EXPERIMENTAL ANALYSIS OF PAC ENCASED COLD FORMED STEEL SECTIONS

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ABSTRACT

Cold formed steel is material having high ductility and high strength to weight ratio but when it is subjected to flexural load or high compressive load it gets failed due to local or torsional buckling due to high slenderness ratio and small thickness. This property of CFS section can be improved by encasing these specimens with concrete or some other encasing material. Use of such encased cross section can be possible in precast or cast in-situ primary structural member. Till now many researcher have conducted experimental analysis on concrete in-filled cold formed section but very small research have been made on concrete encased cold formed steel. In this study attempt is made to encase the CFS sections by Polystyrene aggregate concrete and their flexural performance is assessed. Three different fabricated CFS sections were used for the analysis and their flexural performance was assessed by three point bending test. To check the accuracy of experimental approach finite element analysis was also done.
The results obtained from both analyses were compared. This comparative study on different cold formed steel sections encased with polystyrene aggregate concrete will give better alternative option in future as flexural member also in earthquake resistant design of building.
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Keyword : - *Cold formed steel section(CFS), Polystyrene Aggregate concrete(PAC),flexural member.*

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1. INTRODUCTION

The cold formed steel sections are manufactured from carbon or low steel alloy sheet strip plate in cold rolling machines or by press brake operations. The thickness of such members usually ranges from 0.4mm to about 6.35 mm. Such members are now a days widely used in building construction, Bridge construction, storage tank, Highway products, Drainages facilities, grains bins, transmission towers, Car bodies, railway coaches and various types of equipment.[15] The reason behind growing popularities of cold formed steel includes high strength to weight ratio, ease of fabrication, economy in transportation, and ease of handling. Due to high ductile behavior CFS sections are also be used in earthquake resistant design of structure.
Generally CFS sections are manufactured from thin plate element due to which they are susceptible to high local or torsional buckling. Due to this weakness in CFS section they are not normally used as primary members. To overcome with this disadvantage many researcher have studied the different composites of cold formed steel. Composite structural member composed of two or more dissimilar material joined together to act as single unit, the resulting system is stronger than the sum of its parts. At present PAC encased cold formed steel sections are turn out to be most popular construction adoption in medium rise and residential building and such composite sections can be used as primary structural member due to substantial improvement in buckling capacity.

In the field of Civil engineering design and construction of economic structure is a factor which leads to research on composite of cold formed steel structure. In this project an attempt is made to study comparative analysis of flexural strength of concrete encased cold formed steel by varying shape of section.. In this study concrete encased specimen with different cross sections of cold formed steel like Z section, built up I section and double C sections are encased with polystyrene aggregate concrete (PAC). The flexural behavior of all these sections was tested in three point bending test. Comparative analysis of these sections considering their flexural strength, strength to weight ration and ease of construction was made and most economical and feasible section were selected.

1.1 Objective

1. To investigate the flexural performance of polystyrene aggregate concrete encased cold formed steel section.
2. To compare load carrying capacity of different CFS sections encased with Polystyrene aggregate concrete.
3. To analyze the suitability of Polystyrene aggregate concrete as encasing material.
4. To develop new lightweight composite beam element.

1.2 Literature Review

Faqi et al. [1] studied numerically and experimentally behavior of CFST column under axial compression with variations in aspect ratio of elliptical section. They tested 21 specimens out of which 18 specimens were cold formed in filled concrete section and 3 specimens were cold formed elliptical hollow section. They had compared there result obtained from experimental and numerical analysis with standard design methods. Result obtained from comparison proved that Chinese standard (CB50936) and design method EC4, gives accurate prediction of load carrying capacity of member. The specimen were casted with varying percentage of aspect ratio from 1 to 2.5 and steel tube to concrete area ratio from 5-12%. After the experiment analysis it was calculated that CFST column subjected to concentric loading failed by shear failure of concrete in fill and removal of steel tube are also presented. Inward buckling of steel tube were minimized due to concrete infill. Load bearing capacity and ductility of CFST column decreases considerably with increase in aspect ratio of column. Finite element model were also developed and results were compared.

