SHEAR TESTS OF ALUMINIUM LIPPED CHANNEL BEAMS

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Abstract. *Recently, the use of aluminium sections as primary load bearing members has increased significantly in the building industry. Aluminium as a new constructional material has several advantages in building structures. Corrosion resistance and durability are very notable among its features, making the material long-lasting in the building systems. Moreover, high ratio of strength-to-weight, reduced cost of transportation and ease of erection and fabrication are the other important features of this material. The popularity of aluminium structures has attracted attention regarding the efficiency and design of many sections, and lipped channel beam (LCB) is one of these sections. The vulnerability of aluminium in buckling due to low elastic modulus compared to steel has raised the issue about the shear failure of aluminium LCBs. Hence an experimental study was conducted to investigate the shear behaviour of LCBs and to verify current design rules. Shear tests have been carried out using commonly available ten different aluminium LCBs. The test specimens were loaded at mid-span at the shear centre until failure. The three modes of shear failure including shear yielding, inelastic, and elastic shear buckling were investigated in this study. The results obtained from the tests were then compared with the predictions using the current Aluminium shear design rules in the Australian/New Zealand standard. The comparison showed that the current shear design rule is unsafe to predict the shear capacity of aluminium LCBs specifically in the yield and inelastic regions. Hence, appropriate modifications were proposed for the current design rules to predict the shear strengths of aluminium LCBs and the accuracy of the proposed design rules were verified against test results. This paper presents the details of this experimental study and the improved design rules to predict the shear capacity of aluminium LCBs.*

Keywords: Aluminium; Lipped channel beam; Shear behaviour; Experimental study; Design rules

1 INTRODUCTION

Aluminium alloy has been used in several construction applications including buildings, bridges and other special structures. The use of aluminium alloy members in the construction industry has increased during the last decade due to the improved performance of aluminium. Firstly, aluminium alloy is more durable than other building materials as it is weatherproof and corrosion-resistant which gives a longer service life for structures. Secondly, aluminium alloy can be extruded in a broad range of cross-sectional shapes, enabling aluminium alloy to be used efficiently under a wide variety of loading conditions. Thirdly, aluminium has a high strength-to-weight ratio, which gives the strength required for the design without increasing the dead load of the structures (Su et al. 2014). All these specifications can increase the confidence of using aluminium in the construction industry.

One of the main uses of aluminium sheet is when it is forged into C-Section purlins, also known as Lipped Channel Beams (LCBs). The popularity of aluminium LCB has increased due to the efficiency and design of these sections. However, the vulnerability of aluminium in buckling due to low elastic modulus compared to the steel has raised the issue about the shear failure of aluminium LCBs.

(a)


(b)

Figure 1 (a) Aluminium (LCB) (b) Aluminium frame (DIY Trade 2013)

The shear behaviour of cold-formed steel beams has been widely researched in the past. LaBoube and Yu (1978) studied the shear strength of cold-formed steel LCBs. They have considered the web slenderness ratio, the edge support conditions (obtained by the flanges with different flat width to thickness ratios) and different grades of steel in their study. Pham and Hancock (2010) and Keerthan and Mahendran (2015) conducted a series of shear tests of cold-formed steel LCBs with various section depths and thicknesses. A detailed experimental study was carried out by Keerthan and Meahendran (2010) to study the shear behaviour of hollow flange channel beams known as LiteSteel beams. A series of shear tests was conducted to further study the effect of real support conditions on the shear strength of LiteSteel beams (Keerthan et al. 2015).

While the shear behaviour of cold-formed steel beams has been widely researched, limited studies have been carried out on aluminium beams. An experimental study was carried out by Wang et al. (2016) to investigate the shear buckling behaviour of I-shaped aluminium alloy beams under concentrated loads. Orun and Guler (2017) investigated the buckling behaviour of thin-walled aluminium beams mostly used in aircraft applications under shear vertical loading. However, no research study has been conducted yet to investigate the shear behaviour of aluminium LCBs.

Hence, an experimental study was conducted at Griffith University using ten different aluminium sections to investigate the shear behaviour of aluminium LCBs. The ultimate loads obtained from the experimental study were compared with current design rules (SA 1997), which was found to be unsafe in yield and inelastic regions. Thus, modification of the current shear design rules was proposed. This paper presents the details and results of this experimental study with comparison of ultimate loads obtained from tests and current design rules. It also presents the improved design rules to accurately predict the shear capacity of aluminium LCBs.

