STRUCTURAL BEHAVIOUR OF BUILT-UP COLD-FORMED STEEL COLUMN UNDER AMBIENT TEMPERATURE AND STANDARD FIRE

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Cold-formed steel (CFS) is a popular material with various advantages. Its easy production and assembly allow engineers to speed up the construction process. However, CFS is susceptible to buckling because of its natural thinness, especially when dealing with high temperatures. The unprotected CFS behaviour under fire is expected to have little strength compared to the hot-rolled steel. At present, CFS column subjected to standard fire has been done by few researchers. The study included the difference in shape and size of the column, differences in thickness, steel grade, column length, and restraint or unrestraint in thermal elongation. However, the larger size is more reliable to be used as the column but has never been tested in fire. The test for unrestrained thermal elongation columns is also unavailable. As such, the purpose of this study was to evaluate the structural behaviour of CFS columns under ambient and fire conditions. Based on these behaviours, the experimental findings were compared with the prediction from BS EN 1993-1-2: 2005 to evaluate the suitability of the code for CFS column fire design. In achieving the objectives, an investigation into fire resistance subjected to the ISO 834 fire standard was conducted on the CFS column. The variables involved were the CFS sections with various cross-section types and service loadings known as the degree of utilization. Three types of cross-sections, known as channel, back-to-back (BTB), and box-up (BU) sections, were studied. First, the column was preloaded at 30%, 50%, and 70% of its ultimate strength to simulate the real fire situation. Then, the column was exposed to the ISO 834 fire standard condition. The temperature at the column surface and the time were recorded until the CFS column failed. The temperature increase on the column surface were monitored using thermocouple Type K, and the analyses of these thermocouple readings were used to evaluate the mean temperature of the column. The results showed that the shape had no significant effects on the critical temperature of the CFS columns. The temperature behaviours of a BTB column for all degrees of utilization showed that the web had a lower temperature compared to the flange due to the greater thickness of the web. Meanwhile, the failure temperature of the CFS could reach up to 600ºC for 30% degree of utilization. The critical temperature and time for the column could be used in proposing a fire safety design rule for the CFS column. The modified design curve for the CFS column was also proposed. It is concluded that the BS EN 1993-1-2: 2005 could be used to evaluate the safe buckling load under fire by including a modification factor due to buckling behaviour for built-up and channel CFS columns.

ABSTRAK

Keluli terbentuk sejuk (CFS) adalah bahan yang popular dengan pelbagai kelebihan. Pengeluaran dan pemasangannya yang mudah memberikan pilihan kepada jurutera untuk mempercepatkan proses pembinaan. Walau bagaimanapun, CFS mudah melengkok, terutama ketika berada dalam suhu tinggi kerana sifatnya yang tipis. Tingkah laku CFS yang tanpa perlindungan di bawah api dijangka mempunyai kekuatan yang sedikit berbanding dengan keluli tergelek panas. Pada masa ini, kajian tiang CFS yang terdedah kepada kebakaran telah dilakukan oleh beberapa penyelidik. Kajian ini merangkumi bentuk dan saiz tiang yang berbeza, ketebalan yang berbeza, gred keluli, panjang tiang dan juga sekatan atau tiada sekatan dalam pemanjangan haba. Walau bagaimanapun, saiz lebih besar yang sesuai untuk digunakan sebagai tiang tetapi tidak pernah diuji dalam kebakaran. Ujian tiang tanpa sekatan pemanjangan haba masih tidak pernah dilakukan lagi. Tujuan kajian adalah untuk menilai tingkah laku struktur tiang CFS di bawah keadaan suhu persekitaran biasa dan kebakaran. Berdasarkan tingkah laku ini, dapatan eksperimen dibandingkan dengan ramalan daripada BS EN 1993-1-2: 2005 untuk menilai kesesuaian kod untuk mereka bentuk kebakaran tiang CFS. Untuk mencapai tujian ini, siasatan terhadap ketahanan api yang berdasarkan standard kebakaran ISO 834 dilakukan pada tiang CFS. Pemboleh ubah yang terlibat adalah CFS dengan pelbagai jenis keratan rentas dan beban perkhidmatan yang dikenali sebagai darjah penggunaan. Tiga jenis bentuk, yang dikenali sebagai channel, back-to-back (BTB), dan box-up (BU) telah dikaji. Tiang dimampatkan pada suhu persekitaran untuk mengenal pasti tingkah lakunya dan membandingkannya dengan kod reka bentuk. Untuk mensimulasikan keadaan kebakaran sebenar, tiang dibebankan pada 30%, 50%, dan 70% dari kekuatan maksimumnya. Kemudian tiang tersebut didedah kepada keadaan standard kebakaran ISO 834. Suhu di permukaan tiang dan masa kebakaran direkod sehingga tiang CFS gagal. Peningkatan suhu pada permukaan tiang dipantau dengan menggunakan termokopel Jenis K dan analisis bacaan termokopel ini digunakan untuk menilai suhu purata tiang. Hasil kajian menunjukkan bahawa bentuk tidak mempunyai pengaruh yang signifikan terhadap suhu kritikal tiang CFS. Tingkah laku suhu tiang BTB untuk semua darjah penggunaan menunjukkan bahawa web mempunyai suhu yang lebih rendah berbanding bebibir kerana ketebalan web yang lebih besar. Sementara itu, suhu kegagalan CFS dapat mencapai hingga 600ºC untuk darjah penggunaan 30%. Suhu dan masa kritikal untuk tiang dapat digunakan dalam cadangan kod reka bentuk keselamatan kebakaran untuk tiang CFS. Keluk reka bentuk yang diubah suai untuk tiang CFS juga dicadangkan. Disimpulkan bahawa BS EN 1993-1-2: 2005 boleh digunakan untuk menilai beban lengkuk yang selamat di dalam kebakaran dengan mengambil kira faktor pengubahsuaian disebabkan tingkah laku lengkuk tiang binaan dan channel CFS.