Peter et al. [2] performed experimental investigation on polystyrene aggregate concrete braced cold formed steel element and panel. Overall testing program was divided in to two parts in first part PAC braced CFS beams were tested and in second part CFS braced panel were tested. In element testing program two CFS channel section with two different configurations encased in PAC concrete were tested for four point bending test. In panel testing program full scale floor panel subjected to uniformly distributed load were tested. After the experimental analysis it was concluded that main beneficial caused by PAC was due to bracing not as composite action.

Ben et al. [9] investigated behavior of column concrete in filled cold formed stainless steel tube column. The concrete used for analysis was 40 to 80 MPa and steel tensile strength up to 536 MPa to 961 MPa. A series of tests was conducted on square and rectangular hollow section in filled with different concrete grades. The depth to thickness ratio was varied from 25.7 to 43.3. The specimens were tested in axial compressive testing machine with 4600N capacity. The test strength and load axial relationships were measured for each column specimen. Failure of column was observed due to local buckling and crushing of concrete. In some specimen local buckling of steel tube was predominant. They also calculated the design strength of concrete in filled stainless steel column by using various design approach using guidelines specified in American specification. By comparison of strength obtained from various design approach and test strength it is recommended to use design rules in American and Australian/ New Zealand specification.

2. TESTING PROGRAM

In the present study testing program is dived into two phases. In first series cube specimens of polystyrene aggregate concrete were casted with different percentage of fly ash replacing cement and different percentage of waste polystyrene aggregate. Total nine different mixtures were prepared and cubes were casted for compression testing. Size of cube was 150x150x150cm. From the result obtained from this testing series best alternative mixture of PAC was selected for encasing CFS section in second phase of testing program. In second phase different cold formed steel sections (Z- section, 2-C and built up I section) are encased in polystyrene aggregate concrete with best alternative mixture obtained from phase one. These encased CFS section were tested for flexural three point bending test under UTM at Gharada Institute of Technology, Lavel. Along with these encased specimen CFS section without encasing are also tested for flexure with same cross sectional properties and loading conditions.

Table -1: Properties of Aggregate

Properties	Natural fine aggregate	Waste Polystyrene Aggregate
Bulk densities	1647 kg/m^3	6.86 kg/m^3
Fineness Modulus	3.15	5.1
Specific Gravity	2.47	0.011
Water absorption	0.5	11%

2.1 Testing of PAC Cube specimen

Cube specimens were casted with nine different mixtures with help of hand mixing only. Mixing with concrete transient mixture was difficult because of light weight of aggregate. After 24 hours cubes were kept curing tank for curing for 28 days. While casting flay ash were replaced to cement up to 40% and percentage of course aggregate were varied up to 60% of total volume of concrete. Proportioning of material was done on volume basis. Weight proportioning might have given irrational mass of polystyrene aggregate. Following table will give detail about quantity of material. The size cube casted was 150x150x150mm as per IS 456: 2000

The entire cube specimens tested for compression under compression testing machine. Loading arrangement for testing is as shown in figure. Compression testing machine was with 3000 KN capacity with a hydraulic loading arrangement and digital display.

Table -2: Details of mixture

Sr. No	Mixture No.	Binder		Fine aggregate	
		OPC %	Fly ash	NFA%	WPA%
1.	PAC1	100	0	40	60
2.	PAC2	100	0	60	40
3.	PAC3	100	0	100	0
4.	PAC4	80	20	40	60
5.	PAC5	80	20	60	40
6.	PAC6	80	20	100	0
7.	PAC7	80	40	40	60
8.	PAC8	80	40	60	40
9.	PAC9	80	40	100	0

2.1 Testing of PAC encased CFS section

Cold formed steel section used for testing were built up I section, Double channel section and Z- section Dimensions and properties of sections are explained in table no. 2. In this second phase of testing factory made cold formed steel sections are fabricated to a suitable form. Then they are incased with polystyrene aggregate concrete. PAC used for encasing was concrete with 60 % polystyrene and 40% fly ash.