2 EXPERIMENTAL STUDY

2.1 Test Specimens

A total of ten shear tests of back to back aluminium LCBs under three-point loading was conducted to understand the shear behaviour of these sections. The nominal web height of the specimens varied from 150 to 400 mm with two different nominal thicknesses (2.5 and 3.0 mm). Table 1 shows the measured dimensions of the test specimens used in this experimental study. These sections are made from marine grade structural aluminium alloy 5052 H36. An aspect ratio (shear span / clear web height) of 1.0 was considered in this experimental study. A number of repeat tests was also undertaken to check the reliability of the test set-up and results. The test specimens are selected such that all three shear failures, namely, elastic shear buckling, inelastic shear buckling and shear yielding, were included in the experimental study.

Table 1 Geometric and material properties of aluminium LCBs

No.	LCBs	D(mm) Web height	B (mm) Flange width	L (mm) Lip depth	t(mm) Web thickness	r_i(mm) Radius
1	15025	155.1	61.9	22.8	2.47	5.1
1R	15025	155.3	62.1	23.1	2.49	5.1
2	15030	155.2	63.1	23.4	2.97	5.3
2R	15030	155.1	62.8	23.2	2.99	5.3
3	20025	204.5	75.1	23.1	2.53	5.2
4	20030	205.3	75.2	23.8	3.03	5.4
5	25025	255.4	76.1	25.4	2.51	5.2
6	25030	255.9	77.1	26.1	2.94	5.1
7	30025	302.5	110.9	29.5	2.49	5.2
8	30030	303.4	111.2	30.02	2.95	5.4
9	35030	352.1	126.5	28.2	2.89	5.1
9R	35030	352.5	126.9	27.9	2.94	5.2
10	40030	405.2	125.2	29.9	2.95	5.9

2.2 Material Properties

Material properties were obtained for the ten aluminium LCBs by conducting tensile coupon tests taken longitudinally from the web of the sections. Six samples were tested for each section of aluminium LCBs, and they were in tension while measuring the load and strain until a fracture occurred. The average yield tensile strength, ultimate tensile strength and modulus of elasticity of these six samples of each section were calculated and presented in Table 2. Based on the table, the total average values of E, f_y and f_u are 68129 MPa, 225.4 MPa and 274.1 MPa, respectively.

Table 2 Material properties of aluminium LCBs

Sections	15025	15030	20025	20030	25025	25030	30025	30030	35030	40030
E (MPa)	66083	69275	68915	66777	68753	68189	68125	68533	68776	67862
f_y (MPa)	222	226	233	230	227	227	224	228	224	213
f_u (MPa)	272	273	278	272	277	275	274	280	274	266

2.3 Test Set-up and Procedure

The test was conducted at the Griffith University structural lab using the Material Testing System (MTS) machine. Two sections were bolted back to back using three T-shaped steel plates to prevent other failure modes of test specimens including torsion, web crippling and flange crushing. Angle straps were used to eliminate distortional buckling and to prevent any unbalanced shear flow. A gap between back to back specimens was provided to allow the test specimens to behave independently and to apply the load at the shear centre. 70 mm wide web side plates were used at the loading point and at the two end supports to prevent the out of plane movement of the web. The web side plates were used at both sides of each section, and bolted with the T-shaped plates to the sections as shown in Figure 2. The thickness of the web side plates were based on the shear centre of the sections.

The assembled pair of aluminium LCBs was positioned accurately in the test rig with simply supported boundary conditions. The load was applied by moving the cross-head of the MTS machine at a constant rate of 1 mm/minute until the test specimen failed. The MTS machine recorded the applied load and the stroke until failure. Moreover, four laser displacement transducers were used, which recorded the lateral and vertical deflections of four specific points of the specimens as shown in Figure 3.