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LIST OF ABBREVIATIONS

BS EN	-	British Standard European Norm
BTB	-	Back - to - back
BU	-	Box-up
C	-	Channel
CFS	-	Cold Formed Steel
CUFSM	-	Cross-Section Elastic Buckling Analysis
DSM	-	Direct Strength Method
FEM	-	Finite Element Model
GB	-	Guobiao Standards
HRS	-	Hot Rolled Steel
ISO	-	International Organization for Standardization
UTM	-	Universal Testing Machine
LVDT	-	Linear Displacement Variable Transducer
TL	-	Thermocouple level

LIST OF SYMBOLS

f_y	-	Yield Stress
f_u	-	Ultimate Stress
f_{yb}	-	Basic Yield Stress
E	-	Elastic Modulus/ Modulus of elasticity/ Young's modulus
f_{pr}	-	Proportional limit stress
G	-	Shear modulus
μ	-	Degree of utilisation
LB	-	Local buckling
TB	-	Torsional buckling
DB	-	Distortional buckling
$G\text{-}F$	-	Global-flexural buckling
b_e	-	Effective width
B	-	Actual width
σ_{CR}	-	Critical stress to lead to local buckling
D	-	Web
L	-	Lipped
F	-	Flange
T	-	Thickness
A	-	Area
I_{yy}	-	Second Moment of Area on y-axis
I_{zz}	-	Second Moment of Area on z-axis
Z_{yy}	-	Modulus of Section on y-axis
Z_{zz}	-	Modulus of Section on z-axis
λ_y		Slenderness ratio on y-axis
Λz		Slenderness ratio on z-axis
X	-	Centroid
	-	Yield stress at high temperature
$f_{0.2,normal}$	-	Yield stress at ambient temperature
E_T	-	Elastic modulus at high temperature
E_{normal}	-	Elastic stress at ambient temperature

T	Temperature
$f_{p,_T}$	Proportional limit stress at high temperature
$f_{p,_{normal}}$	Proportional limit stress at ambient temperature
$f_{u,_T}$	Ultimate stress at high temperature
$f_{u,_{normal}}$	Ultimate stress at ambient temperature
$\varepsilon_{u,_T}$	Ultimate strain at high temperature
$\varepsilon_{u,_{normal}}$	Ultimate strain at ambient temperature
$N_{b,\ Rd}$	Buckling resistance at ambient temperature
$N_{fi,b,Rd}$	Buckling resistance at fire
$N_{cr,F}$	Buckling resistance due to flexural buckling
$N_{cr,T}$	Buckling resistance due to torsional buckling
C	Contraction
T	Time
H	Height
L	Length
Lcr	Critical length
$\Delta\theta_{a,t}$	Increase in temperature
Δt	Increase in time
k_{sh}	Correction factor or shadow effect
A_m/V	Section factor
A_m	Surface area
V	Volume of member perunit length
C_a	Specific heat of steel
$h_{net,d}$	Net heat flux per unit area
α_c	Convection coefficent
θ_g	Gas tempearture
θ_m	Steel surface temperature
Φ	View factor
ε_f	Emissivity of fire
ε_m	Emissivity of member
θ_r	Radiation temperature
ρ_a	Unit mass

$\theta_{a,cr}$	Critical temperature
μ	Degree of utilisation
P	Steel perimeter exposed to fire
A	Steel area
A_{eff}	Effective steel area
χ_{fi}	buckling reduction factors at fire
α	imperfection factors
$\bar{\lambda}$	non-dimensional slenderness ratio at ambient
$\bar{\lambda}_{\theta}$	non-dimensional slenderness ratio at fire
λ_F	non-dimensional slenderness ratio due to flexural buckling
λ_T	non-dimensional slenderness ratio due to torsional buckling
$k_{y,\theta}$	Yield stregth reduction factor
$k_{E,\theta}$	Elastic modulus reduction factor

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CHAPTER 1

INTRODUCTION

1.1 Overview Background

Fire accident in building and infrastructures is considered as one of the most serious, terrible and dangerous environmental hazards. It contributes to disastrous personal human injuries, devastating damage, loss of life, and production and capital losses. Fire and Rescue Department of Malaysia has reported that the increase in fire is very significant when a total of 36,043 fire calls were recorded in year 2018 compared to 28,853 calls in 2017 (Malaymail, 2019). Table 1.1 shows that there 5,449 fire cases reported by the Fire and Rescue Department of Malaysia (KPKT 2019). Housing related cases contributed the highest number at 2209 cases followed by shops and factories at 469 and 288, respectively.

