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EXPERIMENTAL INVESTIGATION OF CFRP STRENGTHENED I-SHAPED COLD FORMED STEEL BEAMS

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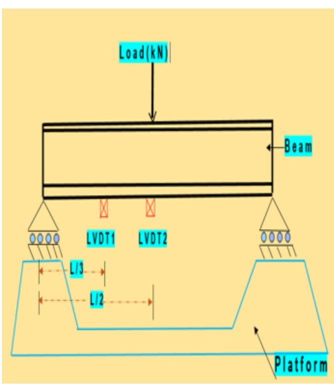
Graphical abstract



Abstract

Cold formed steel differ from hot rolled steel by its lesser thickness and weight. The cold formed steel applicable in roof purlin, pipe racks and wall panels etc. Due its lesser wall thickness the cold formed steel member subjected to buckling. The enhancement of load carrying capacity of the cold formed steel member can be achieved by external strengthening of CFRP. In this study cold formed channel members connected back to back to form I shaped cross section using screws. These built up beam members were 300mm, 400mm and 500mm in length with 100mm screw spacing and edge distance of 50mm were chosen for testing. CFRP fabric cut according to length, width of built up beams and wrapped outer surface of beam using epoxy resin. Experiments were carried out in two sets firstly plain built up beams and secondly CFRP wrapped beams. The test results shows that increased load carrying capacity and reduction in deflection due to CFRP strengthening. Experimental results were compared with AISI standards which are in good agreement. Experimental results shows that CFRP strengthening is economic and reliable.

Keywords: Cold formed steel, built up beam, experimental, carbon fibre reinforced polymer, AISI

Abstrak

Rangka keluli gelek sejuk (Cold formed steel) adalah berbeza daripada rangka keluli gelek panas (Hot rolled steel) dari segi pengurangan ketebalan dan berat. Rangka keluli gelek sejuk (Cold formed steel) digunakan di dalam bumbung purlin, rak paip, panel dinding dan sebagainya. Pengurangan keupayaan daya tampug belan rangka keluli gelek sejuk (Cold formed steel) boleh dicapai dengan mengukuhkan luran CFRP. Di dalam kajian ini, rangka keluli gelek sejuk (Cold formed steel) membentuk saluran yang menghubungkan kembali bentuk keratan rentas I dengan menggunakan skru. Binaan rasuk yang dipilh untuk ujikaji adalah 300mm, 400mm dan 500mm panjang dengan jarak 100mm di antara skru dan jarak tepi sebanyak 50mm telah dipilih untuk ujikaji. Fabrik pemotongan CFRP adalah mengikut panjang, luas rasuk dan balutan luar rasuk dengan menggunakan gam epoksi. Ujikaji dijalankan dengan menggunakan dua set binaan iaitu rasuk biasa dan rasuk yang di baluti CFRP. Keputusan ujikaji menunjukkan peningkatan keupayaan daya tampung dan pengurangan pesongan adalah disebabkan oleh pengukuhan CFRP. Dapatan daripada ujikaji ini telah dibandingkan dengan standard AISI dan ianya menunjukkan keputusan yang baik, di mana pengukuhan CFRP adalah lebih ekonomi dan boleh dipercayai.

Kata kunci: Rangka keluli gelek sejuk (Cold formed steel), binaan rasuk, ujikaji, polimer tetulang gentian karbon, AISI

1.0 INTRODUCTION

In early 20th century cold formed steel members were manufactured in USA. The main difference in cold formed steel section to hot rolled steel section is lesser thickness. Due to its small thickness it can offer various complex shapes. These sections are subjected to various failure modes [1]. Cold formed steel beams are subjected to instabilities such as local, distortional, lateral-torsional buckling and their interactions. These failure modes may effect on the ultimate strength of cold formed steel members which may possible at cross section yield [2]. The buckling in cold formed steel members causes due to low torsional stiffness, high slenderness and geometric imperfections [3]. Laterally braced edge stiffened lipped channel members moment capacity were tested. The moment capacity may be affected by local bucking and distortional buckling [4]. The cold formed steel members proved to be best in architectural appearances, corrosion resistant and ease of fabrication [5].

When High modulus of CFRP used for strengthening of steel beams which increases the ultimate load and stiffness [6]. Carbon fibre reinforced polymers are one of the composite material using in a construction industry which are applicable in strengthening and repair of a structural member. These material used because of very high stiffness to-weight and strength-to-weight and durability in aggressive environments [7]. Circular hollow beam sections are strengthened using CFRP which are tested for flexural strength, the results shows that the enhancement of strength and moment capacity [8].

