International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 5, Sept-Oct-2020, ISSN (Online): 2395-566X

Design of Aluminum Alloy Channel Section Beams

Post Graduation Student Ajay Kumar T. A., Associate Professor A. Thangadurai
Departmentt of Civil Engineerring
JCT College of Engineering&Technology
Coimbatore, Tamil Nadu, India

Abstract*- Aluminum alloy members of channel sections are widely used in lightweight structures, especially as pillars of curtain wall systems and brace and chord members in roof trusses. This paper presents both experimental and numerical studies on the behavior of aluminum alloy channel section beams. In this study, four-point bending tests under minor-axis and major-axis bending were carried out. The test specimens included plain and lipped channel sections of both 6063-T5 and 6061-T6 aluminum alloys. A finite-element (FE) model of the channel section beam was developed by using the FE package ABAQUS. The ultimate bending resistances and failure modes of the FE model were compared with the results from the bending tests. The validated model was employed for the parametric study to generate numerical simulation results. A total of 55 new experimental and numerical beam results were compared with predictions from existing aluminum alloy design specifications from the United States, Australia/New Zealand, Europe, and China. Additionally, two commonly used design approaches—the continuous strength method (CSM) and the direct strength method (DSM)—were applied to predict bending capacities for comparisons. A modified DSM approach for aluminum alloy channel section beams is proposed herein. Finally, reliability analyses were conducted to evaluate the aforementioned design methods. The results show that, in comparison with other considered design methods, the CSM provides more accurate and consistent results for aluminum alloy plain and lipped channel section beams.

***Keywords*- Aluminum alloy; Beam; Channel section; Continuous Strength method; Direct strength method; Testing; Numerical investigation.**

I. INTRODUCTION

Aluminum alloys have many desirable characteristics, such as great durability, high strength–to–weight ratios, and favorable corrosion resistance. Based on these advantages, aluminum alloys are commonly employed in long-span roof systems and in damp and corrosive environments. In applications of aluminum alloy structures, closed sections, such as square and rectangular hollow sections (SHSs and RHSs) are common cross-section shapes. Open sections are also popular in engineering structures because they are easy to connect. Therefore, the local buckling behavior and ultimate bending resistance of channel section beams were investigated by the experiments and numerical simulation described in this paper.

There have been many studies on aluminum alloy beams. Moen et al. (1999a, b) investigated the behavior and failure modes of the RHS and I-section beams under moment gradient loading. This study showed the effect of strain hardening on the rotational performance of aluminum alloy flexural members and flexural members of SHS and compared the experimental results with aluminum alloy codes from the United States, Australia/ New Zealand, and Europe. In addition, the study proposed design formulas for SHS flexural members based on the direct strength method (DSM). Su et al. (2014, 2016b) compared the bending strengths predicted by specifications and by the continuous strength method (CSM) and concluded that compression and bending strengths calculated using the specifications are conservative. Guo et al. (2015) presented an investigation on flexural-torsional buckling of T- and I-section beams and proposed fitting formulas to estimate buckling capacities. Wang et al. (2016) presented an investigation on the local buckling of I-section beams under concentrated loads and found that intermediate stiffeners and a thick web are helpful to increase the bearing capacity of the beams. Feng et al. (2017) studied SHS/RHS beams with circular holes and compared the experimental results with the design results. They found that the DSM provided relatively accurate predictions. These studies focused to a large extent on the design of extruded aluminum alloy beams; there are few studies on channel section beams.

Though there are limited studies on aluminum alloy channel section beams, a great number of studies on steel channel section members have been carried out in recent years. For example, Young and Rasmussen (1998a, b) presented compression tests on fixedend plain channel steel columns and evaluated the specifications using test

results; design recommendations of channel steel compression members were also proposed. Lee et al. (2005) found an optimum cross section of a cold-formed channel steel beam using a micro genetic algorithm and presented optimum design curves for various load levels. Maduliat et al. (2012) conducted a series of bending tests on the inelastic bending behavior of cold-formed channels (with or without stiffeners) and provided design rules considering such behavior. Wang and Young (2014) investigated steel channel beams experimentally and numerically to improve the DSM. Ye et al. (2016) optimized cold-formed steel channel beams to enhance their bending capacities for practical applications.
Zhao et al. (2019) presented tests on cold-formed steel channel flexural members with holes in the webs and proposed a corresponding DSM accordingly. Zhao and Gardner (2018) proposed the CSM for stainless steel beams with singly symmetric sections, such as angles, channels, and T-sections. To summarize, the present study was based on key findings reported in the aforementioned literature.