The trend of building fire cases in Malaysia is at higher number more than 5000 cases over the year 2013 to 2019 as shown in Figure 1.1 (Statistic KPKT 2019). This data has increased from 3447 cases in year 2007 (Salleh and Ahmad, 2009). Beitel and Iwankiw (2008) conducted a historical survey on the multi-story building which collapses due to fire accident. Based on their study, 22 cases of fire induce collapse was categorised according to structural materials. There are seven cases involving concrete collapse, six from structural steel, five from brick/masonry, two cases from an unknown material, and two cases from wood.

Table 1.1 Building fire cases in Malaysia in 2017 (Statistic KPKT 2019)

Type of Building	**Total**
Shop	469
Factory	288
Warehouse	27
Store	343
Workshop	96
Hotel	36
Shopping Centre	17
Office	99
Public Hall	10
Cinema	0
Entertainment Club/Pub/Bar	5
Restaurant	88
Terrace House	863
Flat House	257
Apartment/Condominium	234
Squatters	116
Long/Traditional House	125
Mosque/Surau	26
Temple	23
Kitchen	443
Laboratory	7
Public Higher Education Institution	7
Privet Higher Education Institution	2
Government Primary School	29
Privet Primary Scholl	2
Government Secondary School	32
Privet Secondary Scholl	2
Government Pre-school/Kindergarten	9
Privet Pre-school/Kindergarten	5
School Hostel	13
Workers' Hostel	58
Public Hospital/Clinic	23
Privet Hospital/Clinic	7
Shop House	110
Residential House	1,341
Church	1
Livestock Estate	11
Budget Hotel/ Premise	4
Hotel/Homestay	16
Others	205
Total	5,449

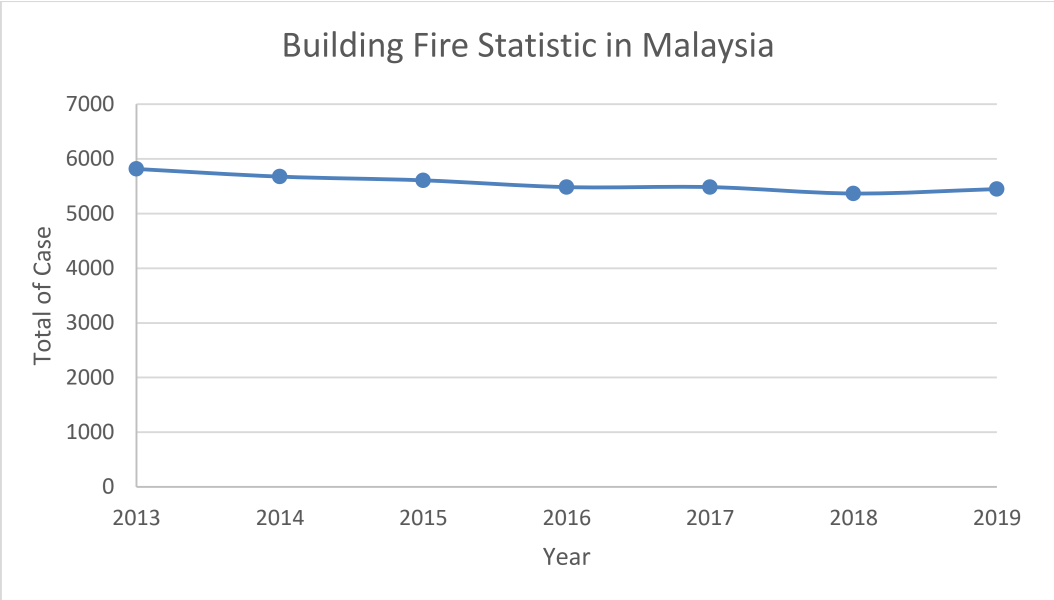


Figure 1.1 Building fire cases statistics in Malaysia for 2012–2019 (Statistic KPKT)

In construction activity and modern building design, the use of economical materials and construction project methods is a major concern to fulfill client demands. Cold-formed steel (CFS) as known as steel-based material has been applied significantly as load-bearing structural section in several building constructions. CFS which is popular due to its comparable strength, lightweight component, high resistance on corrosion, and ease fabrication and handling has been selected in the modern building structural element. In order to meet the fire safety design requirements, CFS must perform well in terms of its integrity and stability for a particular period during a fire incident. This assessment is important to give enough time for occupants to evacuate the building and firefighters to contain the fire. This is also important to minimise losses and reduce repair and rehabilitation costs after the fire. During a fire incident, a firefighter has to re-evaluate the tactical time frames when dealing with lightweight steel-framed buildings. Other structural materials usually provide 20 minutes fire resistance. Additionally, CFS with a lightweight section offers slightly or no warning on cracking and failure or moaning sounds as in timber structure (Karl, 2006). It was reported that the structural bearing members made of lightweight CFS elements failed at one time due to thinner thickness (Karl, 2006). Figure 1.2 shows the remaining of a lightweight steel frame after fire exposure.

