A SYSTEMATIC REVIEW: EXPERIMENTAL AND NUMERICAL STUDIES ON THE MECHANICAL PROPERTIES OF CFS SECTION AT ELEVATED TEMPERATURE AND AFTER COOLING DOWN

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by

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Dalam beberapa tahun kebelakangan ini, keselamatan kebakaran bangunan keluli terbentuk sejuk telah mendapat perhatian lebih banyak dan anggota keluli terbentuk sejuk telah memperluas penggunaannya di bangunan kediaman, komersial dan perindustrian. Ianya penting untuk menjalankan tinjauan sifat-sifat mekanikal keluli terbentuk sejuk pada suhu tinggi dan setelah sejuk. Kajian ini bertujuan untuk melakukan tinjauan literatur sistematik untuk mengenal pasti jurang dalam pengetahuan semasa mengenai sifat-sifat mekanikal keluli yang dibentuk sejuk ketika mengalami proses peningkatan suhu dan penyejukan, menjadikannya lebih berguna untuk pengamal dan penyelidik. Terdapat empat fasa protokol tinjauan literatur sistematik, iaitu merumuskan pertanyaan tinjauan, menentukan strategi mencari, menentukan pengekstrakan data dan menentukan sintesis data. Objektif kajian ini adalah untuk meninjau penyiasatan eksperimen dan berangka yang telah dilakukan dalam memeriksa sifat-sifat mekanikal bahagian keluli terbentuk sejuk pada suhu tinggi dan setelah menyejukkan. Tinjauan ini juga membincangkan pengaruh suhu tinggi dan penyejukan terhadap sifat-sifat mekanikal anggota keluli terbentuk sejuk. Berdasarkan penemuan yang diperhatikan dari penyelidikan eksperimental, ujian keadaan tetap adalah pendekatan yang paling popular sekarang digunakan untuk sifat mekanik keluli pada suhu tinggi sementara untuk penyelidikan berangka, persamaan ramalan biasanya disajikan dalam kajian berangka untuk menentukan sifat mekanikal keluli terbentuk sejuk. Kemudian, oleh kerana keupayaan tinggi untuk menangani masalah bukan linear, ABAQUS lebih baik untuk penyelidikan berangka. Menurut penemuan, didapati bahawa gred keluli terbentuk sejuk yang berbeza dan bahagian keluli terbentuk sejuk yang berbeza mempengaruhi sifat mekanikal keluli terbentuk sejuk seperti kekuatan hasil, kekuatan tertinggi, modulus elastik dan kemuluran pada suhu yang berbeza.

ABSTRACT

In recent years, the fire safety of cold-formed steel (CFS) buildings has gained more attention and cold-formed steel (CFS) members have expanded their use in residential, commercial and industrial buildings. It is important to review the mechanical properties of the cold-formed steel at elevated temperature and after cooling down. This study is purposely to conduct a systematic literature review to identify gaps in current knowledge of mechanical properties of cold-formed steel when subjected to elevated temperature and cooling down process, making it more usable for both practitioners and researchers. There are four phase of systematic literature review protocol, i.e., formulate review question, define searching strategy, define data extraction and define data synthesis. The objective of this study is to examine experimental and numerical investigations conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down. It also discusses the influence of elevated temperatures and cooling down on mechanical properties of cold-formed steel (CFS) section. Based on the finding observed from experimental investigation, steady-state test is the most popular approach now employed for the mechanical properties of steels at elevated temperature while for numerical investigations, predictive equations are commonly presented in numerical studies to determine the mechanical properties of cold-formed steel (CFS). Then, due to the high capacity to handle non-linear issues, ABAQUS was preferably for numerical investigation. According to findings, it has been found that different type of CFS grade and different type of CFS section affect the mechanical properties of CFS such as yield strength, ultimate strength, elastic modulus and ductility at different temperature.

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LIST OF ABBREVIATIONS

CFS	Cold-formed steel
SLR	Systematic literature review
RO	Review objective
RQ	Review question
USM	Universiti Sains Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background

Steel has become a preferred structural material in the construction industry due to its many benefits over other construction materials. The steel used in a building is divided into two types, namely hot-rolled steel and cold-formed steel. The various advantages of cold-formed steel are gaining popularity in the fields of research and construction, particularly in developing countries. As a structural element, cold-formed steel is utilized in constructing low-rise residential buildings, transmission towers, and industrial buildings. It is also used in the building of bridges, storage, and drainage systems. Cold-formed steel components are commonly used as a supplementary structural element in building construction. However, due to its inherent characteristics such as higher weight to strength ratio, non-combustibility, adaptability, and ease of processing, the use of cold-formed steel in buildings has recently increased. It is also a reasonable choice for engineers, contractors, and property owners due to its good structural performance and profitability. Cold-formed steel is formed by either press-braking or cold roll-forming to achieve the desired shape.