In this experimental studies CFRP strengthened cold formed steel built up beams of various lengths, thickness were tested and corresponding maximum loads at failure, modes of failure, effect of screw, economic studies and deflection were noted. The experimental results were compared with AISI standards and reported.

2.0 METHODOLOGY

2.1 Test Specimens

The built up beams of length 300mm, 400mm and 500mm chosen for testing with a thickness of 0.6mm, 0.75mm and 1mm. These built up beams were procured from Bluescope Lysaght Malaysia sdn Bhd. The modulus of elasticity, ultimate tensile strength, poison's ratio are $2.06\times10^5 N/mm^2$, 674.8MPa and 0.3 respectively. The cross sectional properties of cold formed steel built up beams are mentioned in Table 2. Carbon fibre reinforced polymer flat sheets procured from Mapei Malaysia Sdn Bhd which is MAPEWRAP C UNI-AX 300/50 having mechanical properties of tensile strength, weight and thickness were 181.8 Mpa, $300g/m^2$ and 0.4 mm respectively. MC-Dur 1209 Epoxy resin used to stick the CFRP sheets on the outer surface of the cold formed built up beams. All built up beams were connected with self-drilling screws at the web of the channel section are as shown in the Figure 1. Similarly CFRP strengthened cold formed built up beams as shown Figure 2.

Figure 1 Cross section of plain I section

Figure 2 Cross section of CFRP wrapped

2.2 Tension Coupon Tests

Tension coupon tests were conducted to know the true stress-strain properties of cold formed steel and CFRP as shown in the Figure 3 and 4. The cold formed steel cut into 12.5 mm width, 200mm length with a gauge length of 50mm as shown in Figure 3. The CFRP fabric cut into 50mm width and 250mm length as shown in Figure 4. The dimensions of tension coupon specimens were obtained from ASTM standards [22]. The prepared test specimens were placed in a pneumatic and mechanical grips according to the sizes in the universal testing machine with a pre load of 250N and test speed of 3mm/min. The true stress-strain values obtained from the tension coupon test are summarised in Table 1.

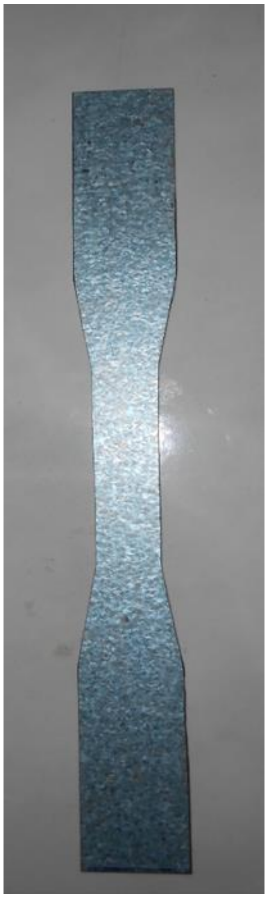


Figure 3 Cold formed steel

Figure 4 CFRP

Table 1 Material properties of cold formed steel and CFRP

	Eo (MPa)	$\sigma_{0.2}$ (Mpa)	σ_{u} (Mpa)	ϵ_{u} (%)
Cold formed steel	2.06×10^5	659.9	674.8	6.6
CFRP	2.43×10^4	178.9	181.8	1.0

2.3 Testing of Beams

The prepared cold formed beams were tested in universal testing machine with a load capacity of 300kN. The single point load is applied on the mid span of the beam. The cold formed beams were placed in the adjustable platform of maximum one metre length, the platform was adjusted according to the length of the beam. The beams were externally connected with linear variable displacement transducer (LVDT) to measure the vertical displacement of the beam. There were two LVDT connected to beam, one located at the one third span another at the mid span of the beam. Data logger was connected to this set up to record the results on every increment of load. The test set up as shown in Figure 5 and 6.