Figure 1.2 Remaining of a lightweight steel frame after a fire (Karl K. Thompson, 2006).

1.1.1 Cold-formed Steel (CFS) Member

CFS as load-bearing structures could fail due to buckling, residual stress due to press breaking and cold forming, geometrical imperfection due to element slenderness or thin thickness, and low fire stiffness. A CFS section is usually an open section that is prone to failure in several buckling modes under compression due to unsymmetrical section geometry. Georgieva et.al (2012a) reported that CFS strength is not only determined by its cross-sectional geometry but also determined by connection type (intermediate and at the ends), overall buckling length effect and interconnection quality. A high concentration force on a very thin section due to large bolt forces may also cause premature failure. Besides that, the elongation of bolt holes will lead to bearing failure.

Under the fire conditions, CFS is a temperature-dependent material where it loses its strength more rapidly compared to hot-rolled steel (HRS). A review by Kolarkar (2010) shows that the HRS remains its full strength up to 400°C and beyond that, it decreases steeply. CFS loses its strength 10% to 20% more than HRS and it starts at 150°C, as shown in Figure 1.3. On the other hand, the thickness is an important element when dealing with CFS as local buckling is a critical issue due to the thin element of the CFS section. A research conducted by Nirosha (2010) and Jingjie *et al.* (2020) found that, during a fire, the CFS beam failed due variety of buckling, similar to the situation at the ambient temperature. Several researchers conducted material strength behaviour study of CFS subjected to elevated temperature and produced a complete model of material strength based on several parameters, such as steel grades and thickness. However, the research data are still in debated. Hence, it is required to evaluate the actual material properties of CFS at high temperature.

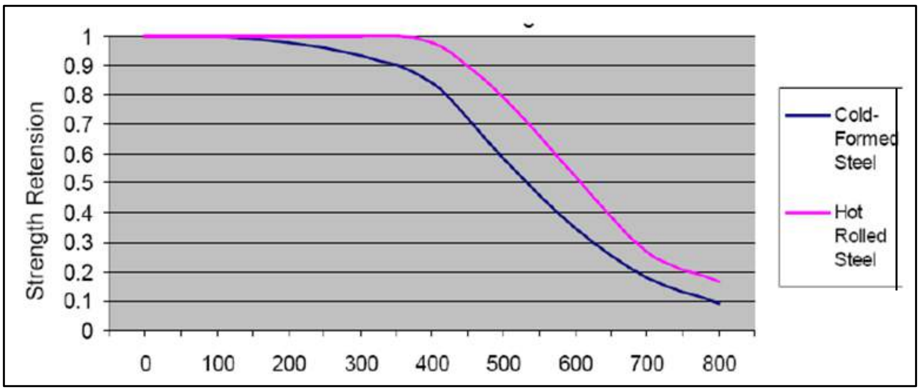


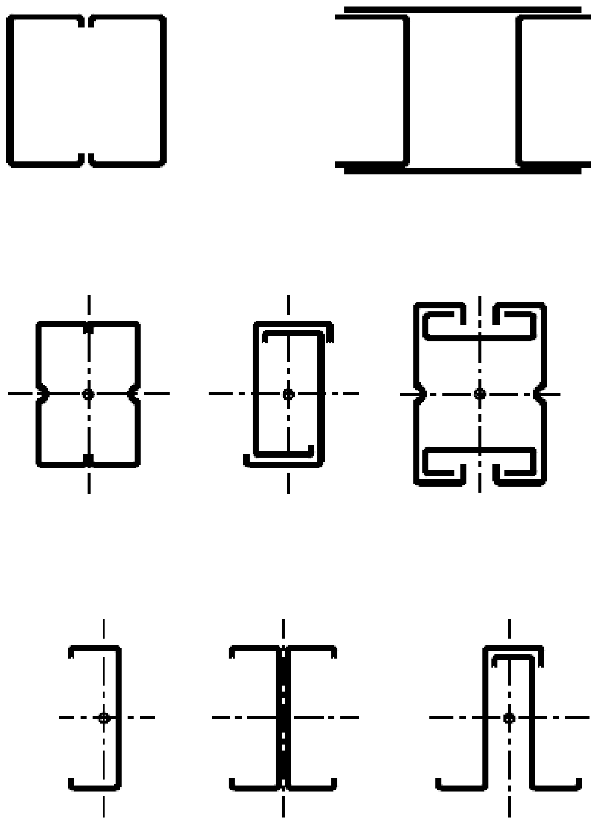
Figure 1.3 Strength of steel relative to yield strength at elevated temperature (Kolarkar, 2010)

