International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 01 | Jan 2021 www.irjet.net p-ISSN: 2395-0072

Current Research on Cold-Formed Steel Structures: A Review

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Abstract - *Cold-formed steel structures (CFS) are being popular now days because of its many advantages like light weight, fast construction, etc. The continuous improvement is being done in analysis, design and manufacturing process of CFS. This paper highlights the recent study carried out on CFS which will be helpful for further research and improvements in properties. The structural components like CFS beams, columns are reviewed with its structural behavior. The loading conditions and its effect, temperature rise effect and mechanical properties are reviewed in this paper.*

Key Words: Cold-formed steel, mechanical properties, beam, column, temperature rise

1. INTRODUCTION:

There are mainly two types of steel, hot rolled steel and cold-formed steel. For hot rolled steel the raw material is exposed to the heat while for clod-formed steel the metal sheets are rolled and bent at room temperature. The cold-formed steel is manufactured by two methods namely, cold rolling and press braking. The cold-formed steel have high corrosion resistance, the construction speed is high as well as it have high strength to weight ratio. The cold-formed steel is easy to install and it is light weight. It is suitable for fast construction and hence time saving construction. The cold-formed steel can be molded in any desired shape hence it is flexible for use in any shape of structure. The disadvantage of CFS is that, it has low fire resistance i.e. the properties of material may change at high temperature.

2. REVIEW:

2.1 Behavior of CFS at different Loading Conditions:

Viorel et al. [2] had done study on the effect of eccentric compression about minor axis of column of lipped channel section. The buckling behavior and failure pattern of column has been discussed for different ranges of eccentricities. For positive eccentricity, column buckles in distortional mode while for smaller negative eccentricity, column buckles in local distortional or local mode and for higher negative eccentricity there is local buckling mode.

HungPham & Hancock [5] used the lipped channel sections for study of elastic buckling in shear. The members used were divided into 40 different longitudinal strips so that the shear strength results will be more accurate. To determine shear buckling coefficients the members having different length, flange width and lip size were used.

Table -1: Variation of shear buckling coefficient with respect to section dimensions

Flange width (mm)	Flange to web depth ratio	l (mm)	Member length to web depth ratio	kv	Result
0.01	0.00005	200	1.0	5.130	Flange with lips & short member length improves shear buckling capacity of web
0.01	0.00005	400	2.0	1.009	
20	0.1	200	1.0	9.379	Increments of shear buckling coefficients are greater at smaller lengths.
20	0.1	400	2.0	6.089	

Where, "l" is member length and "kv" is shear buckling coefficient.

When the lip sizes are smaller, for same value of shear buckling coefficient the flanges should be wider.

Table -2: Buckling modes of channel section for various flange width

Flange Width (mm)	Shear buckling coefficient (kv)	Buckling mode
0.01	0.034	Buckles sideway
20	1.173	Twisting
60	4.142	Distortional
120	6.473	Local

From the above table it is concluded that, channel section buckles in twisting mode as flange width increases, for larger flange width the channel section will have local buckling mode.

Arthy & Aruna [13] have used the build-up beam sections of cold-formed steel for study under monotonic and cyclic loading. The numerical and experimental investigation was carried out in the research. As test specimen, double angle connected back to back with lips and without lips were used. The twelve specimens were considered for the study. "The experiments were conducted with two bolted end conditions with central point load. Effects of lip and ultimate moment carrying capacity on cyclic load reversal, hysteresis behavior, the effect of flat width to thickness ratio, reduction in stiffness with respect to a number of cycles and ductility of failure were extensively studied"[13]. For determination of deflection in beams the deflectometers were utilized. The load carrying capacity of plain beam was 60% less than that of lipped beam. It was observed that the by increasing number of cycles, strength and stiffness of flexural members decreases.