Figure 5 Plain built up beam attached with LVDT

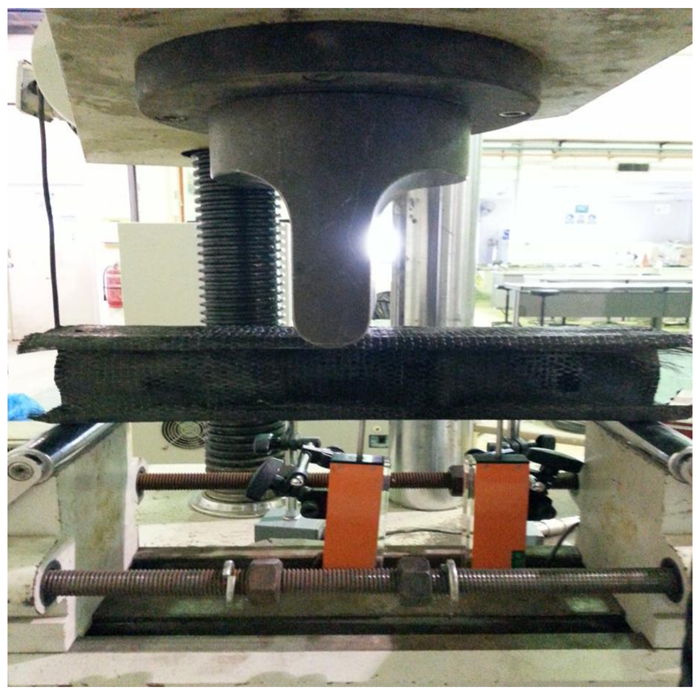


Figure 6 CFRP strengthened built up beam attached with LVDT

Table 2 Sectional properties of built up sections

Depth of web	Thickness (mm)	Mass Kg/m	Moment of Inertia of I shaped sections (mm⁴)	
			Ixx	Iyy
75	0.6	0.78	181156.63	69750.92
75	0.75	0.99	224332.43	86264.09
75	1	1.3	294450.85	112986.61
100	1	1.72	737399.22	261903.23

2.4 Design Rule

The following design procedure is applied to calculate the maximum allowable bending moment and maximum allowable load for the I-shaped flexural members subjected to buckling as specified in AISI 2007 [9]. The following specification apply to I, Z, C and other singly symmetric sections.

$$Mn = Se.\ Fy = Sc.\ Fc \tag{1}$$

Se = Elastic section modulus of effective section.
Fy = Yield stress of steel.
Sc = Elastic section modulus of effective section.
Fc = Elastic buckling stress.

$$Fe = \frac{\pi^2 \ E\ C_b \ \ d\ I_{yc}}{S_f \ \ (K_y\ .\ L_y)^2} \tag{2}$$

E = Modulus of elasticity of steel.
C_b= 1, Where C_b is the bending co efficient.
d = Depth of the section.
I_{yc} = Moment of inertia of compression portion.
Sf = Elastic section modulus of unreduced section.
Ky = Effective length factor
Ly = Unbraced length

$$Fc = \frac{10}{9} F_y \left(1 - \frac{10\ Fy}{36\ Fe}\right) \tag{3}$$

Allowable moment Ma

$$Ma = \frac{M_n}{\Omega_b} \tag{4}$$

Mn Nominal flexural section strength

Ω_b = 1.67 (ASD)

Maximum allowable moment at mid span

$$Ma = \frac{W.l}{4} \tag{5}$$

Allowable maximum point load at mid span

$$W = \frac{M_a\ \ 4}{l} \tag{6}$$

3.0 RESULTS AND DISCUSSIONS

The experimental investigation of cold formed plain and CFRP strengthened built up beams results are discussed. The flexural members load carrying capacity of specified beams were tested and reported as shown in the Table 3. Experimental results were compared with maximum load resistance calculated using AISI specification as shown in Table 4. Experimental results of deflection and failure modes were observed and discussed.

3.1 Load Carrying Capacity of Built Up Beams

The tests were conducted on plain and CFRP strengthened beams, results are as shown in Table 3. There is an increase in capacity ranges from 9.19 % to 25.88% with an average increase of 18.9% as compared in Table 3. The enhancement of strength due to increase in cross section area of built up members and achieving the strong stiffness in CFRP wrapping. Maximum load observed from the experimental studies were compared with maximum load capacities calculated using AISI specification and tabulated in Table 4.