CFS has been widely used as wall framing system. Starting in the year of 2002, the study of CFS compression member at elevated temperature are done to identify a fire behaviour of the wall. (Ranawaka & Mahendran, 2009b; Chen & Young, 2007a; Feng *et al*, 2004; Feng *et al.*, 2003a; Feng *et al*, 2003b; Feng *et al*, 2003c; and Kaitila, 2002). Basically, the studies were conducted to evaluate the behavior of CFS under compression subjected to elevated temperature. After the behavior of CFS at elevated temperature is well understood, the wall made up with CFS and fire resistance material were tested to evaluate its behavior. On the other hand, a test for cold-formed stainless steel column was conducted by a few researchers, namely Ng and Gardner (2007), To and Young (2008), Hassanein (2010), Uppfeldt *et al.*,(2008), and Gardner and Ng (2006). The results generally showed that stainless steel had a higher stiffness retention factor compared to hot rolled steel (HRS). However, it is well known that stainless steel has a higher material cost than HRS. The price of stainless steel and HRS as reported in April 2014 by the World Steel Prices (2014) was 2778 USD and 713 USD per-tonne, respectively. To solve this issue, CFS can be proposed to be used as column for developing the low-rise buildings (up to two-storey). Up to date, the study of CFS column under fire condition become significant due to popularity of application as column structure. Therefore, the fire performance of the CFS column can be studied to improve fire safety issue.

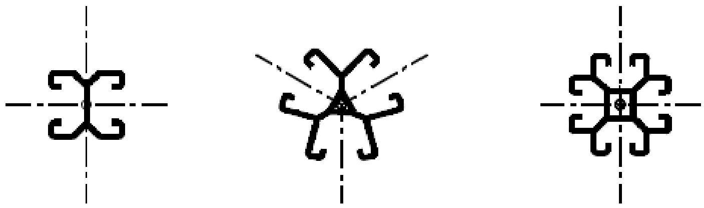
Fire resistance greatly depends on massivity (shape factor), shape and size of the cross-section, load level, and buckling length. The performance criterion of steel columns with a load-bearing function needs to meet the stability criteria (Wardenier, 2001). In designing a bare steel column, the determination of the critical temperature column failure and thermal response of the column is vital. Both criteria are considered for the column, which is exposed to fire distributed along the column length.

1.1.2 Built-up Cold-formed Steel (CFS) Member

A built-up CFS section is usually recognised as a combination or composition of normal CFS sections such as C (cee), Z (zee), Ɛ (sigma), hat, or angle section to create an innovation and new section. The new section is linked and jointed by using self-drilling screws, self-tapping screws, bolts and nuts, or weld. Figure 1.4 shows a variety of the built-up CFS section that used for structural or non-structural components or utilised for compression and tension members



a) Close built-up CFS section



b) Open built-up CFS section.

Figure 1.4 Example of types of built-up CFS for compression and tension members

The advantages of the built-up CFS section are numerous and can be organised into two categories, namely strength and stability (mechanical strength) and production and handling. Table 1.2 shows the advantages of built-up CFS.

Table 1.2 Advantages of built-up CFS section

No	Production and Handling	Mechanical Strength
1.	Easy to produce (fasten bolt, screw, or weld the standard shape (C, Z) without building a special production method for a complex shape).	Higher stability capacity (the double section has greater cross-section properties).
2.	Erection and formation of CFS structure are more rapid and without using heavy lifting machines or equipment (appropriately equipped for two-storey building or an emergency temporary house).	The symmetric section can eliminate eccentricity between gravity and shear centre that removed a certain buckling failure effect (out-of-plane movement and distortional buckling).
3.	Composed CFS members are relatively cheap alternatives to a single section. If not laterally supported, a single section easily fails in overall buckling, hence, built-up is the best solution (Georgieva *et al.*, 2012a).	Closed sections or box sections permit spanning longer distances between the supports condition and able to sustain the heavier loads rather than single C-sections (Reyes & Guzmán, 2011).
4.	CFS has proper corrosion protection using zinc and zinc alloy hot-dip galvanised coatings. It can tolerate and resist the physical requirements produced during fabrication, production, distribution, storage, installation and also transportation of steel-framing members (Technical Note on Cold-Formed Steel Construction, 2011).	

1.1.3 Built-up Cold-formed Steel (CFS) Column

The built-up CFS column is favourable and has been recognised and utilised due to its excellent structural behaviour. In modern building construction, the use of the CFS column as a frame structure in residential construction is applied for buildings that are up to two-storey as show in Figure 1.5. For the double C-section, the I-section arrangement is used to strengthen the external frame columns whereas the hollow section arrangement is used to support the long beam.