Steel's structural performance is affected by its chemical composition and manufacturing process. The behaviour of structural components such as steel sheets and plates is Important, and features such as output and strength of the tensile, fatigue strength, stress-strain characteristics, elasticity modulus, tangent and shear modulus, elongated capacity, durability and resistance, all need to be addressed in order to ensure appropriate utilisation (Billah et al., 2019). Each of the structural component behaviour has its different importance; for example, yield strength refers to the structural strength of cold-formed steel members. Next, when a cold-formed steel section is subjected to

flexure and compression, tensile strength is less critical since yield stress and buckling stress is considered to be more important. Steel's ductility is an important property, particularly in structural applications. It is the condition of a material in which it can sustain plastic deformation without being ruptured.

The elastic modulus, yield strength, and ultimate strength are the most common material properties parameters, and their values are obtained using the following rules. The initial slope of the stress-strain curves is used to determine the elastic modulus. The yield strength is the lowest yield point of yield point elongation for sharp-yielding stress-strain curves and 0.2% proof strength for gradual-yielding stress-strain curves. Furthermore, the highest stress point of the stress-strain curves is the ultimate strength. Figure 1.1 shows the definitions of ambient and elevated temperature mechanical properties such as yield strength (0.2% proof stress), stress at 2% total strain, 0.05% proof stress, Young's modulus, ultimate strength, ultimate strain and fracture strain.

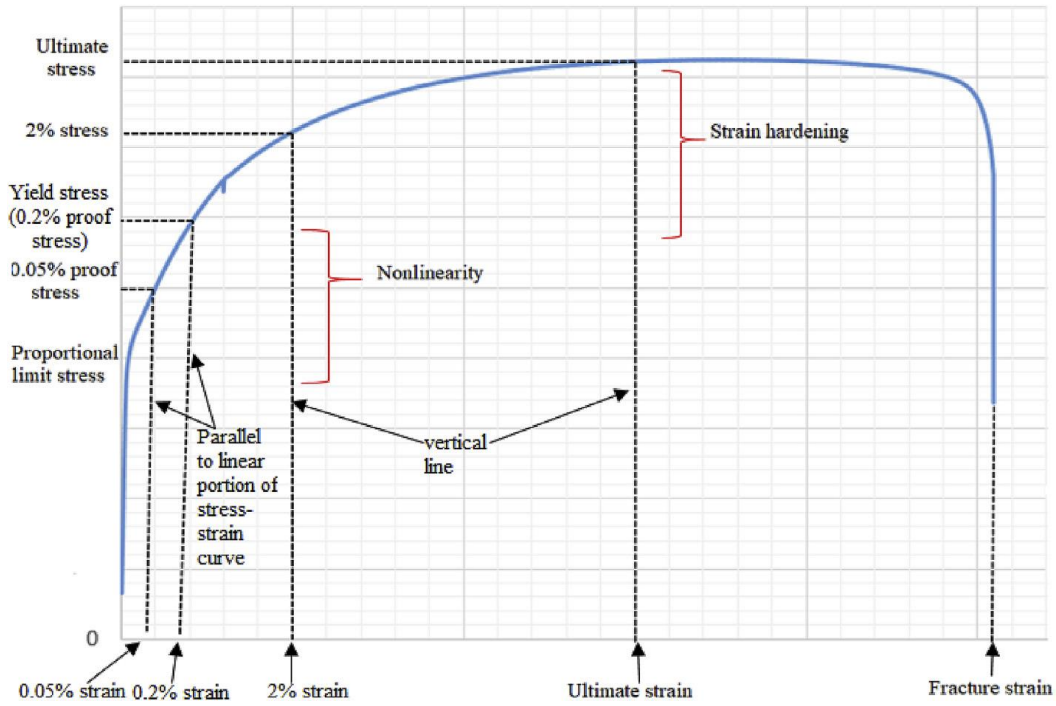

Figure 1.1: Definitions of mechanical properties (Source: Rokilan & Mahendran, 2020)

Material properties play an important role in structural steel members' performance. Hence, knowing the mechanical properties of structural steel members is important for design purposes (Chen & Young, 2005). The mechanical behaviour of structural steel elements, especially for hot-rolled steel, at ambient temperature conditions has been well documented and incorporated in current design codes, however, this is not the case for cold-formed steel and when cold-formed steel is exposed to fire (Maraveas, 2019). It is important to review the mechanical properties of the cold-formed steel at elevated temperature and after cooling down. This study is purposely to conduct a systematic literature review to identify gaps in current knowledge of mechanical properties of cold-formed steel when subjected to elevated temperature and cooling down process.

1.2 Review questions

The aim of this study is to answer the following review questions:

RQ1. What are the mechanical properties of cold-formed steel (CFS) sections without fire?

RQ2. How the experimental investigations have been conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down?

RQ3. How the numerical investigations have been conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down?

RQ4. How elevated temperatures and cooling down process influence the mechanical properties of the cold-formed steel (CFS) sections?

1.3 Objectives of the systematic review

The objectives of this study are as follows:

RO1. To examine experimental and numerical investigations conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down.

RO2. To examine the influence of elevated temperatures and cooling down on mechanical properties of cold-formed steel (CFS) section.

1.4 Scope of the systematic review

The state of the art of experimental and numerical studies on the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down are examined using a systematic review. A systematic review will go through four phases of systematic literature review (SLR) protocol. Systematic literature review (SLR) protocol is about the protocol that specifies all the procedure that will be followed during the review process.