Table -3: Properties of CFS sections.

Sr. no	Designation	Dimensions	Yield strength	Coating thickness
1	C100	100x40x15x1.2	240 mPa	90 GSM
2	C140	100x50x20x2x2	240 mPa	120 GSM
3	Z100	100x40x15x1.2	240 mPa	90 GSM

1. Built up I section: Built up I sections are fabricated two channel section size 100x40x15x2 mm placed back to back with bolting arrangement. Bolts used are 3mm diameter and 4.6 Grade. Bolts are placed at 100mm edge distance and 150 mm pitch distance (Distance measured along length of member). Staggered bolting was to avoid formation of weaker plane.
2. Double channel section**:** These specimens are fabricated with two channel sections 140x50x20x2 mm placed face to face. Both lip of each channels are connected to each other with two bots of 3mm Diameter at 100mm edge distance. Grade of bolt used were 4.6.

Fig -1: Cold formed sections used for the experimental work

The fabricated shown in fig.1 along with Z- section are encased in polystyrene aggregate concrete. Casting work is done at concrete technology laboratory of MPCOE, Velneshwar. Length of beam specimens was same for all which is equal to 500 mm. Cross sectional dimension of beam were different for different CFS section. Following Table no. 3 illustrates the dimension, Designation and properties of section. To make adhesive bond between CFS section and concrete Epoxy Standard Adhesive made by Araldite was used. Total six type of specimens were casted. Three specimens with chemical bond , and three specimens without chemical bond. To heck improvement in Load bearing capacity of beam element CFS section without encasing were also tested with same CFS sectional properties.
The entire beam specimens were tested for three point bending test under universal testing machine at GIT lavel. Beams were rested on simple roller support and point load is applied at centre.

Table -4: Beam element details

Sr. No	Section Details	Bonding details	Dimension	Designation
1	Built up I section	Chemical bond	80x100x500	EBICH100
		No chemical bond	80x100x500	EBI100
		Without encasing	80x100x500	BI100
2.	Double channel section	Chemical bond	100x140x500	E2CCH140
		No chemical bond	100x140x500	E2C140
		Without encasing	100x140x500	2C140
3.	Z- section	Chemical bond	100x100x500	EZCH100
		Without encasing	100x100x500	EZ100
		Without encasing	100x100x500	Z100

3. NUMERICAL ANALYSYS

To validate result obtained from experimental work numerical analysis was done with help of finite element software ANSYS. Results obtained from numerical work were also compared with experimental work. Solid 185 element is used for the analysis. Solid 185 is used for the three dimensional modeling of solid structure. . To simulate the experimental condition deflection the flexural member was restrained in Y and Z direction but in X direction it was free. The ANSYS software performs static, buckling and nonlinear analysis by itself for unit load as it is based on finite element analysis. Here for nonlinear analysis of flexural member the central point load was applied at mid span.

Numerical analysis of double C section, built up I section and Z section with chemical bonding was conducted. Boundary condition, loading condition and restrains were applied as discussed in above section to simulate the experimental condition. Deformations of each specimen for each loading increment were observed. From this numerical analysis it is clear that the result obtained from the experimental test were fairly accurate. Results obtained from numerical analysis ANSYS were much closer to experimental result. Failure pattern observed for all cross sections were also same in experimental as well as numerical analysis.