Table 3 Comparison of test results for Plain beams to CFRP strengthened beams

Sections	Max load on Plain sections (kN)	Max load on CFRP sections (kN)	% increase in capacity
2C75x0.6x300mm	3.391	4.483	24.35
2C75x0.6x400mm	3.174	4.128	23.11
2C75x0.6x500mm	3.058	3.764	18.75
2C75x0.75x300mm	5.237	5.843	10.37
2C75x0.75x400mm	4.825	6.510	25.88
2C75x0.75x500mm	4.798	5.850	17.98
2C75x1x300mm	9.601	12.436	22.79
2C75x1x400mm	9.032	11.210	19.43
2C75x1x500mm	8.723	10.540	17.23
2C100x1x300mm	11.870	15.891	25.30
2C100x1x400mm	10.023	11.038	9.19
2C100x1x500mm	9.350	10.620	11.95
Mean			18.9

Table 4 Comparison of test results with load capacity

Sections	Max load on Plain sections (kN)	Max load capacity (Resistance) based on AISI standards (kN)
2C75x0.6x300mm	3.391	13.095
2C75x0.6x400mm	3.174	9.996
2C75x0.6x500mm	3.058	7.985
2C75x0.75x300mm	5.237	16.202
2C75x0.75x400mm	4.825	12.368
2C75x0.75x500mm	4.798	9.879
2C75x1x300mm	9.601	21.263
2C75x1x400mm	9.032	16.231
2C75x1x500mm	8.723	12.965
2C100x1x300mm	11.87	39.153
2C100x1x400mm	10.023	29.887
2C100x1x500mm	9.35	23.873

3.2 Deflection

Deflection were measured using two LVDT, positions are as shown in Figure 5 and 6. The deflections were observed in both plain and CFRP strengthened sections. From the experimental results it is noted that CFRP wrapping reduce the deflection in the built up members due to increased cross sectional area of built up column and stiff bonding of cold formed steel and CFRP. In plain built up beams maximum deflection noted as 12.35 mm and 11mm deflection noted in CFRP strengthened built up beams at one third span. The maximum deflection noted as 14.15 mm and 13.1 mm noted in the mid span of the plain and CFRP strengthened beams respectively. The deflection of plain and CFRP strengthened cold formed steel beams at one third ad mid span as shown in Figure 7 and 8.

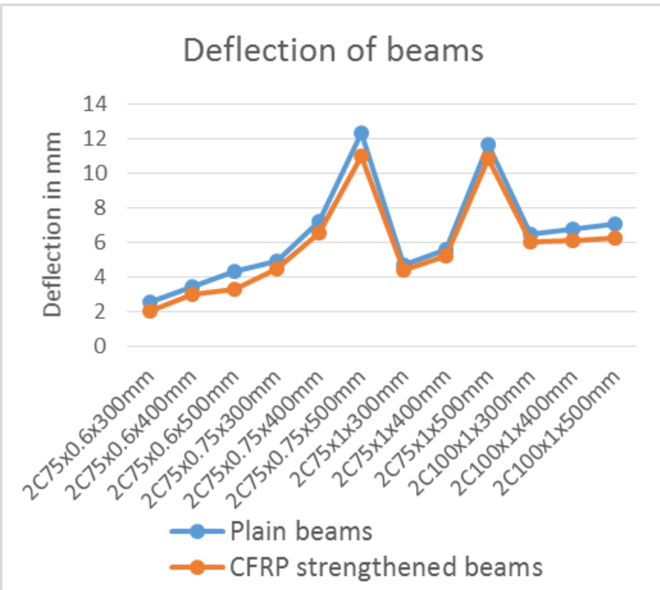


Figure 7 Built up beams deflection measured at one-third span

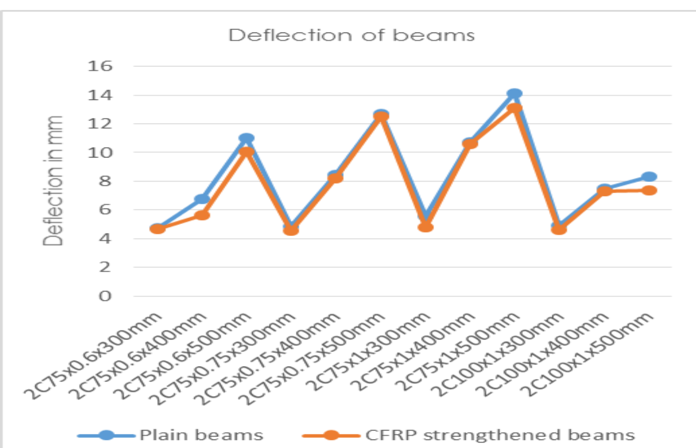


Figure 8 Built up beams deflection measured at mid span

3.3 Modes of Failure in Built Up Beams

The failure were observed in the plain and CFRP strengthened built up beam sections. The cold formed steel beams were failing by local bucking as shown in Figure 9-12. Local buckling is the one where corner of the beam is in fixed position, in this study local buckling mainly observed in bottom flange of the beam. The flanges are having free edges which allow to buckle the flanges. Since the two channels were connected back to back using screws at web portion of the beam, hence there is less chances buckle at the web portion.

