Flexural Response Analysis of Cold Formed Ferritic Stainless Steel Closed Built-Up Beam

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Abstract- *This study presents a flexural response analysis of cold formed ferritic stainless steel closed built-up beams. The aim of the study is to investigate the nonlinear flexural behaviour of these beams subjected to bending loads. The study includes experimental and numerical investigations. Experimental tests are carried out on specimens of cold formed ferritic stainless steel closed built-up beams with different geometries. The beams are subjected to four point bending loads, and their deflections and strains are measured. Numerical stimulations were also performed using finite element analysis software to simulate the behavior of the beams under bending loadings. The numerical models were validated using the experimental data. The results of the study show that the nonlinear flexural behavior of the cold formed ferritic stainless steel closed built-up beams is significantly affected by the geometrical parameters of the beams. The numerical results were found to be in good agreement with the experimental results. The study concludes that cold formed ferritic stainless steel cold built-up beams can be used as an alternative to traditional structural materials, such as steel and concrete, in many applications. The findings of this study can be used to optimize the design of cold formed ferritic stainless steel closed built–up beams, and to improve the accuracy of numerical simulations of their behavior under bending loads.*

I. INTRODUCTION

Stainless steel alloys have been developed in the early 20th century; it took many decades to spread their functional usage in construction industries. The stainless steels produce a passive layer of chromium oxide for self-healing when exposed to oxygen to prevent the corrosion of the top surface. Cold-formed stainless steel light gauge members are widely used in construction industries due to their corrosion resistance, aesthetic appearance, less and easy maintenance, speed and quality in construction due to light- weight, reusable and recyclable nature. They are formed from thin sheets without the application of heat. Carbon, Iron, Manganese, Chromium, Nickel and Molybdenum are the main elements of any alloy. The physical and mechanical properties are controlled by modifying these elements. In general, carbon and iron improve the strength and hardness, manganese improves the toughness, strength and hardenability, chromium content improves the corrosion resistance, nickel content improves the resistant to both heat and corrosion and molybdenum enhances the resistance to crevice and pitting corrosion.

CLASSIFICATION OF STAINLESS STEEL

Stainless steel is classified into five major grades based on their chemical compositions/microscopic structures such as Austenitic, Ferritic, Martensitic, Duplex and Precipitation hardening. Austenitic grade has more chromium, molybdenum and nickel elements, and it produces good strength and malleability.

Ferritic grades have less nickel content and chromium as a main alloying element, and these produce good mechanical and corrosion resistance. Martensitic grades have slightly more carbon content when compared with ferritic, and they are used to produce medical tools. Duplex is a combination of austenitic and ferritic stainless steel grades, and it creates higher strength. Likewise precipitation hardening is a heat-resisting steel, so it is used in turbine and aerospace parts.

FERRITIC STAINLESS STEEL

Ferritic stainless steel has been developed during 20th century. Neverthless, its growth started in the 1980s, and has been adopted in various industrial applications. It comes under 400 series; it has less nickel, chromium as a primary alloying element ranging from 10.5% to 30%. It can develop by low carbon level and weldable grade during the steel making process. It has good physical, mechanical properties, corrosion resistance and higher 0.2% proof stress. The nickel price is unstable when compared with chromium and the other alloying materials. The price of ferritic stainless steel is stable since chromium is a primary alloying element. Due to the above reasons, ferritic stainless steel is chosen as an alternative material for structural applications. In the current research, 430 grade of EN 1.4016 produced by M/s Jindal Stainless Limited, India, is used in experimental investigation

COLD-FORMED STAINLESS STEEL BUILT-UP MEMBERS

Light gauge cold-formed stainless steel C and Z sections are used mainly as secondary members like purlin, girt, ladder, handrail and so on. Nowadays, the hollow sections, built-up sections made from C and Z profiles, are used in many structures as primary load-carrying members like columns, floor joists, roof truss and so on. Therefore a structural engineer needs to modify the section geometry according to the structural requirements. This modification would create a complex nature to complete the analysis and design of sections with the loading and support conditions.

II. LITEREATURE REVIEW

This chapter has reviewed the literature related to single CFS open and hollow sections, the single cold-formed stainless steel open and hollow sections, the built-up CFS sections and ended with the evaluation of design guidelines. The existing researches on CFS single and built-up section, cold- formed stainless steel section subjected to transverse and axial load which includes three-point, four-point, concentric and eccentric loading has been reviewed. The various failure modes such as local, distortional, global and combined local/lateral-torsional buckling are also reviewed from open, closed and built-up sections. The material properties, stress-strain behaviour, geometric imperfections and strain hardening effects due to cold-forming for cold-formed sections are also studied. Additionally, the available design rules in American standard, European standard, Direct strength method included in North American specification and Continuous strength method proposed by various researchers are also reviewed. The overall and the specific objectives for the present research are formulated based on the gap identified.

Researchers are carried out on cold-formed ferritic stainless steel closed built-up sections. There are no simplified design rules available in the existing specifications/standards. The present study would focus on the built- up cold-formed ferritic stainless steel composed of two lipped channel sections oriented face-to-face and connected by spot welding. The simplified design rules would be developed to assess the capacity of the cold-formed ferritic stainless steel built-up beams.