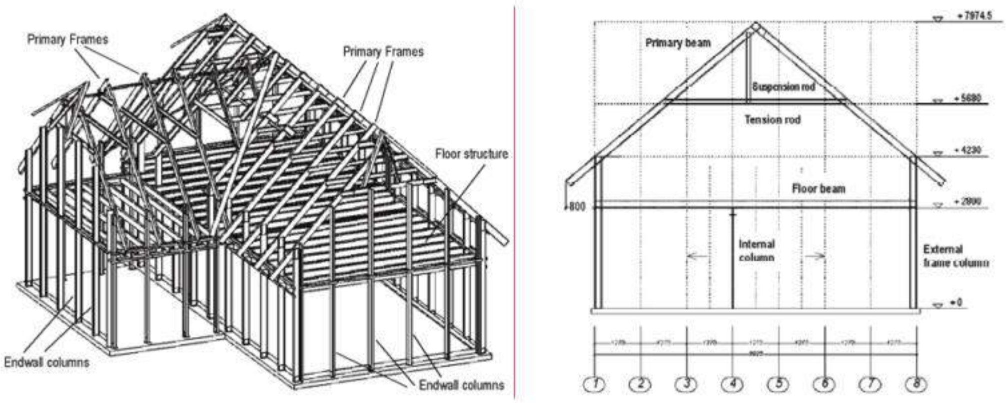


Figure 1.5 Residential house building frame (Dunai, 2007)

The study on the built-up CFS section using a variety of connection methods has been done invoving screw, bolt and nut, and weld connection. Most of built-up columns are test at ambient temperature. Stone and LaBoube (2005) experimented the built-up CFS section with the built-up CFS I-section proposed the stud by using self-drilling screws with two numbers which were spaced at a set of intervals. Mei *et at.*, (2009) tested the built-up CFS section by using two lipped C-sections with the dimension of the web, 100 mm, and thickness of 1.6 mm as a compression member connected by using a self-drilling screw which is recognised as back-to-back (BTB) section. Dunai (2007) did an experimental activity on built-up CFS with the shape of a box-up (BU) column fastened using a self-drilling screw located at the flange and the size of the C-section that used in the study is 150 mm × 200 mm. Next, Li e*t al.*, (2010) tested the CFS BU section produced by C-section with a depth of 100 mm and connected by using a self-drilling screw. Young and Chen (2008) established the built-up CFS with jointing the C-section with intermediate stiffeners using self-tapping screws at the flange and categorising as a closed section and lastly did a compression test.

Meanwhile, for column test under fire was conducted by Laím *et al*. (2020). They using a self-drilling screw to form a built-up CFS Sigma section with intermediate stiffener. Jingjie *et al*. (2020) produced built-up CFS column using 150 mm channel section and steel sheet connected using self-drilling screw. Craveiro, *et al.*, (2014) and Craveiro *et al.*, (2016) was conducted built-up using 150 mm CFS channel column using self-drilled screw.

The study of CFS column connected using weld also available. The column were test at ambient. Whittle and Ramseyer (2009) developed and tested a CFS BU section with fastened using weld to CFS C-section with a thickness of 4.76 mm. The weld was connected at the bottom and top sections with the length welds of 50.8 mm and also at intermediate positions with the length welds of 25.4 mm along with the member. Reyes and Guzmán (2011) used seam welds with different weld spacings to form a BU member. Piyawat *et al.*, (2012) proposed the built-up CFS with connecting by stitch welding and tested the BU members. While Besevic and Kukaras (2011) implemented the study of mechanical behaviour on built-up CFS by connecting two lipped C-sections with point welding for the compression test purpose.

There is only one research studied welded column test under fire. Pires (2021) used continues weld along the length of to form build-up box a 2 m column. It was expose to ISO fire.

1.2 Problem Statements

The applications of built-up shapes, such as in a composing member has attracted the attention of light-steel frame designers to widen CFS applications to larger structures. Besides, the built-up shape has several advantages in terms of its production, handling, and mechanical strength, which can affect the total cost of a project. It is also suitable for the fast construction of low-rise buildings (up to two-storey). However, the fire resistance of CFS is a critical issue because it is susceptible to having a low stiffness level when exposed to fire.

In observation, the CFS column with various size and connection were used to form a built-up column. The investigation of the CFS column composed of large sizes of channel section to act as a column has been done by Dunai (2007). All studies on the built-up CFS column was conducted under ambient temperature to determine the structural behaviour and mechanical strength. From literature, it was explained that the end condition of the column is caused shearing occur at the column end. Therefore identification of support end are required since variety of end condition are used in previous research. Since the channel CFS section size used by (Dunai, 2007) are unavailable in Malaysia market. Hence, the size of channel section that produce in Malaysia were used in this study. The choice of steel grade and dimension are based on available CFS product in Malaysia. For the large size of the 200 mm CFS channel section, a specified steel grade of G450 is available. The thickness of 1.9 mm and 200 mm is similar to the Dunia (2007) found to be appropriate for 1 to 2-story houses.

