International Journal of Scientific Research in Engineering & Technology
Special Issue, Volume 4, Issue 3 (May-June 2024), PP: 30-34.
Recent Advances in Civil Engineering and Technology (REACT)-2024
www.ijsreat.com ISSN No: 2583-1240

Development of Optimum Lightweight Cold-Formed Steel Composite Built-Up Beams

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To Cite this Article: *Fathima R.M[1], Nisha Varghese[2], "Development of Optimum Lightweight Cold-Formed Steel Composite Built-Up Beams", International Journal of Scientific Research in Engineering & Technology Volume 04, Issue 03, May-June 2024, PP: 35-43.*

Abstract: *Over the last decade, there has been a significant growth in research efforts to enhance the flexural behavior of Cold formed steel (CFS) built-up beams by proposing different strengthening methods to prolong or eradicate buckling deformations. This paper discusses numerical study on the development of optimum lightweight cold-formed steel composite built-up beams. This study aims to develop CFS composite built-up beams that are not only lightweight but also possess high strength and stiffness. To evaluate the performance CFS composite built-up beams with varying infill lightweight materials. Glass Fiber Reinforced Polymer (GFRP) and Ultra Lightweight Cement Composite (ULCC) were sandwiched between the CFS channels in the web and flange region to construct the lightweight composite beams. GFRP in flange and GFRP in web composite specimen (GFGWS) shows increase in load carrying capacity by 140% compared to no filled CFS built-up beams. The project evaluates the effectiveness of various stiffening arrangements of bearing stiffeners in CFS composite built-up beams. The diffe rent arrangement of bearing stiffeners are vertical, Longitudinal, Diagonal end and V shaped middle plus Diagonal end patterns.GFGWS with Longitudinal Stiffeners shows good performance compared to other arrangements of bearing stiffeners.The research aims to develop an optimum section of intermittently stiffened lightweight CFS composite built-up beams.The various combinations of intermittent stiffening and GFRP plank packing were adopted to improve the performance of beam.Multi-folded flange with flange and web packed GFRP composite specimen (MGFGWS) show 22% of weight reduction compared to GFGWS built-up beams,it shows good performance in case of cost-effective approach. All of the beam specimens were subjected to four-point bending with simply supported boundary conditions. The study considers the load-carrying capacity, deflection, Moment capacity, ductility and stiffness characteristics of the composite beams.This complete study is performed analytically using ANSYS software.*

Key Word: *Cold-formed steel sections, Built-up beam, intermittently stiffening, GFRP, ANSYS*

I.INTRODUCTION

Lightweight CFS (Cold-Formed Steel) composite built-up beams are innovative structural elements used in construction that leverage the strengths of cold-formed steel in combination with other lightweight materials. These composite beams are engineered to offer a high strength-to-weight ratio, making them particularly advantageous in various construction applications The demand for lightweight construction materials has been steadily increasing due to the need for sustainable and cost-effective building solutions. Cold-formed steel (CFS) members are widely employed as primary and secondary load-bearing elements in buildings due to their inherent advantages of being lightweight and their high load-carrying capacity, dimensional flexibility, recyclability, and dimensional stability. Cold-formed steel with composite materials helps to attain the full yield moment capacity.

The composite nature of these beams allows for optimal utilization of materials and efficient transfer of loads. By strategically placing the individual steel sections based on the anticipated load distribution, the beam's overall strength and stiffness can be maximized, resulting in a structurally efficient member.One of the key advantages of lightweight CFS composite built-up beams is their reduced weight compared to traditional steel or concrete beams. The lightweight nature makes them easier to handle and install on-site, reducing construction time and labor costs. Light weight CFS composite built-up beams find applications in various construction projects, including residential, commercial, and industrial buildings. They are used in floor and roof systems, as well as in load-bearing walls, to provide structural support and integrity.

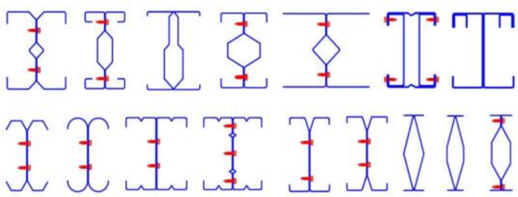


Fig.1 Stiffened built-up sections

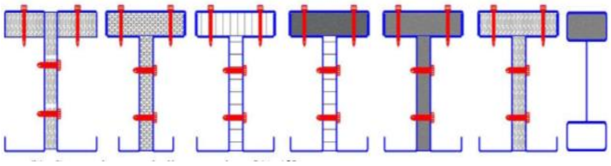


Fig.2 Composite built-up section

II.NUMERICAL INVESTIGATION

- To study the effect of different infill lightweight materials:

a) Glass fiber reinforced polymer (GFRP)
b) Ultralight weight cement composite (ULCC).

- To evaluate the effectiveness of different stiffening arrangements of bearing stiffeners in cold-formed steel composite built-up beams.
- To develop optimum section of intermittently stiffened lightweight cold-formed steel composite built-up beams.