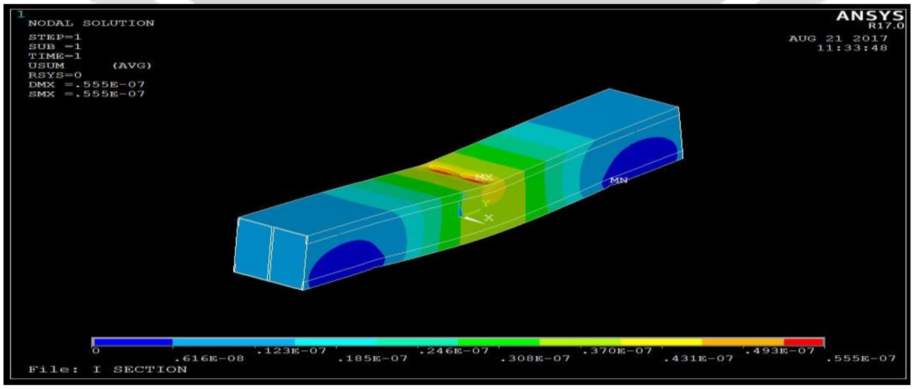

Fig -2: Cold formed sections used for the experimental work

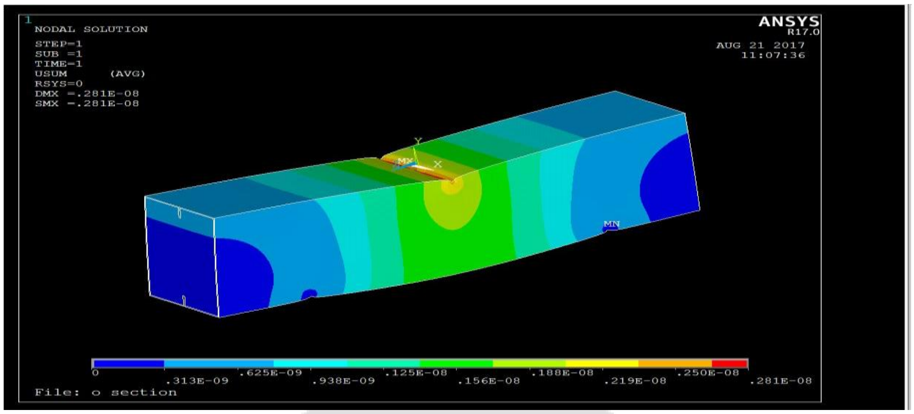

Fig -3: Cold formed sections used for the experimental work

4. RESULTS AND DISCUSSION

Result obtained from testing program is interpreted here under two heads. One is test results of PAC cube compression testing and second is flexural testing of PAC encased CFS section.

4.1 PAC cube test results

Compression test result of PAC cube specimen shows that compressive strength of cube decreases with increase in amount of polystyrene aggregate. Compressive strength of control specimen with 0% polystyrene aggregate was 13 to 15 mPa where as compressive strength of specimens with polystyrene aggregate was in range of 0.75 to 2.90 mPa. Density is also one of the parameter considered in the light weight concrete. Density of PAC varies with the percentage of concrete and it also inversely proportional to the percentage of polystyrene aggregate present. After the analysis of all the mixtures and their load carrying capacity it is clear that Mixture (PAC8) with 40% fly ash and 60% polystyrene aggregate carries maximum compressive load. One more mixture (PAC2) with 0% fly ash and 40% polystyrene also gave better result. Failure of these specimens was brittle failure. In major cases cracks were formed from the top surface of cube running diagonally throughout the section.

Table -5: Result of compression testing

Sr. No	Mixture No	Density (kg/m^3)	Compressive Strength (mPa)
1	PAC1	811	1.3
2	PAC2	1326	1.9
3	PAC3	2130	14.6
4	PAC4	960	1.11
5	PAC5	1286	1.67
6	PAC6	2016	15.06
7	PAC7	954	0.76
8	PAC8	1362	2.9
9	PAC9	2100	13.6

4.1 Flexural tests results

Built up I section, Double channel section and Z- section are the three sections which are tested under flexural load. Result of each specimen type were compared with their hallow section without encasing and encasing using chemical bond.