Continuous Strength Method (CSM)

The CSM is a deformation based design method. Afshan& Gardner (2013b) have assessed CSM is cross-sectional slenderness. limits and strain hardening effects. Bock *et al.* (2015b) have proposed a modified CSM equation for non-slender sections. Further, Zhao *et al.* (2017) have proposed a modified CSM equation for slender sections. The slenderness limit of the section is kept as 0.68, which is used as a boundary between the non-slender and the slender sections. Similar to the DSM, the cross-section classification and the effective width calculations are not required in CSM. In addition, the CSM allows for strain hardening in determining the cross section resistance.

Flexural-Torsional Buckling

Flexural-torsional buckling is a combination of translation and rotation for the entire section and the wavelength is repeated in-between the other two modes.

In the current research, Cold-Formed Ferritic Stainless Steel (CFFSS) built-up beam composed of lipped channel sections orientated face- to-face is used to assess the flexural behaviour.

Distortional Buckling

Distortional buckling will occur in flexural members if compression flange is not restrained with the floor or roof covering material. It is a combination of the rotation and translation about buckling lines and one half-wave occurs in an unbraced portion of the section.

Local Buckling

Higher plate slenderness is common in cold-formed sections since they have very thin wall thickness. Local buckling is the instability of its own cross-sectional geometry before the yielding of material takes place. Local buckling mode is only the rotation about buckling lines for cross-section geometry and waves repeatedly occur at a shorter length.

Comparison of the test and the numerical moment capacities with the design moment capacities predicted by SEI/ASCE 8-02

Description	SEI/ASCE 8 02	
	M_u/M_{ASCE-I}	$M_u/M_{ASCE-II}$
Number of data	135	23
Mean	1.11	1.10
COV	0.125	0.036
Resistance factor	0.8	0.8
Reliability index (β_1)	3.19	3.47
Resistance factor	0.9	0.9
Reliability index (β_2)	2.84	3.08

Comparison of the test and the numerical moment capacities with the design moment capacities predicted by EC3

Description	EC3		
	M_u/M_{EC3}	$M_u/M_{EC3-G\&T}$	$M_u/M_{EC3\ PRO}$
Number of data	158	158	158
Mean	1.15	1.10	1.09
COV	0.073	0.069	0.071
Resistance factor	0.8	0.8	0.8
Reliability Index (β_1)	3.39	3.24	3.17
Resistance factor	0.9	0.9	0.9
Reliability Index (β_2)	3.01	2.88	2.82

Comparison of the test and the numerical moment capacities with the design moment capacities predicted by DSM with overall, low and high slenderness

λ_l	Description	DSM				
		M_u/M_{DSM}	M_u/M_{DSM-RR}	$M_u/M_{DSM-ARR}$	$M_u/M_{DSM-W\&Y}$	$M_u/M_{DSM-PRO}$
Overall	Number of data	158	158	158	158	158
	Mean	0.95	1.07	0.96	1.30	1.08
	COV	0.117	0.125	0.128	0.169	0.051
	Reliability index (β_1)	2.55	3.04	2.55	3.70	3.36
	Reliability index (β_2)	2.27	2.70	2.26	3.29	2.99
≤ 0.776	Number of data	67	67	67	67	67
	Mean	1.07	1.18	1.09	1.41	1.10
	COV	0.053	0.055	0.055	0.116	0.042
	Reliability index (β_1)	3.30	3.74	3.40	4.33	3.44
	Reliability index (β_2)	2.93	3.32	3.02	3.85	3.06
> 0.776	Number of data	91	91	91	91	91
	Mean	0.87	0.99	0.87	1.22	1.07
	COV	0.068	0.099	0.068	0.153	0.053
	Reliability index (β_1)	2.34	2.81	2.34	3.47	3.30
	Reliability index (β_2)	2.08	2.50	2.08	3.09	2.94

III. CONCLUSION

An experimental and numerical investigation on the structural performance of the CFFSS closed built-up beams is done in the present research. The tensile coupons are prepared in accordance with IS 1608:2005 and AS 1391:2007 and tested to determine the material properties at flat and corner regions in the first stage of the research. Before testing, the geometrical imperfections of the specimens are measured and press braking operation is used to fabricate the CFFSS lipped channels.

A detailed parametric study has been carried out under four-point bending, and the outcomes are detailed based on section geometries, slenderness parameter, strain ratio, yield strength values and deformed shapes.

The ultimate moment capacity of the CFFSS closed built-up beams obtained from the parametric studies is compared with the nominal strengthpredicted by using SEI/ASCE 8-02, AS/NZS 4673, EN 1993-1-4, Modified EC3 by Gardner and Theofanous (2008) and DSM in AISI S100-2016, DSM proposed in literature Rossi *et al.* (2013), Arrayago*et al.* (2017), Wang and Young (2016b) and Continuous strength method (Bock *et al.* 2015b and Zhao *et al.* 2017). In comparison, the SEI/ASCE 8-02, AS/NZS 4673 standards are found to predict the moment capacity of the CFFSS closed builtupsections better. The new design equations are proposed based on EC3, DSM and CSM. Further, the applicability of the existing and proposed equations is assessed by using reliability analysis

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