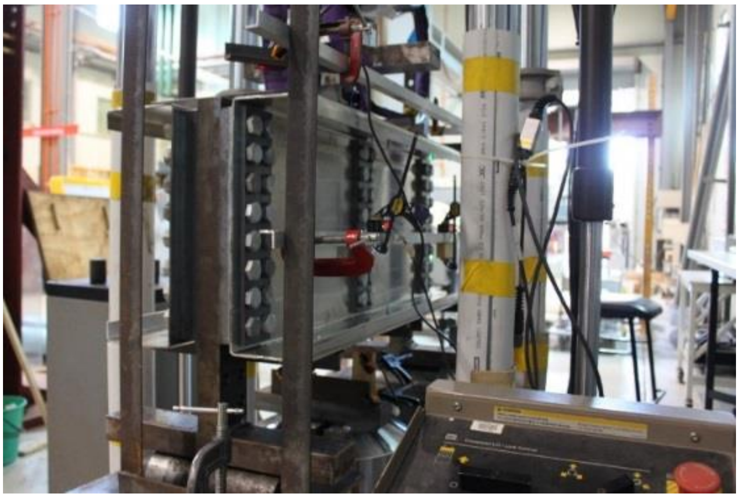


Figure 2 Experimental test set-up

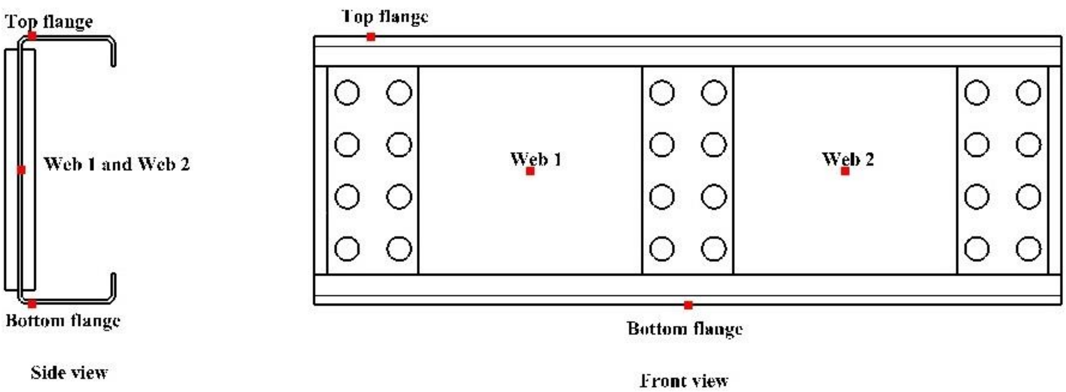


Figure 3 Schematic of laser displacement transducers' positions

2.4 Test Results and Discussion

The shear test results of ten different aluminium LCBs are presented and discussed in this section. It was found that the shear behaviour of aluminium LCBs was quite similar to cold-formed steel LCBs. The typical load-displacement graph obtained from the shear test is shown in Figure 4. As can be seen in this figure, the curve recorded by the bottom flange laser is quite similar to the curve obtained from the MST machine. However it should be noted that the deflection obtained from laser is more representative than the one measured by the MTS. Moreover, the displacement recorded by top flange laser located at the end of the beam does not have much displacement, indicating that the sample did not slip vertically down through the holes. The deflection curves of the two lasers located at the webs had almost similar behaviour.

Table 3 presents the ultimate loads obtained from the shear tests with aspect ratio of 1.0. Figure 5 presents the shear failure modes of two different aluminium LCBs.