1. Study of CFS Composite Built-Up Beams with Varying Infill Light Weight Materials

Four models of cold-formed steel composite built-up beams with varying infill lightweight materials were modeled to achieve the intended objectives. Each beam had a total span of 2300 mm and an effective span of 2100 mm, with a steel sheet thickness of 1.6 mm. Screws with a diameter of 6.4 mm and a length of 35 mm were used. To prevent early-stage buckling deformations, the screws were spaced at 50 mm transversely and 250 mm longitudinally. T-shaped bearing stiffeners were made from two 1.6 mm thick plain CFS angle sections (50 mm × 50 mm).These infilled model were compare with non filled Rectangular Hollow-flange Specimen (RHFS).The dimension details of the CFS composite built-up beam are provided in Table 1. The details of Screw spacing in CFS composite built-up beams is shown in Fig.3.The details of the CFS composite built-up beams with varying infill lightweight materials are shown in Fig.4.

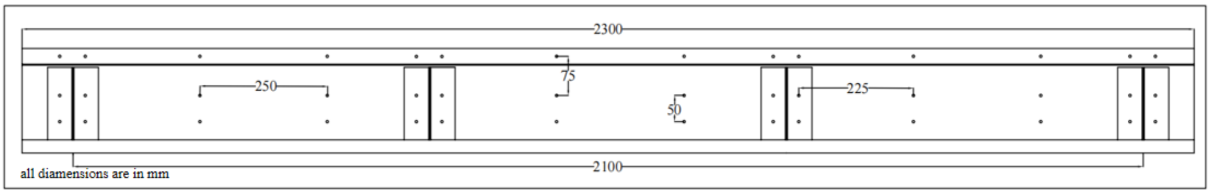


Fig.3 Details of Screw spacing in CFS composite built-up beams.

The infilled materials used in here are Glass Fiber Reinforced Polymer (GFRP) and Ultra Lightweight Cement Composite (ULCC). GFRP stands for Glass Fiber Reinforced Polymer/Plastic and reflects a group of plastics that are reinforced with glass fibers to provide it with high strength and (moderate) stiffness, while reducing weight compared to most other materials like metals The efficiency of different combinations of GFRP and ULCC is analyzed.Ultra-lightweight cement composite (ULCC) contains smooth steel fibers ordinary Portland cement, water, silica fume, chemical admixtures, cenospheres. The cenospheres are hollow alumino-silicate spheres with particle sizes ranging from 10 to 300 mm.Material properties of GFRP and ULCC are provided in Table 2.

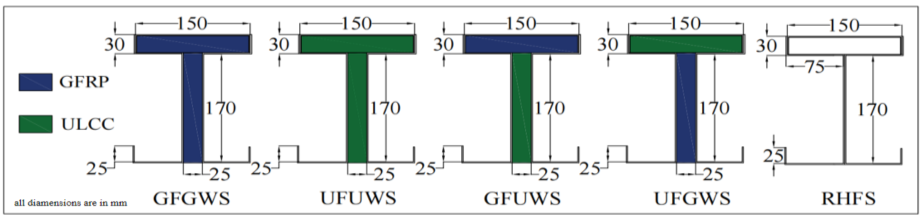


Fig.4 Details of CFS composite built-up beams with varying infill light weight materials

Table 1: Dimension details of CFS composite built-up beam

Specimens	Dimension
Steel Beam	2300mmx150mmx200xmm, 1.6mm thickness
Infill Material	2300mmx150mmx30mm- Flange 2300mmx170mmx25mm-Web
Stiffener	50mmx50mm , 1.6mm thickness
Screw	6.4 mm diameter, 35mm length

Table 2 : Material properties of GFRP and ULCC

Glass Fiber Reinforced Ploymer (GFRP)	Ultra Lightweight Cement Composite (ULCC)
Young's modulus - 1.04x104 MPa	Young's modulus - 15980 MPa
Poisson's ratio - μ – 0.275	Poisson's ratio - μ – 0.2
Density - 1750 kg/m^3	Density - 1550 kg/m3
Yield strength -25 MPa	Yield strength -3.03 MPa

2. Study of CFS Composite Built-Up Beams with Different Stiffening Arragements of Bearing Stiffeners

Four models of CFS composite built-up beams with different stiffening arrangements of bearing stiffeners are designed. Labelling description of various specimens are provided in Table 3. The Details of CFS composite built-up beams with different stiffening arrangements of bearing stiffeners are shown in Fig.5.

Table 3: Labelling description of various specimens.