Martin et al. [15] have discussed the changes in compressive load carrying capacity with respect to the positions of perforations on lipped channel sections. The results were obtained from numerical, experimental and theoretical investigations. For study of buckling behavior of lipped channel section, the non-linear buckling analysis was used. The pitched roof and three hinge flange mechanism was used to find the post failure curves. The researchers concluded that the member having perforations on web have less stiffness than that of member having perforations on flanges.

2.2 Temperature Effect:

Muftah et al. [8] have studied the effect of post elevated temperature on channel sections. The two experiment was performed in two stages. In first stage the member was heated at temperature of 1000^{0}C to 1100^{0}C in furnace then in second stage the member was cooled down to achieve the ambient temperature. The tensile coupon test was conducted for tensile strength using UTM with maximum load of 50kN at constant strain rate. The other parameters like color; weight reduction was also observed at post elevated temperature.

Table -3: Effect on color with varying temperature

Temperature	Color Change
200-400^{o}C	Change to light white color
600^{o}C	White and yellow on surface, black at outline
800^{o}C	Change to yellow color, coating was peeling out
1000^{o}C	Change to dark yellow, coating was lost and burned

From study it was concluded that, there is sudden drop in elastic modulus while yield strength and ultimate strength reduces gradually at post elevated temperature.

Fadhluhartini et al. [8] have used lipped channel columns for the study at high temperature. To record the temperature rise in the furnace the thermocouples were used. In the experiment, first of all the column was subjected to loading and then the temperature in furnace was increased gradually. It was observed that as temperature increases the resistant time of column decreases. It was observed that due to greater thickness of web it has lower temperature than the flange.

Zhen et al. [9] have discussed the manufacturing processes of cold-formed steel mainly full annealing and partial annealing method. The steady-state method was used for investigation of mechanical properties of steel because of its advantage like it directly gives stress strain curve and the temperature effect is neglected. The properties like failure mode, ductility and stress strain curve were examined at elevated temperature. As temperature increases up to 200^{0}C, the ductility of steel decreases but because of some chemical reactions occurred at high temperature, ductility increases after 300^{0}C. From the experiments and reviews the retention factors were established for two types of steel.

Nirosha & Mahendran [10] have used tensile coupon test based on transient state test method to study mechanical properties of steel. In the experiment the member was heated in the electric furnace until the desired temperature is obtained, after that the tensile load was applied until failure by maintaining constant strain rate and constant temperature. The laser speckle extensometer and 5mm strain gauges were used to measure strain in the member. The review includes comparison of various mechanical properties like elastic modulus, yield strength, ductility and ultimate strength at both normal and elevated temperature. It is concluded that, regardless of thicknesses and steel grades, elastic modulus decreases. The ultimate strength of low strength cold-formed steel at 200^{0}C rises by about 20% compared to that at ambient temperature. At ambient temperature, low strength steel exhibits higher ductility than that of high strength steel.

2.3 Other Parameters:

Dar et al. [1] have done the experimental as well as numerical study on cold-formed steel beams with various stiffening arrangements. The hot rolled steel was tested to compare the structural performance and efficiency with CFS. The selected CFS beams was have different width to thickness ratio, stiffening arrangements and geometry. The beam consists of back to back channel sections with the bolted connections. The four models were considered for study:

1. Unstiffened model
2. Angle stiffened model

3. Unstiffened lightest model
4. Stiffened lightest model

From the study it was concluded that the load carrying capacity will increase due to angle stiffeners in which the compression flange lip was welded to inside.

Senbhaga & Sathya.S [6] have used cold formed purlins with lipped sections for pratt truss of hot rolled steel. The two types of connections were considered for study that is sleeved connections and overlapped connections. For determination of deflection the gravity loading teat and three point loading tests were adopted. The section properties for C and Z section are:

Table -4: Section dimensions of Z and C section

Section	Z Type	C Type
Length of each purlin	200mm	200mm
Length of purlin specimen	1.5m	1.5m
Lip length	20mm	20mm
Screw thickness	3mm	3mm
Thickness of purlin	3.15mm	3mm

From study it was observed that the overlapped connection carries more load than other connections. The Z with lipped section is more economical than C with lipped section.