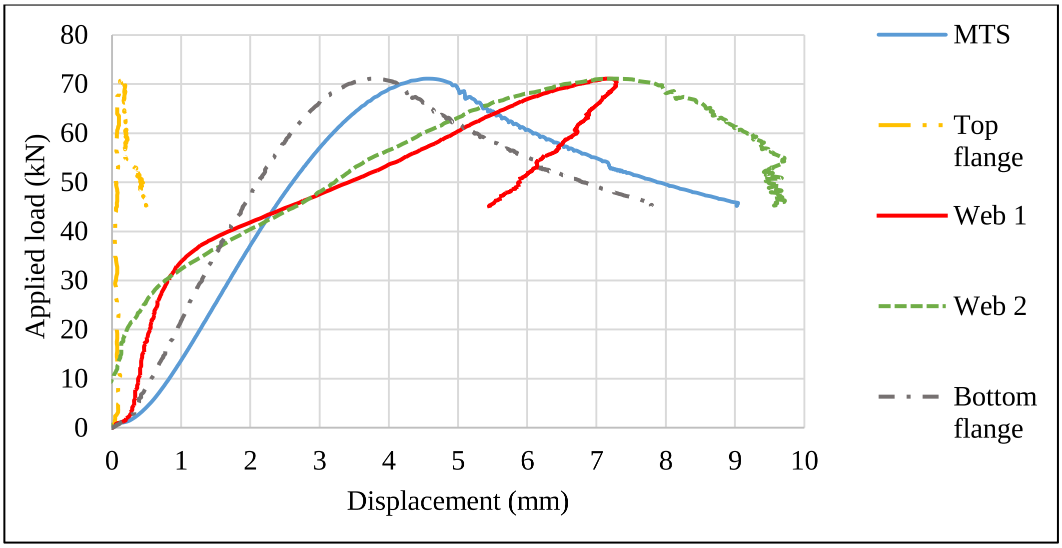
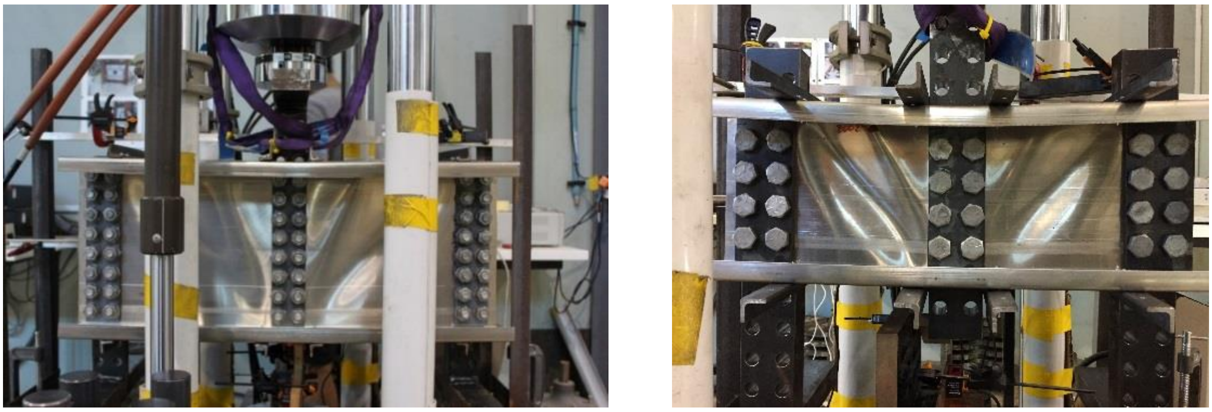


Figure 4 Load-displacement of shear test section 40030 with aspect ratio 1

Table 3 Shear test results obtained from AS/NZS1664.1, tests and proposed design rules

Sections	15025	15030	20025	20030	25025	25030	30025	30030	35030	40030
Exp. (kN)	47.8	58.65	52.44	69.53	56.65	73.47	56.91	81.86	85.01	81.76
Exp./ Current	1.05	1.08	0.83	0.92	0.88	0.81	1.05	0.93	1.18	1.23
Exp./ Prop	1.05	1.08	0.94	0.94	0.99	0.95	1.07	1.04	1.19	1.23



(a) Section 35030 (b) Section 20025

Figure 5 Shear failure modes in two different test specimens

3 SHEAR DESIGN RULE DEVELOPMENT

The shear stress in stiffened flat webs in aluminium structures is predicted using Equations (1) - (3) according to AS/NZS 1664.1 (SA 1997).

$F_L = F_{sy}$ for $\frac{a_e}{t} < S_1$ (1)

$F_L = 1.375[B_s - 1.25D_s(\frac{a_e}{t})]$ for $S_1 < \frac{a_e}{t} < S_2$ (2)

$F_L = \frac{1.375\pi^2 E}{(1.25\frac{a_e}{t})^2}$ for $S_2 < \frac{a_e}{t}$ (3)

with $a_e = \frac{a_1}{\sqrt{1+0.7(\frac{a_1}{a_2})^2}}$ (4)

where a_1 and a_2 are shorter and longer dimension of rectangular panel respectively.

The slenderness limits S_1 and S_2 are determined using Equations (5) and (6).

$$S_1 = \frac{\boldsymbol{B_s} - \frac{\boldsymbol{F_{sy}}}{1.375}}{1.25\boldsymbol{D_s}} \quad (5)$$

$S_2 = \frac{a_e}{t}$ (at the intersection of above shear stress equations) (6)

The buckling constants B_s, D_s and C_s are determined using Equations (7) – (9).

$B_s = F_{sy}[1+\frac{(F_{sy})^{\frac{1}{3}}}{11.8}]$ intercept, MPa (7)

$D_s = \frac{B_s}{20}(\frac{6B_s}{E})^{\frac{1}{2}}$ slop, MPa (8)

$C_s = \frac{2B_s}{3D_s}$ intersection (9)

Figure 6 shows the comparison of test results with the current design rules given in AS/NZS 1664.1. This shows that the shear capacities predicted by AS/NZS 1664.1 are partly unsafe in the yield region and totally unsafe in the inelastic region. The ratios of ultimate loads obtained from tests and current design rule are shown in Table 3. Even though the mean value is 1.00, the corresponding coefficient of variation is 0.143. Hence it was decided to propose improved design rules based on the experimental results to accurately predict the shear strengths of aluminium LCBs.