In present, CFS column subjected to standard fire has been done by few researchers. The study was including the different in shape and size of column, different in thickness, steel grade, column length and also restraint or unrestraint in thermal elongation. The simplest section to make a built-up section is channel section, which may be produce as Back-to back (BTB) or Box-up (BU) section connected by using self-drilling screw. The study conducted by Craveiro, *et al.*, (2014) and Craveiro *et al.*, (2016) was limited to channel size of 150 mm, S280 grade of steel. The column was restraint in thermal elongation. However, the larger size is more reliable to be used as column has never been tested in fire. The test for unrestrained thermal elongation column is also unavailable. To understand the behaviour of unrestrained thermal elongation for large column size in fire, further study on fire conditions can be done to evaluate the response of this column's fire behaviour, which can be used in future fire safety design.

At present the guideline of CFS structure under high temperatures is according to the BS EN 1993-1-2 (2005) which is based on hot-rolled steel design. It has to be designed as Class 4 (slender) cross-section with reduction factors for material properties same as hot-rolled steel material with the limiting temperature is

350°C. Figure 1.6 shows the critical temperature from carbon steel recommended in BS EN 1993-1-2 (2005). The strength of CFS at high temperature is a function of material strength properties at ambient that multiply with material reduction factors due to high temperature. At present Kankanamge and Mahendran (2011) and Chen and Young (2007b) were done material test at high temperature for steel grade G450 and 1.9 mm. The results was found differences. Hence, it is required to evaluate the actual material properties of CFS at high temperatures and compare them with the existing study. Based on the behavior of CFS at ambient and fire conditions, the finding can be used to evaluate the suitability of guidelines for CFS structure under high temperatures according to the BS EN 1993-1-2 (2005).

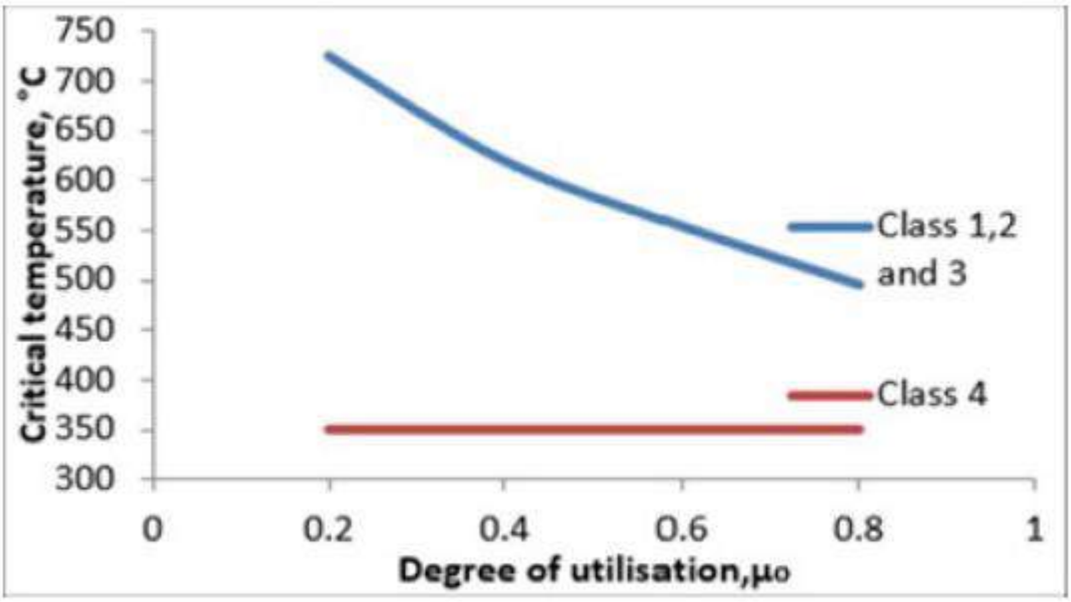


Figure 1.6 The critical temperature with a degree of utilisation from carbon steel recommended in BS EN 1993-1-2: 2005

Evaluation of critical time and temperature of the CFS column were relevant in the present situation since design guideline for this type of structure is still unclear. Currently, the critical temperature for Class 4 section is 350°C. However, few research data found that this value is conservative. The evaluation of critical temperature based on degree utilisation for CFS subjected to ISO 834 can be studied to justify of produce new curve specifically for CFS.

1.3 Research Objectives

The aim of this research is to investigate the fire behaviour of CFS under compression when subjected to fire. To achieve it, the following objectives are set out:

1. To determine the structural behaviour of CFS column under ambient temperature.
2. To determine the temperature behavior of CFS column under compression when subjected to fire.
3. To formulate the structural behavior and temperature behavior of CFS column under compression based on Eurocode.