A number of design specifications for aluminum alloy structures have been published in different countries, including the (American) Aluminum Association's Aluminum Design Manual (hereafter AA) (AA 2015), the Australia/New Zealand standard Aluminum Structures–Part 1: Limit State Design (hereafter AS/NZS) (AS/NZS 1997), the European Eurocode 9: Design of Aluminum Structures—Part 1-1: General Rules and Rules for Building (hereafter EC9) (CEN 2007), and the Chinese Code for Design of Aluminum Structures (hereafter CN) (Ministry of Construction 2007). Furthermore, the DSM and the CSM are two widely used approaches for aluminum alloy member design. The DSM, initially proposed by Schafer and Peköz (1998) for cold-formed carbon steel structures, is included in the American Iron and Steel Institute's North American Specification for the Design of ColdFormed Steel Structural Members (AISI 2016). Zhu and Young (2008, 2009) modified the DSM for aluminum alloy SHS/ RHS beams (Zhu and Young 2009) and circular hollow section (CHS) columns (Zhu and Young 2008). The CSM was first developed by Gardner and Nethercot (2004) for stainless steel hollow members. It employs a base curve to determine the relationship between cross-section slenderness and deformation capacities. Su et al. (2016a) modified the CSM for aluminum alloy columns, simply supported beams, and continuous beams.

This study investigated the buckling behavior of channel section beams experimentally and numerically. Ten four-point beam tests including 6063-T5 and 6061-T6 alloys were tested. A nonlinear finite-element (FE) model for the channel section beams was developed using ABAQUS version 6.14 (Dassault Systèmes 2014). The FE model was validated against the experimental results. Upon validation, a parametric study was conducted to generate 45 numerical results. The combined data pool from the experimental program and the parametric study was compared with design strengths predicted by the AA (2015), the AS/NZS (AS/NZS 1997), the EN9 (CEN 2007), the CN (Ministry of Construction 2007), the CSM (Zhao and Gardner 2018), and the DSM (AISI 2016). The DSM was also further modified for the aluminum alloy channel section beams in this study. Additionally, reliability analyses were carried out to assess the reliability of all existing and new design methods.

II. LITERATURE REVIEW

Man-TaiChen[a] BenYoung[b1] presents the experimental and numerical investigation on the behavior of cold-formed steel elliptical hollow section beams. In the test program, a total of 20 beam tests was conducted. Four elliptical section series with the nominal cross-section aspect ratio ranging from 1.65 to 3 were bent about the major and minor axes in both three-point and four-point bending configurations. Finite element models were established to replicate the beam tests numerically. Based upon the validated model, extensive parametric study was conducted on 235 beam specimens to study the behavior of cold-formed steel elliptical hollow sections subjected to bending. The results obtained from experimental and numerical investigation were used to assess the existing design methods and to propose modified design methods for cold-formed steel elliptical hollow section beams. It should be noted that the current design codes do not cover the design of elliptical hollow section beams. The flexural strengths of beams were compared with the design strengths predicted by the equivalent diameter and equivalent rectangular section methods proposed by previous researchers, the traditional design methods using equivalent diameter as well as the Direct Strength Method and the Continuous Strength Method. The applicability and reliability of these design methods were assessed. The results indicate that the existing design methods are not capable to predict the flexural strengths of cold-formed steel elliptical hollow section beams in accurate and reliable manner. In this study, the modified Direct Strength Method and Continuous Strength Method are proposed, which provide accurate and reliable flexural strength predictions.

Chen, M. T., and B. Young studied The structural behavior of cold-formed steel semi-oval hollow sections under bending was studied through experimental and numerical investigation. The semi-oval hollow sections investigated in this study were cold-formed from hot-extruded seamless carbon steel circular hollow sections. A total of 20 beams was tested for both four-point and three-point bending configurations. The sections were bent about the major axis in both positive and negative directions. The tests were replicated numerically by means of rigorous finite element analyses. Based on the validated finite element model, an extensive parametric study was conducted on 198 beam specimens with a wide range of cross-section geometries subjected to pure bending about the major axis in both positive and negative directions. The current design rules for steel structures, such as Australian/New Zealand standards, European codes as well as American and the North American specifications, do not cover the design of semi-oval hollow sections. Therefore, the ultimate flexural capacities of beam specimens obtained from the test program and numerical investigation were only compared with the design strengths predicted by the Direct Strength Method and the Continuous Strength Method. The applicability and reliability of these two design methods were evaluated through reliability analysis. The results show that the existing design methods provide quite conservative and scattered design strength predictions for cold-formed steel semi-oval hollow section beams. In this study, modifications on the Direct Strength Method and the Continuous Strength Method are proposed, which provide better design strength predictions with improved accuracy in a reliable manner.