Laim et al. [7] have selected different types of CFS beams like C, I, R and 2R by combining C profile (lipped channel) and U profile (channel) for the study of ultimate stress developed in beams at ambient temperature. The four point bending test was conducted on the beams. In order to prevent the destruction of sections by high temperatures produced during fire resistance tests, fire protection mortar was filled between the profile flanges at elevated temperature. The following points were concluded from the research:

1. "Cold-formed steel beams are very sensitive to local, distortional and global buckling and also their interactions" [7].
2. For better structural behavior of the beams, lipped U sections should be used instead of U sections.

Soheila et al. [11] have investigated the post-yielding behavior under bending of cold-formed channel sections with partially stiffened elements. The experimental studies were carried out and a semi-empirical analysis was performed. Experimental and numerical analysis was undertaken of cold-formed channel sections, each with a partially stiffened element. The researcher was used the Monash pure bending rig to perform bending tests. The tension tests were conducted using a 500kN capacity Baldwin universal testing machine to assess the material properties of sections. The results from experiments were compared with the Australian design rules and revisions were proposed to the rules. By using the test observations and the yield line mechanism model, the ultimate capacity of the tested sections was determined and compared with the test results. In review it is recommended that, for slender cold-formed channel sections under bending, the accurate and reliable capacity predictions should be made.

Narayanan & Mahendran [16] have studied the distortional buckling behavior of innovative cold-formed steel columns. They performed more than fifteen laboratory experiments on intermediate length innovative cold-formed steel columns under axial compression. It is observed that, "the columns were failed by distortional buckling with very little post-buckling strength" [16]. The THINWALL program was used to determine the section and buckling properties of innovative CFS column. The finite element analyses were used to investigate the non-linear ultimate strength behavior and distortional buckling behavior of column. The researchers compared the strain and deflection results from analyses and experiments. Using Australian Cold-formed Steel Structures Standard, the ultimate design load capacities were determined and compared with finite element analyses and experiments. The researchers concluded that, "the residual stresses had only a very small effect on the ultimate load" [16].

Asraf et al. [17] have used "a combination of experimental tests and non-linear elasto plastic finite element analyses to investigate the effect of holes on web crippling under interior-two-flange (ITF) loading conditions; the cases of both flange fastened and flange unfastened were considered" [17]. The relationship was obtained between experimental studies and finite element analyses. Researchers used the finite element model for parametric study on position of holes and various sizes of holes in web of section. They proved that, the ratio of hole depth to web depth and the ratio of distance from edge of the bearing to flat depth of web are key factors affecting the web crippling strength. The design guidelines were suggested in the form of web crippling strength reduction factors, which were conservative for the effects of both finite element and experimental results.

3. GAP ANALYSIS:

The extensive study on cold-formed steel has been done. In previous studies, research is carried out on effect on mechanical properties like ductility, stress strain curve, etc. at post elevated temperature. The researchers have studied the buckling behavior of cold-formed steel, effect of different loading conditions on CFS, etc. But there is still need of more research on the CFS.

4. CONCLUSION:

The following points are concluded from the above review:

1. For positive eccentric compression loading about minor axis of column distortional buckling will occur and for negative eccentric compression local buckling will occur.

2. For CFS sections, there is sudden drop in elastic modulus while yield strength and ultimate strength reduces gradually at post elevated temperature. The ductility of CFS decreases at higher temperature. Due to greater thickness of web it has lower temperature than the flange.

3. "Cold-formed steel beams are very sensitive to local, distortional and global buckling and also their interactions" [7].

4. As flange width increases, channel section buckles in twisting mode.
5. There is very small impact of residual stress on ultimate load.
6. For specimen with perforations on web have low rate of reduction in stiffness than that with perforations on flanges.

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