Specimen Notation	Specimen Description
GFGWS	GFRP in flange and GFRP in web composite specimen
GFGWS -VS	GFGWS with Vertical Stiffeners
GFGWS -LS	GFGWS with Longitudinal Stiffeners
GFGWS -DS	GFGWS with Diagonal end Stiffeners (GFGWS-DS)
GFGWS -VDS	GFGWS with V shaped middle + Diagonal end Stiffeners (GFGWS-VDS)

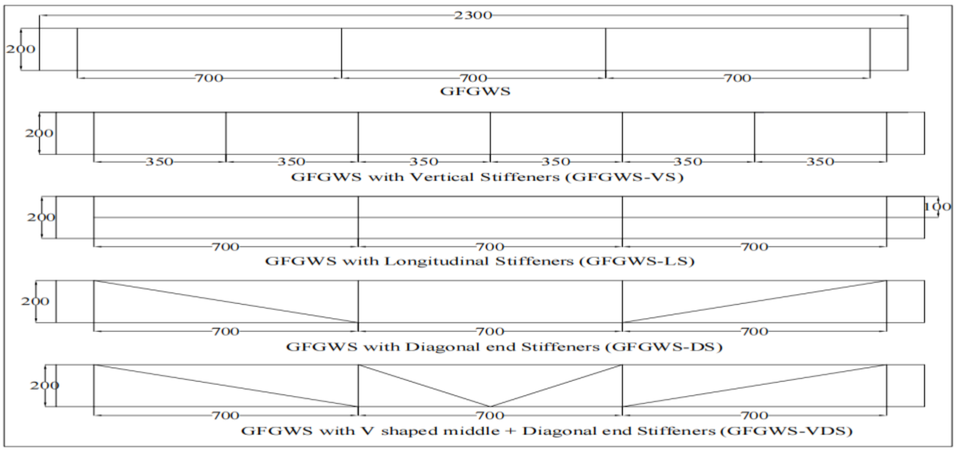


Fig.5 Details of CFS composite built-up beams with different stiffening arrangements of bearing stiffeners

3. Study Various Combinations of Intermittently Stiffened Lightweight Cfs Composite Built-Up Beams

Three models of various combinations of intermittently stiffened lightweight cold-formed steel composite built-up beams is designed and labelled as: Flange and web packed GFRP composite specimen (GFGWS),Complex edged flange with flange and web packed GFRP composite specimen (CGFGWS),Multi-folded flange with flange and web packed GFRP composite specimen (MGFGWS)In the first two models (GFGWS and CGFGWS), GFRP was used to fill the entire web and flange. In the third model (MGFGWS), GFRP filled the entire flange, and 12.5 mm thick GFRP planks (146 mm wide and 70 mm long) were placed on both sides in the central moment zone only.

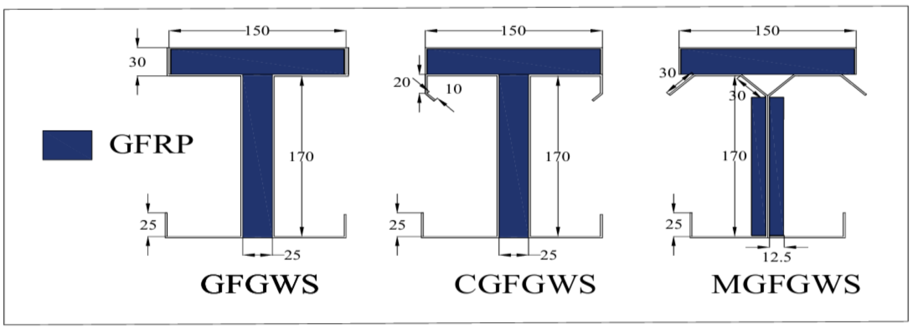


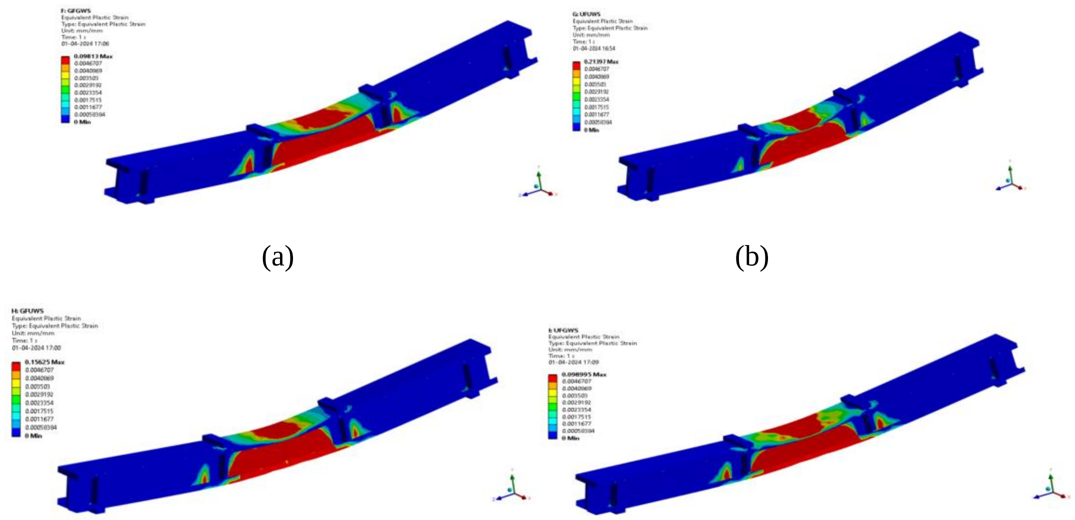
Fig.6 Details of Intermittently stiffened lightweight cold-formed steel composite built-up beams

III. NUMERICAL RESULTS

1. Study of CFS Composite Built-Up Beams With Varying Infill Light Weight Materials

In the nonlinear analysis, both material and geometric non linearity was considered. In case of large displacements there will be change in shape of structure and this one cannot be neglected. Hence its deformed configuration should be considered. Material non linearity is associated with inelastic behavior of material. Incorporating nonlinear properties of materials allows accurate calculation of stress distribution and helps in predicting its buckling capacity accurately.