Feng, R., W. Sun, C. D. Shen, and J. H. Zhu. Both three-point and four-point bending tests were conducted on aluminum square and rectangular beams with circular perforations. Test specimens consist of 9 perforated and 4 imperforated beams subjected to gradient and constant bending moment. The extrusion of 6061-T6 and 6063-T5 heat-treated aluminum alloys were used to manufacture square and rectangular hollow sections (SHS and RHS), respectively. The evaluation of the strength and behavior of aluminum square and rectangular beams focuses on the effects of the aspect ratio, the ratio of plate width, the ratio of plate slenderness, the ratio of perforation dimension and the number of perforations. Test results including the ultimate strengths, failure modes of local and flexural buckling failure, bending moment versus curvature curves and strain distributions along the circular perforations are all reported, which were employed to assess the suitability of the current design specifications. The comparison of test strengths with design strengths shows that the modified DSM for aluminum structural members is somewhat conservative with the lowest value of COV, whereas other design specifications for cold-formed steel and aluminum structural members are quite conservative with comparatively high value of COV. It is also demonstrated from the comparison that the perforated sections close to the mid-span of the beams are the critical section under gradient and constant bending moment. In addition, the comparison of test strengths with design strengths also reveals that the current design rules for perforated cold-formed steel and aluminum structural members are all conservative, in which North American Specifications (NAS) for perforated cold-formed steel structural members are generally appropriate with the lowest value of COV.

Guo, X., Z. Xiong, and Z. Shen. 2015. Both three-point and four-point bending tests were conducted on aluminum square and rectangular beams with circular perforations. Test specimens consist of 9 perforated and 4 imperforated beams subjected to gradient and constant bending moment. The extrusion of 6061-T6 and 6063-T5 heat-treated aluminum alloys were used to manufacture square and rectangular hollow sections (SHS and RHS), respectively. The evaluation of the strength and behavior of aluminum square and rectangular beams focuses on the effects of the aspect ratio, the ratio of plate width, the ratio of plate slenderness, the ratio of perforation dimension and the number of perforations. Test results including the ultimate strengths, failure modes of local and flexural buckling failure, bending moment versus curvature curves and strain distributions along the circular perforations are all reported, which were employed to assess the suitability of the current design specifications. The comparison of test strengths with design strengths shows that the modified DSM for aluminum structural members is somewhat conservative with the lowest value of COV, whereas other design specifications for cold-formed steel and aluminum structural members are quite conservative with comparatively high value of COV. It is also demonstrated from the comparison that the perforated sections close to the mid-span of the beams are the critical section under gradient and constant bending moment. In addition, the comparison of test strengths with design strengths also reveals that the current design rules for perforated cold-formed steel and aluminum structural members are all conservative, in which North American Specifications (NAS) for perforated cold-formed steel structural members are generally appropriate with the lowest value of COV.

S.Maduliat[a], M.R.Bambach[b], X.L.Zhao[a] The aim of this paper is to investigate the inelastic bending capacity of cold-formed channel sections, and provide design rules to account for such behaviour. An extensive experimental and analytical analysis of 42 cold-formed channel sections in three different geometric categories is conducted, including simple channel sections, channel sections with simple edge stiffeners and channel sections with complex edge stiffeners. The sections were cold-formed from G450 steel with nominal thickness of 1.6 mm, and varying theoretical buckling stresses ranging between elastic to seven times the yield stress. The results of the pure bending experimental investigations show that current international cold-formed steel specifications are conservative, for channel sections with low slenderness values. The experimental results are used to propose revisions to current international cold-formed steel specifications.

Moen, L. A., O. S. Hopperstad, and M. Langseth. An experimental program for evaluating the rotational capacity of aluminum beams subjected to a moment gradient loading is presented. The study focuses on local buckling and on the tensile failure susceptibility. Results are compared with design codes. Beams of different tempers, cross sections, and lengths were tested. Some beams were welded, whereas others were unwelded. Uniaxial tensile tests revealed a pronounced plastic anisotropy in the extruded beams. Tests from the reduced strength zone near welds indicate a local ultimate strength on the order of 67% of the parent material yield strength in alloy AA 6082-T6. Nevertheless, the local failure mode is ductile. The strain-hardening behavior of the material and compressive flange width-thickness ratio have a strong influence on both the moment capacity and the rotational capacity of aluminum beams. The magnitude of the moment gradient has a significant influence on rotational capacity, whereas the effect on the moment capacity is not very pronounced in the experiments. Welded members may suffer a tremendous loss of rotational capacity owing to premature tensile failure. Moreover, the tests provide a calibration basis for numerical modeling.

