conclusion

For the development of BFRC sandwich panel, construction methodologies containing both prefabricated and cast-in-situ has been used incorporating the advantage of no form work by using prefabrication technique partly and less transportation cost by using cast-in-situ technique partly. From the experimental studies, it was observed that the ultimate load for the BFRC panel is 25 kN for a deflection of 10 mm. In the post peak region of the ultimate load, the panel exhibited 200% more deflection than the deflection observed at ultimate load with less than 10% reduction in the ultimate load and hence suitable for flooring units. The failure of the BFRC panel is mainly governed by crushing of top skin of BFRC panel. The FE model (Top and bottom partially tied) is created by assuming 70% frictional slip in both top and bottom skin and the model exhibited 27 kN load carrying capacity for a deflection of 6 mm. This model is found to have better correlation with experimental behaviour of the panel with error of 3.84% corresponding to ultimate strength of the panel. The load deflection behaviour as such is in concurrence with the experimental behaviour, implying the partial frictional interaction of the top and bottom skin with the core in the elastic region. Further from the numerical studies it can be concluded with improved connection mechanism between skin and core, both strength and stiffness of panel can be enhanced.

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