SOLID 186 element was used to model the elements.The element size adopted was 25 mm.The element shape of meshing was Hexahedron.The component was modelled in the XY plane in which the beam specimen were subjected to four-point bending with simply supported boundary conditions. Load was provided in the form of displacement-controlled method.

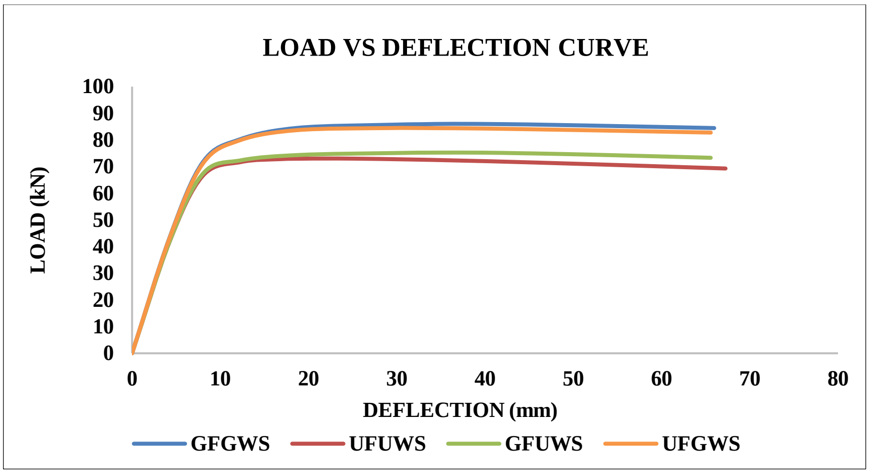


(a) (b) (c) (d)

Fig.7 Equivalent plastic strain of CFS composite built-up beams with varying infill materials (a) GFGWS (b)UFUWS (c)GFUWS (d)UFGWS.

Table 4: Results of CFS composite built-up beams with varying infill materials.

Model	Weight (kg/m)	Ultimate Deflection (mm)	Ultimate Load (kN)	Yield Load (kN)	Yield Deflection (mm)	Ductility	Moment (kN m)	Stiffness (kN/m)
RHFS	19.709	15.20	35.76	15.091	2.5326	6.002	12.516	2.353
GFGWS	30.6139	36.421	86.048	43.36	4.2369	8.5961	30.117	2.363
UFUWS	28.9321	21.724	73.036	41.848	4.2546	5.1060	25.563	3.362
GFUWS	29.7573	34.346	75.254	41.88	4.2492	8.0829	26.339	2.191
UFGWS	29.789	28.88	84.458	43.092	4.2343	6.8204	29.560	2.924



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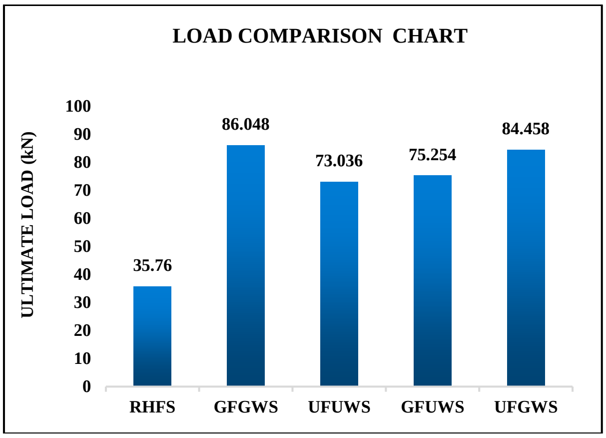

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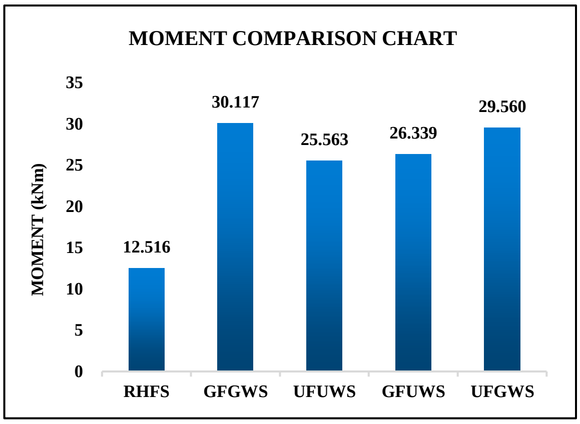