Moen, L. A., O. S. Hopperstad, and M. Langseth. An investigation into the feasibility of applying the finite-element method as a tool for cross-sectional classification for structural codes is carried out. A numerical model of rotational capacity of aluminum beams is established using the nonlinear implicit code given in the *ABAQUS/Standard Theory Manual*. The performance of the model is compared with experimental results presented in the companion paper in this issue. A sensitivity study is carried out in order to establish the sensitivity of the predicted results to model parameters that are not well defined at different section slenderness levels. The results obtained compare well with the experiments in that discrepancies between the experimental and numerical models have a limited effect on the results. Furthermore, the results show clearly that the finite-element model can be used to predict the load-deflection behavior under local buckling of compact aluminum beams, provided that the plastic anisotropy and the uniaxial stress-strain behavior of the material is well described. The validated model provides a basis for future parametric studies aimed at an improved understanding of the inelastic behavior of aluminum beams and improved cross-sectional classification in structural design codes.

Mei-NiSu[ab] BenYoung[a] LeroyGardner[b] Two series of simply supported bending tests on aluminium alloy square and rectangular hollow sections have been performed. The test program comprised 14 three-point bending tests and 15 four-point bending tests. The test specimens were fabricated by extrusion from grades 6061-T6 and 6063-T5 heat-treated aluminium alloys, with width-to-thickness ratios ranging from 2.8 to 20.5. Measured geometric and material properties, together with the full load–deflection histories from the test specimens, were reported. Observed failure modes included local buckling, material yielding and tensile fracture. Further experimental data were gathered from the literature. Finite element (FE) models were developed and validated against the test results, and then used to perform parametric studies, in which a total of 132 numerical results were generated. The experimental and numerical results were used to evaluate the bending resistance provisions of the American [1], Australian/New Zealand [2] and European [3] Specifications, as well as the continuous strength method (CSM). The moment capacities predicted by the three design specifications were found to be generally conservative, while the CSM provided more accurate and more consistent predictions due to the recognition and systematic exploitation of strain hardening.

Mei-NiSu[a]BenYoung[b]LeroyGardner[c]studied Aluminium alloys are nonlinear metallic materials with rounded stress–strain curves that are not well represented by the simplified elastic-perfectly plastic material model used in most existing design specifications. Departing from current practice, the continuous strength method (CSM) is a recently developed design approach for aluminium alloy structures, which gives consideration to strain hardening for non-slender sections. The CSM is a deformation-based method and employs a base curve to define the continuous relationship between cross-section slenderness and deformation capacity. This paper explains the background and the two key components of the CSM: (1) the base curve, which is extended herein such that the method covers both non-slender and slender sections and (2) the strain hardening material model. Three international design specifications from America, Australia/New Zealand and Europe, as well as the CSM are compared with approximately 900 aluminium alloy experimental and numerical results. Reliability analyses have been carried out to assess the reliability level of different design methods according to both the American Institute of Steel Construction (AISC) and European Standard (EN 1990) approaches. Finally, worked examples of the CSM for aluminium alloy stub columns and continuous beams are illustrated in this paper.

III. CONCLUSIONS

This study focused on aluminum alloy flexural members of channel sections. Four-point bending tests were carried out on both plain and lipped channel section beams under minor-axis and major-axis bending. According to the test results, the failure modes of local buckling and distortional buckling were observed for lipped channel section beams bent about their major axes. For the rest of the specimens, the failure mode was found to be local buckling. A finite-element model of the channel section beams was established and validated with the bending test results (bending strengths and failure modes). The comparisons of the tests and numerical simulations showed the two series of results to be in good agreement. The validated FE model was then employed for parametric analyses and generated 45 numerical results.