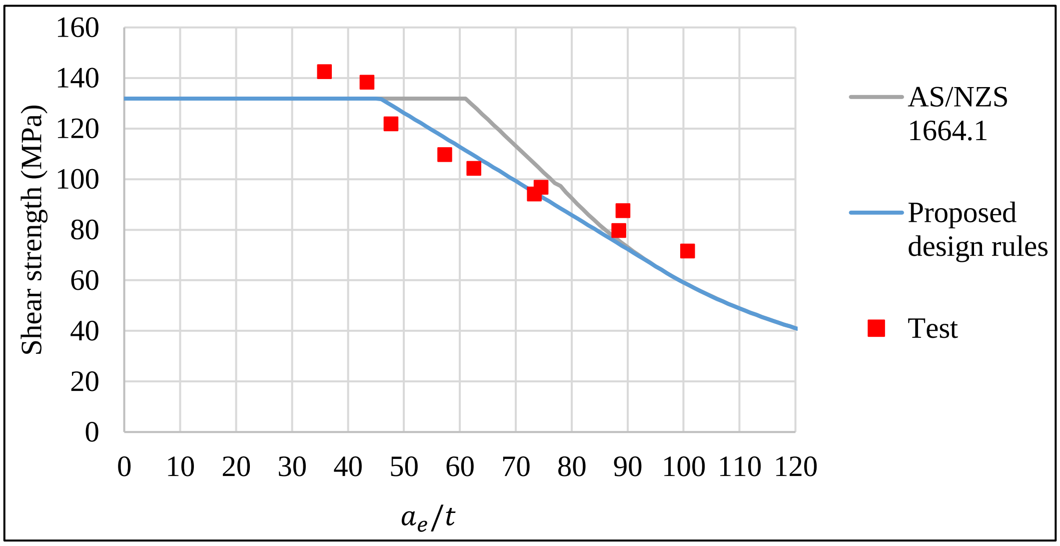


Figure 6 Comparison of tests results with current and proposed shear design rules

The proposed equations to predict the shear stress in stiffened flat webs in aluminium structures are as follows:

F_L=F_{sy} for $\frac{a_e}{t} < S_1$ (10)

F_L= $1.026[B_s - 1.08D_s(\frac{a_e}{t})]$ for $S_1 < \frac{a_e}{t} < S_2$ (11)

F_L= $\frac{1.026\pi^2 E}{(1.08\frac{a_e}{t})^2}$ for $S_2 < \frac{a_e}{t}$ (12)

with a_e based on Equation (4)

The slenderness limits S_1 and S_2 are determined using Equations (13) and (14).

$$S_1 = \frac{\boldsymbol{B_s} - \frac{\boldsymbol{F_{sy}}}{1.026}}{1.08\boldsymbol{D_s}} \quad (13)$$

S_2= $\frac{a_e}{t}$ (at the intersection of above shear stress equations) (14)

The buckling constants B_s, D_s and C_s are determined using Equations (7) – (9), respectively.

Figure 6 presents the comparison of test results with the proposed design rules. The ratios of ultimate loads obtained from tests and proposed design rule are shown in Table 3. The mean value and coefficient of variation are 1.05 and 0.095, respectively. Figure 6 and Table 3 show that the proposed design rules can accurately predict the shear strengths of aluminium LCBs.

4 CONCLUSION

This paper presented an experimental study to investigate the shear behaviour of aluminium LCBs. A total of ten different aluminium LCBs with aluminium alloy 5052 H36 were studied in this research in order to investigate the three different regions of shear failures including shear yielding, inelastic shear buckling and elastic shear buckling. It was found that the shear behaviour of aluminium LCBs was quite similar to cold-formed steel LCBs. The comparison between results of experimental tests and current shear design rules of Australian/New Zealand Standard (AS/NZS 1664) showed that the current shear design rules were unsafe, particularly in the yield and inelastic regions. Therefore, improved shear design equations were proposed based on the test results. This study showed that new design rules can accurately predict the shear strengths of aluminium LCBs.

ACKNOWLEDGMENT

The authors wish to thank Griffith University for providing the necessary facilities and support, and Robert Price from Permalite Aluminium Building Solutions Pty Ltd for providing the test specimens.

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