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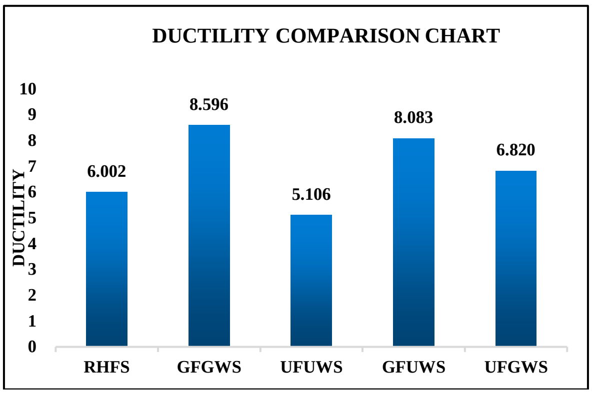

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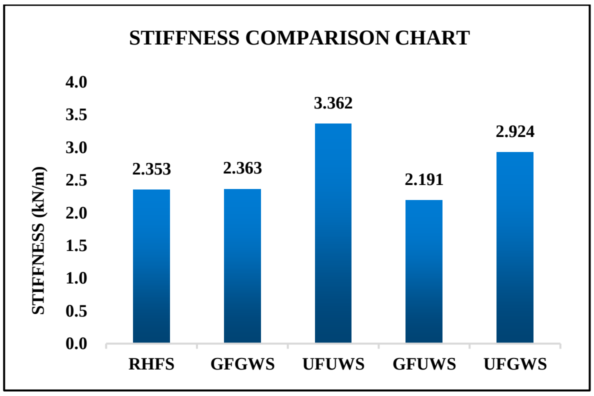
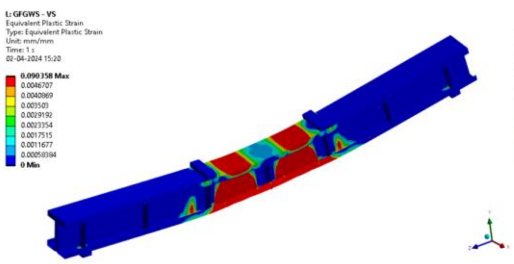


(e)

Fig.8 (a) Load vs Deflection curve (b) Load comparison chart (b) Moment comparison chart (c) Ductility comparison chart (e) stiffness comparison chart of CFS composite built-up beams with varying infill light weight materials.

The efficiency of different combinations of GFRP and ULCC is analyzed.It is observed that,The use of GFRP and ULCC improved the strength , Load carrying capacity and Moment capacity of CFS composite built-up beams significantly compare to no filled CFS built-up beams. GFRP in flange and GFRP in web composite specimen (GFGWS) and ULCC in flange and GFRP in web composite specimen (UFGWS) shows increase in load carrying capacity by 140% and 135% respectively compared to no filled CFS built-up beams.The location of GFRP and ULCC also influenced the flexural performance in these composite beams.The specimen with GFRP infilled flange (GFGWS and GFUWS) shows highest amount of ductility value (43% and 35%).The specimen with ULCC infilled flange (UFUWS and UFGWS) shows highest amount of stiffness value (42% and 25%).GFRP in flange and GFRP in web composite specimen (GFGWS) have the highest amount of load carry capacity, moment capacity and ductility value.Hence,GFRP in flange and GFRP in web composite specimen (GFGWS) shows good performance compared to other infilled CFS composite built-up beams.

2. Study of CFS Composite Built-Up Beams With Different Stiffening Arragements Of Bearing Stiffeners



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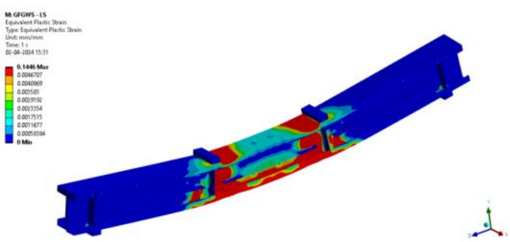

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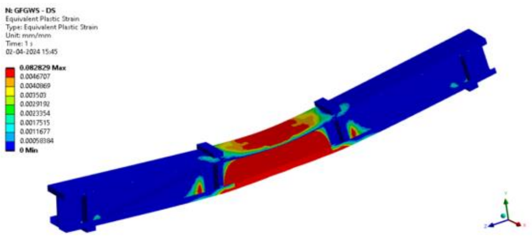

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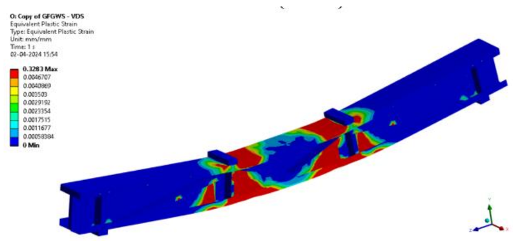
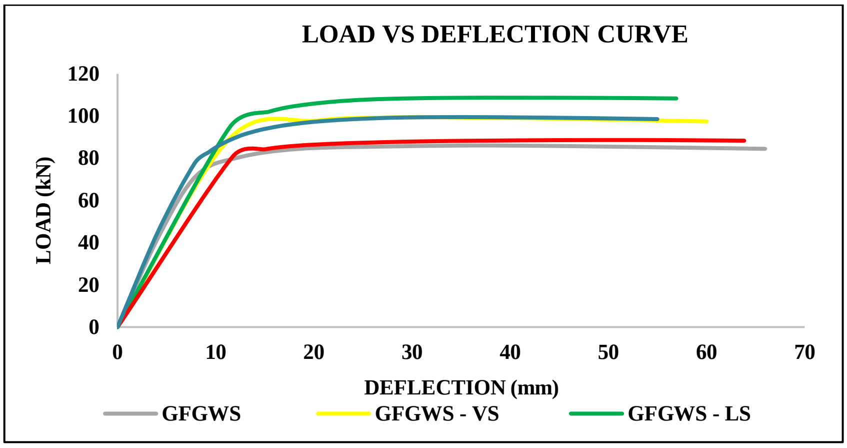