1. Double channel section: It was most stable section among all three types. Failure of this section was due to buckling of compression flange. Load concentration at mid-span leads to the failure of section. As like Z-section there is no significant crack anywhere in the section. Comparison of this failure with failure of hollow sections shows that PAC elements restrained the global failure of section. At the time of failure both channel sections were separated partially away from the bolts and there was slight lateral deflection in the beam. One more bolt at mid-span might have increased load carrying capacity of section. In this specimen concrete is in-filled in CFS section so there was no separation between concrete and steel. Peak load taken by this specimen was 27 kN. Load carrying capacity was increased considerably as compared to double channel section without PAC.

There is no considerable difference between failure pattern of specimen with chemical bond and without chemical bond. The load carrying capacity was considerably high for the specimen with chemical bonding. The ultimate load carried by the specimen without chemical bonding was 19.8 kN.

Table -6: Results of three point bending test

Sr. No	Designation	Member details	Ultimate load taken in kN
1.	E2CCH140	With chemical bonding	27.0
2.	E2C140	Without chemical bonding	19.8
3.	2C140	Without PAC encasing	16.35

Fig -4: Cold formed sections used for the experimental work

2. Built up I section: Failure of built up I section specimen was complex. Initially cracks were developed at centre. These cracks were diagonal cracks starting from compression flange at mid-span and running in both directions. At the time of failure width of these cracks became wide and buckling of compression flange took place. As there is no bonding between steel and concrete separation of concrete portion from CFS section also took place. Ultimate load taken by this specimen was 22.7 kN which is quite high as compared to CFS section. In the specimen with no chemical bonding separation of PAC was also took place and load carried by this section was 15.55 kN. Failure pattern was similar to that of section with chemical boding. But in the section without chemical bond overall deflection was also there.

Table -7: Results of three point bending test

Sr. No	Designation	Member details	Ultimate load taken in kN
1.	EBICH100	With chemical bonding	22.7
2.	EBI100	Without chemical bonding	15.55
3.	EBI	Without PAC encasing	11.23

Fig -5: Cold formed sections used for the experimental work

PAC encased Z- section were also loaded with point load at centre and supported on roller support. Clear unsupported length of beam element was 400mm. During the initial phase of loading load were taken by the both material. At peak load of 8.35 kN first crack was developed at mid-span (200 mm from support). After continuous loading beyond development of crack became wider and sever. Then after some time shear cracks were also developed at support. In the section with no chemical bonding separation of CFS section and PAC element took place. As compared to behavior of Z section without encasing there is significant difference in peak load and failure pattern. Cracks were developed in concrete not in steel. Global buckling of Z- specimen was restrained due PAC elements. After the analysis of failed section it was clear that strength of CFS section was not fully utilized.

Table -8: Results of three point bending test

Sr. No	Designation	Member details	Ultimate load taken in kN
1.	EZCH100	With chemical bonding	8.8
2.	EZ100	Without chemical bonding	7.8
3.	Z100	Without PAC encasing	6.2

Fig -6: Cold formed sections used for the experimental work

5. CONCLUSIONS

This study presented testing program to analyze flexural performance of PAC encased cold formed steel sections. PAC cube specimens were tested for compression and PAC encased CFS beams were tested for flexure. Based on the test results following conclusions are drawn.

1. Cube testing results of PAC element showed that compressive strength of concrete decreases with increase in amount of polystyrene Aggregate.
2. Density of polystyrene aggregate concrete was directly proportional to the amount of polystyrene aggregate present. Density of PAC can be reduced up-to 70% as compared to ordinary concrete.
3. From the flexural test results it was clear that ultimate load carrying capacity of encased sections increases considerably as compared to non composite member. The increase in ultimate load was about 1.4 to 2 times of non composite member. It was due to beneficial effect of PAC element as bracing for CFS section.
4. PAC encased double channel section with chemical bonding showed better performance as compared to other sections. Increment in load carrying capacity in this section was up-to 60%
5. Modes of failure obtained from experimental investigation and finite element analysis have been found to be in acceptable agreements.

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