1.4 Scope of the Study

The scope of this research is limited to experimental of unprotected CFS channel and built-up section only. The CFS used is Grade 450 and dimension of 200 mm depth and 1.9 mm thickness. The support condition was semi-rigid. The compression tested at the ambient condition of the channel and built-up columns were conducted to get the actual axial deformation and cross-section deformation at mid-height only. Various length of members were also tested. The experiments on the CFS channel and built-up CFS column subjected to fire were conducted to identify the actual axial deformation with time and monitor the temperature rises at the steel surface column when exposed to standard fire. The failure modes of the column were observed. The formula of the mechanical properties of the CFS channel and built-up CFS columns were established and used as a guide.

The applied axial concentric load is at a load level of 30%, 50%, and 70% of the ultimate load of channel and built-up CFS column and calculated based on BS EN 1993-1-2 (2005). A parametric study will be selected based on the important factors that are influencing the fire performance of the column, i.e. load level during fire exposure, shape, and size of the column. This study focused on axially loaded columns subjected to ISO 834 (ISO,2014) standard fire exposure.

1.5 Significance of Research

Throughout this research, four significant point of research are described for ensuring the research is classified as an essential topic to study. Firstly, to encourage the use of the cold-formed steel (CFS) as a building material in the construction of housing, small and medium industries building which is capable to reduce the material, production, and maintenance cost. Housing provision with a reasonable cost is categorised as crucial as government responsibilities for all countries in the world. The housing provision by the government is to ensure that social-economic stability and also to promote fair and equitable national development. Therefore, the government has introduced the low or medium cost housing categories in order to help the people in the country to obtain the first home with affordable price and in good quality material and structure. By referring to CFS, the material has great strength due to high strength-to-weight ratio and stiffness, and classified as non-combustible material, has resistance to corrosion problem, and categorised as highly sustainable material which can be recycle and little maintenance. Lastly, to addressed certain requirements that need to be fulfilled by the contractors such as the material able to withstand under fire to a certain limit, less maintenance due to corrosion or termite attack, and more than 10 years' service limit. An affordable housing development is extremely important for millions of people throughout the world. When individuals and families have access to stable and quality affordable housing, they can become part of a diverse community, find and keep jobs, lead healthier lives and take better care of their children.

Secondly, the significance of the research is based on the need the improved fire safety for CFS that is always considered as a critical issue for insurance in Malaysia. Normally, the insurance in construction is divided into two categories, insurance that helped to protect buildings under construction and insurance to protected the property damage when the owners already inhibit the house. The insurance is proposed to protect the house or building from damage due to fire, lightning, explosions, etc. Fire is classified as an important issue in housing and building and all materials that are used as structural components needed sufficient fire-resistant to avoid fire from spreading and results in huge damage to the structure. The insurance is protecting the building or house which in the first place is stable, strong, and stiff structure before being exposed to risk hazard especially fire. Thus, the fire safety design which used CFS must be improved to ensure the insurance companies are willing to offer insurance for the building or house built base on CFS.

Furthermore, fast construction can be done with safety fire hazard. According to specific geographical and economic conditions, the materials for building and construction activities chosen must not be kept away from limited resources, the inevitable rise in the cost, and a long period of production. These issues have increased the tendency to utilise CFS for fast construction and without using high technologies, high energy consumption, and skilled workers. Besides, the use of CFS in building as shown as a lightweight material is an appropriate solution to utilise CFS in high-risk fire hazards areas and high-risk seismic zones rather than traditional material.

Finally, the significant of the research is to promote sustainability and green construction. The construction that uses CFS material offers eco-friendly process and better-performing buildings. The construction procedures with CFS can greatly limit waste and other ecological burdens from end to end.

1.6 Thesis Content

The contents of this thesis are divided into 6 chapters. This chapter highlighted the background of the research, problem statements, objectives and significance of the research. In Chapter 2 an extensive literature review of behaviour of CFS built-up column, material properties at high temperature, and experimental investigations are presented. The detailed research methodology employed in this research is discussed in Chapter 3. It includes material properties test at ambient temperature and high temperature, preparation, and testing of samples at ambient and fire condition. The result of experimental investigations at ambient temperature is presented in Chapter 4. It includes the results on material properties, the results of CFS built-up columns. The results of experimental investigations at fire temperature is presented in Chapter 5. It includes the results on material properties high temperature and fire resistance tests of CFS built-up columns. The fire resistance results were classified into temperature development results and axial deformation. A comparison of CFS built-up column with BS EN 1993-1-2 was also presented. After that a fire model of CFS built-up column based on experimental results is proposed. A summary, conclusion of the entire work, and the recommendations for future study are presented in Chapter 6.

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1. **Muftah, F.**, Mohd Sani, M. S. H., & Mohammad, S. (2019). Eects of Cross-Section Type and Degree of Utilization on Failure Time and Temperature of Cold-Formed Steel Column under ISO Fire. *Metals 9 (9), pp 1-16.* (Scopus & WOS Q2 IF: 2.351)

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