(c)

Fig.9 Equivalent plastic strain of CFS composite built-up beams with different stiffening arrangements of bearing stiffeners (a) GFGWS-VS (b)GFGWS-LS (c)GFGWS-DS (d)GFGWS-VDS.

Table 5: Results of CFS composite built-up beams with different stiffening arrangements of bearing stiffener

Model	Weight (kg/m)	Ultimate Deflection (mm)	Ultimate Load (kN)	Yield Load (kN)	Yield Deflectio n (mm)	Ductility	Moment (kN m)	Stiffness (kN/m)
GFGWS	30.6139	36.421	86.048	43.316	4.2369	8.5961	30.117	2.363
GFGWS - VS	31.807	55.486	97.86	89.204	11.403	4.8659	34.791	3.366
GFGWS - LS	34.302	34.383	108.638	94.61	11.416	3.0118	38.023	3.160
GFGWS - DS	33.067	52.628	88.638	80.838	11.046	4.5923	31.023	1.684
GFGWS - VDS	34.292	32.523	99.466	44.992	4.101	7.9305	34.813	3.058



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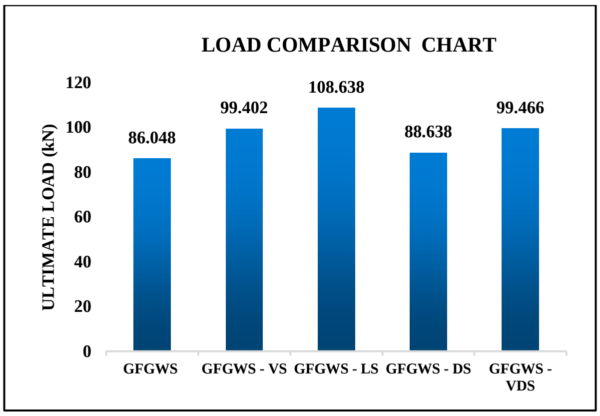

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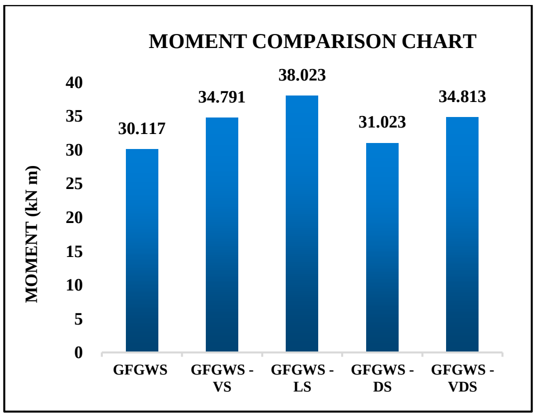

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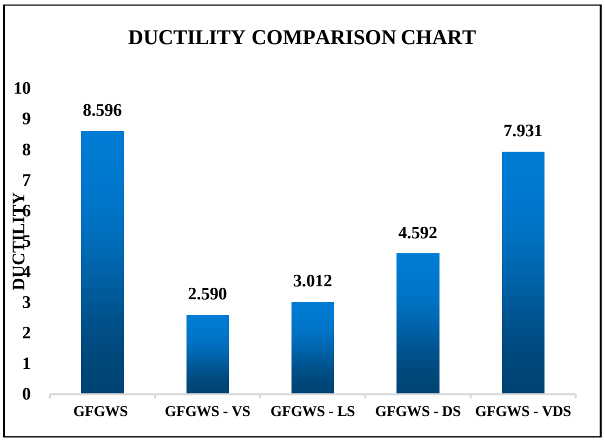

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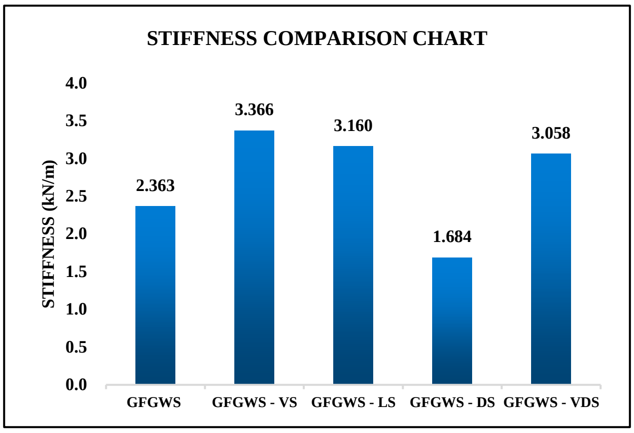