Figure 9 Local buckling failure

Figure 10 Local buckling failure

Figure 11 Local buckling failure

3.4 Effect of Screws on Built Up Beams

Cold formed steel provide an additional opportunity to connect its members with screws, where as hot rolled steel is limited to weld, revit and bolt connection. The self-tapping screws were connected in two rows as shown in Figure 1. The minimum spacing of the screws should not be less three times the diameter of the screws and minimum edge distance of the screws should not be less than the 1.5 times the diameter of the screws [4]. The strength of the each screws were calculated as per AISI specification as shown in Table 5. The design strength were calculated for 1mm thick cold formed steel section with a screw diameter of 5.43mm. Table 5 shows that each screw can take shear strength of 9.89kN and 5.49kN pull over strength.

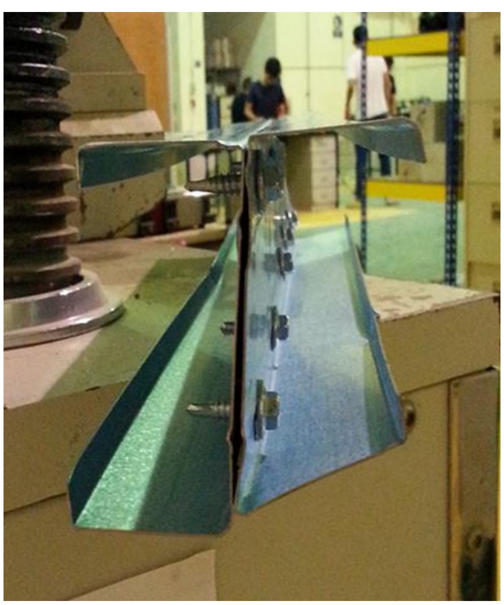


Figure 12 Local buckling failure

Table 5 Design strength of screws connected to cold formed steel

Designation	Design equations	Design strengths (kN)
Nominal shear strength per screw (P_{ns})	$2.7.t_1.d.F_{u1}$	9.89
Nominal pull over strength (P_{nov})	$1.5.t_1.d_w.F_{u1}$	5.49

3.5 Economic Studies on CFRP Srengthening

The economic studies were made on the CFRP strengthening to one metre length of cold formed steel beam with replacing a new one metre length beam. The cost of cold formed steel beam per metre length provided by Lysaght BlueScope steel sdn Bhd. Malaysia. Table 6 shows that cost comparison of CFRP strengthening and replacing of new cold formed beam. The results shows that CFRP strengthening is economical. In replacing of new member the use of machineries may create impact and vibrations to subsequent members which may effect on connections.

Table 6 Cost comparative studies

CFRP strengthening		**Replacing of new member**	
Particulars	Cost in RM	Particulars	Cost in RM
CFRP(0.25mx 1m) size	16.0	Coldformed steel/m	6.0
Adhesive (0.25kg)	5.0	Equipment charges (cutter and supporting jacks)/ hour	50.0
Labour charges(2person x 2 hours)	40.0	Labour charges(1person x 1 hour)	20.0
Total	61.0		76.0

4.0 CONCLUSION

In this experimental study maximum loads, failure modes and deflection at one third length and mid length position were noted for plain and CFRP strengthened cold formed steel beams. The CFRP wrapping is one of the promising technique which increases 18.9% of the load carrying capacity. Experimentally tested plain sections maximum loads were compared with maximum load capacities calculated using AISI standards, where all the beam failed before attaining maximum load resistance. Failure modes were noted in this study and majority of the beams failing by local buckling, where flanges of the channel section were free edges which prone to buckle easily compare to web. The deflection results observed at the one third length and mid length of the beam, as expected more deflection observed at the mid length. The design strengths of screw on attaching the two cold formed were calculated and reported. The economic studies shows that CFRP strengthening technique is economical compared to replacing a new member.

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