International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 5, Sept-Oct-2020, ISSN (Online): 2395-566X

Both test and numerical bending resistances were compared with predictions from the American Aluminum Design Manual, the Australia/New Zealand Aluminum Structures–Part 1: Limit State Design, the European Eurocode 9: Design of Aluminium Structures—Part 1-1, the Chinese Code for Design of Aluminum Structures, the continuous strength method, and the direct strength method. The DSM was modified for minor-axis and major-axis flexural members. The bending strengths calculated by the specifications were shown to be quite conservative. The results show that the CSM provided more accurate and consistent predictions. Finally, the reliability levels of all design methods were evaluated. All design methods were found to be reliable for aluminum alloy channel section beams except for the existing DSM. It is suggested that the CSM be employed and the modified DSM be used for the design of aluminum alloy channel section beams.

IV REFERENCE

[1] AA (Aluminum Association). 2015. Aluminum design manual. Washington, DC: AA.

[2] AISI (American Iron and Steel Institute). 2016. North American specification for the design of cold-formed steel structural members. AISI S100. Washington, DC: AISI.

[3] AS/NZS (Standards Australia/Standards New Zealand). 1997. Aluminum structures—Part 1: Limit state design. AS/NZS 1664. Sydney: Standards Australia/Standards New Zealand.

[4] CEN (European Committee for Standardization). 2007. Eurocode 9: Design of aluminium structures—Part 1-1: General rules and rules for buildings. EN 1999-1-1. Brussels: CEN.

[5] Chen, M. T., and B. Young. 2019a. "Behavior of cold-formed steel elliptical hollow sections subjected to bending." J. Constr. Steel Res. 158 (Jul): 317–330.

[6] Chen, M. T., and B. Young. 2019b. "Structural behavior of coldformed steel semi-oval hollow section beams." Eng. Struct. 185 (Apr): 400–411.

[7] Dassault Systèmes. 2014. ABAQUS analysis user's manual version 6.14. Waltham, MA: Dassault Systèmes.

[8] Feng, R., W. Sun, C. D. Shen, and J. H. Zhu. 2017. "Experimental investigation of aluminum square and rectangular beams with circular perforations." Eng. Struct. 151 (Nov): 613–632.

[9] Gardner, L., and D. A. Nethercot. 2004. "Structural stainless steel design: A new approach." Struct. Eng. 82 (21): 21–28.

[10] Guo, X., Z. Xiong, and Z. Shen. 2015. "Flexural-torsional buckling behaviour of aluminum alloy beams." Front. Struct. Civ. Eng. 9 (2): 163–175.

[11] Lee, J., S. M. Kim, H. S. Park, and B. H. Woo. 2005. "Optimum design of cold-formed steel channel beams using micro genetic algorithm." Eng. Struct. 27 (1): 17–24.

[12] Maduliat, S., M. R. Bambach, and X. L. Zhao. 2012. "Inelastic behaviour of cold-formed channel sections in bending." Thin Walled Struct. 51 (Feb): 158–166.

[13] Ministry of Construction. 2007. Code for design of aluminum structures. GB50429. Beijing: Ministry of Construction of the People's Republic of China.

[14] Moen, L. A., O. S. Hopperstad, and M. Langseth. 1999a. "Rotational capacity of aluminum beams under moment gradient. I: Experiments." J. Struct. Eng. 125 (8): 910–920.

[15] Moen, L. A., O. S. Hopperstad, and M. Langseth. 1999b. "Rotational capacity of aluminum beams under moment gradient. II: Numerical simulations." J. Struct. Eng. 125 (8): 921–929.).

[16] Schafer, B. W., and T. Peköz. 1998. "Direct strength prediction of coldformed steel members using numerical elastic buckling solutions." In Proc., 14th Int. Specialty Conf. on Cold-Formed Steel Structures, 69–76. St. Louis: Univ. of Missouri-Rolla.

[17] Seif, M., and B. W. Schafer. 2010. "Local buckling of structural steel shapes." J. Constr. Steel Res. 66 (10): 1232–1247.

[18] Su, M. N., B. Young, and L. Gardner. 2014. "Deformation-based design of aluminium alloy beams." Eng. Struct. 80 (Dec): 339–349.

[19] Su, M. N., B. Young, and L. Gardner. 2016a. "The continuous strength method for the design of aluminum alloy structural elements." J. Struct. Eng. 122 (Sep): 338–348.

[20] Su, M. N., B. Young, and L. Gardner. 2016b. "Flexural response of aluminium alloy SHS and RHS with internal stiffeners." Eng. Struct. 121 (Aug): 170–180.

[21] Wang, L., and B. Young. 2014. "Design of cold-formed steel channels with stiffened webs subjected to bending." Thin Walled Struct. 85 (Dec): 81-92.