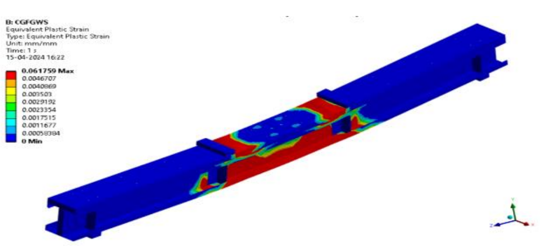
(e)

Fig.10 (a) Load vs Deflection curve (b) Load comparison chart (b) Moment comparison chart (c) Ductility comparison chart (e) stiffness comparison chart of CFS composite built-up beams with different stiffening arrangements of bearing stiffeners.

The efficiency of different stiffening arrangements of bearing stiffeners is analyzed. It is observed that,GFGWS with Longitudinal Stiffeners (GFGWS-LS) shows more load carrying capacity and Moment capacity compare to other arrangements of bearing stiffeners. GFGWS with Longitudinal Stiffeners (GFGWS-LS) and GFGWS with V shaped middle + Diagonal end Stiffeners (GFGWS-VDS) shows increase in load carrying capacity by 26% and 16% respectively compared to GFGWS built-up beams.Hence,GFGWS with Longitudinal Stiffeners (GFGWS-LS) shows good performance compared to other arrangements of bearing stiffeners.

3. Study Various Combinations of Intermittently Stiffened Lightweight Cfs Composite Built-Up Beams

It is observed that,Intermittently stiffened CFS channel section along with the use of GFRP planks as additional stiffeners, significantly improved the load carrying capacity and the moment capacity of the CFS lightweight composite built-up beams.Complex edged flange with flange and web packed GFRP composite specimen (CGFGWS) shows increase in load carrying capacity 15% compared to GFGWS built-up beams.Multi-folded flange with flange and web packed GFRP composite specimen (MGFGWS) shows similar load carry capacity to GFGWS built-up beams. Multi-folded flange with flange and web packed GFRP composite specimen (MGFGWS) show 22% of weight reduction compared to GFGWS built-up beams,it shows good performance in case of cost-effective approach. Multi-folded flange with flange and web packed GFRP composite specimen (MGFGWS) have the highest amount of stiffness value (72%). Hence,Complex edged flange with flange and web packed GFRP composite specimen (CGFGWS) shows good performance compared to intermittently stiffened lightweight cold-formed steel composite built-up beams.



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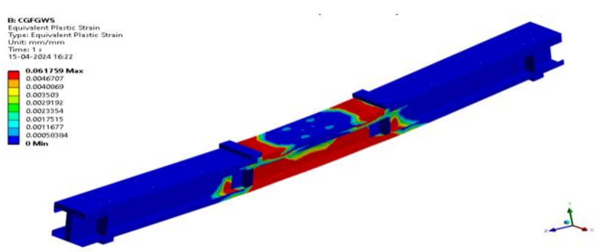


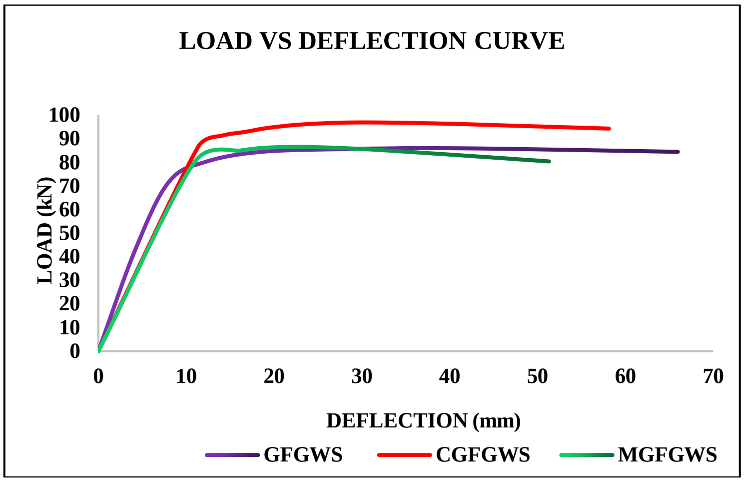
(b)

Fig.11 Equivalent plastic strain of intermittently stiffened lightweight cold-formed steel composite built-up beams (a) CGFGWS (b)MGFGWS.

Table 6: : Results of intermittently stiffened lightweight cold-formed steel composite built-up beams

Model	Weight (kg/m)	Ultimate Deflection (mm)	Ultimate Load (kN)	Yield Load (kN)	Yield Deflection (mm)	Ductility	Moment (kN m)	Stiffnes s (kN/m)
GFGWS	30.6139	36.421	86.048	43.316	4.2369	8.5961	30.117	2.363

CGFGWS	30.6139	40.108	99.168	86.584	11.349	3.534	34.709	2.473
MGFGWS	23.8591	21.286	86.504	80.18	10.965	1.9412	30.276	4.064



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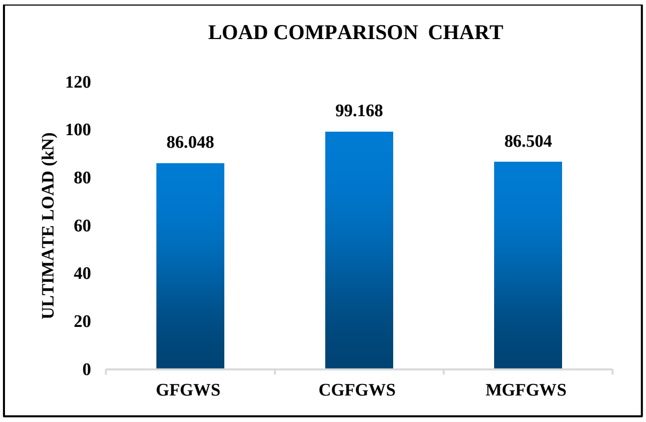
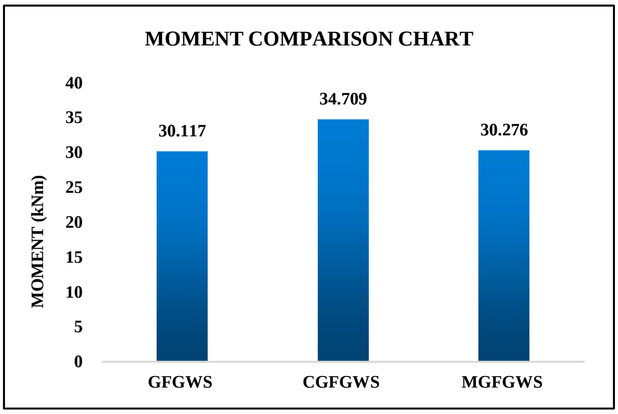
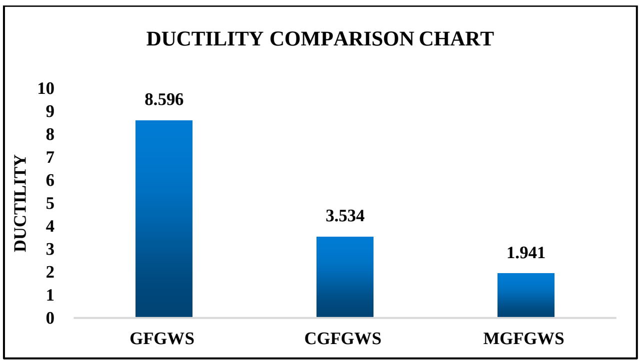
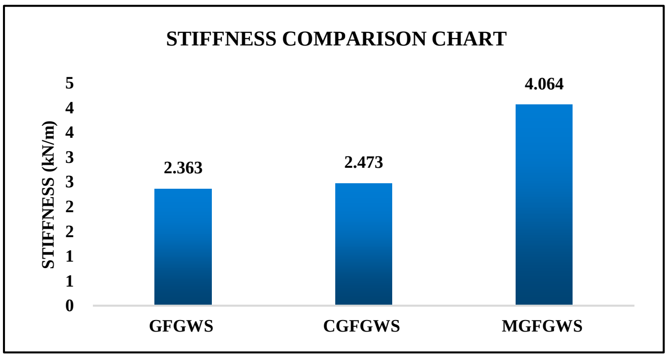




(b) (c)





(d) *(e)*

Fig.10 (a) Load vs Deflection curve (b) Load comparison chart (c) Moment comparison chart (d) Ductility comparison chart (e) Stiffness comparison chart of intermittently stiffened lightweight cold-formed steel composite built-up beams

IV. CONCLUSION

1. The use of infilled light weight material (GFRP and ULCC) improved the strength, Load carrying capacity and moment carrying capacity of CFS composite built-up beams significantly compare to no filled CFS built-up beams.
2. GFRP in flange and GFRP in web composite specimen (GFGWS) shows increase in load carrying capacity by 140% compared to no filled CFS built-up beams.

3. The specimen with GFRP infilled flange (GFGWS and GFUWS) shows highest amount of ductility value (43% and 35%) and The specimen with ULCC infilled flange (UFUWS and UFGWS) shows highest amount of stiffness value (42% and 25%).
4. In case of different stiffening arrangements of bearing stiffeners, GFGWS with Longitudinal Stiffeners (GFGWS-LS) shows more load carrying capacity and moment carrying capacity compare to other arrangements of bearing stiffeners. hence it shows good performance compared to other arrangements of bearing stiffeners.
5. Intermittently stiffened CFS channel section along with the use of GFRP planks as additional stiffeners, significantly improved the load carrying capacity and the moment carrying capacity of the CFS composite built-up beams.
6. Multi-folded flange with flange and web packed GFRP composite specimen (MGFGWS) shows similar load carry capacity to GFGWS built-up beams. Multi-folded flange with flange and web packed GFRP composite specimen (MGFGWS) show 22% of weight reduction compared to GFGWS built-up beams and have the highest amount of stiffness value (72%), so it shows good performance in case of cost-effective approach.

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