The first phase is to formulate the review questions. The review questions were developed based on review topics. The main purpose is to compile all works from previous studies related to mechanical properties of cold-formed steel (CFS) at elevated temperature and after cooling down process. Define searching strategy is the second phase. This phase starts with identifying the main keywords from the review questions and review objectives to perform searching research articles. The searching strategy will go through identification, screening and eligibility processes.

The next phase is to conduct data extraction. Data extraction is the process of reading the full text of each article identified for inclusion in the review and extract the

pertinent data using a standardised data extraction form/table. Perform data synthesis is the last phase. This is the process of bringing together data from a set of review articles with the aim of drawing conclusions about a body of evidence.

1.5 Significance of the systematic review

The anticipated outcome of this project will be a systematic review of the experimental studies and numerical studies conducted on cold-formed steel (CFS) section in terms of mechanical properties at two different conditions, i.e., elevated temperature and after cooling down. This can clarify the attention on the fire safety of cold-formed steel (CFS) in recent time due to increasing usage of cold-formed steel members in residential, commercial and industrial buildings.

CHAPTER 2

SYSTEMATIC LITERATURE REVIEW (SLR): A METHODOLOGY

2.1 Introduction

The methods used in this thesis are discussed in this chapter focuses on the experimental and numerical studies on the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down. The research methodology is built out in such a way that the review questions could be answered and to achieve the review objectives of this thesis.

For this study, there are two main objectives that need to be achieved. Firstly, the objective is to examine the experimental and numerical investigations conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down. Secondly, the objective is to examine the influence of elevated temperatures and cooling down on mechanical properties of cold-formed steel (CFS) section. A systematic literature review (SLR) is utilised to achieve thesis objectives. The systematic literature review will identify the gaps in current knowledge of the mechanical properties of CFS when subjected to elevated temperature and cooling down process.

2.2 Planning of SLR

The main objective of the proposed research methodology was to examine and analyse current existing knowledge and ideas in the experimental and numerical studies on the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down. Towards this purpose, a SLR referred to as a systematic review or review shall be carried out. A systematic review is a well-defined and methodological way to classify, analyse and synthesise the available evidence for a

specific technology in order to clarify the current direction and status of research or to provide background information on research challenges (BA & Charters, 2007).

In this section, the SLR review protocol is defined and subsequently, the steps to identify the current literature on the experimental and numerical studies on the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down are utilised.

2.3 Review protocol

The development of the protocol is an important step in the systematic literature review process as shown in Figure 2.1. The protocol sets out all the measures and procedures used by researchers during the study to neutralise author bias and reduce the danger of validity. A significant element which differentiates SLR from conventional literature reviews is the review protocol.

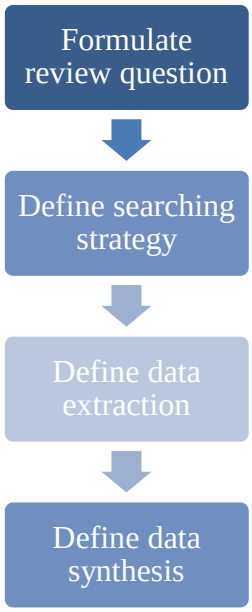

Figure 2.1: SLR protocol

The protocol begins with formulating the review questions, followed by the definition of the searching strategy procedure to be followed. The inclusion and exclusion criteria are then formed to provide a systematic method of selection between

specified primary studies. Subsequently, the data elements extracted from the primary studies are established to help address research questions. And finally, the qualitative method is used to analyse.

2.3.1 Formulation of review questions

The aim at review questions (RQ) that relevant not only for researchers but also for practitioners. The following are review questions (RQ) that have been formulated:

RQ1. What are the mechanical properties of cold-formed steel (CFS) sections without fire?

RQ2. How the experimental investigations have been conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down?

RQ3. How the numerical investigations have been conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down?

RQ4. How elevated temperatures and cooling down process influence the mechanical properties of the cold-formed steel (CFS) sections?

A systematic review is focused on a pre-defined specific review topic and objectives. It is advisable to perform some scoping searches in a database to check for any reviews of the topic and determine if it is an original one. The review questions can then be formulated from there.

RQ1 is formulated by the need to explain the mechanical properties of cold-formed steel (CFS) sections without fire, i.e., elastic modulus, yield stress, ultimate stress and ductility. Next, RQ2 is purposely to compile and classify the experimental investigations conducted in examining the mechanical properties of cold-formed steel

(CFS) sections at elevated temperatures and after cooling down. The steady-state and transient-state tests are the most popular methods for examining the mechanical properties of steels at elevated temperatures (Nie et al., 2020).

Then, similar to RQ2, RQ3 also to compile and classify the numerical investigations conducted in examining the mechanical properties of cold-formed steel (CFS) sections at elevated temperatures and after cooling down. For example, a series of mechanical properties prediction equations for the entire family of steels used in CFS structures has been proposed. Lastly, RQ4 is purposely to clarify the influence of elevated temperature and cooling down process on mechanical properties of cold-formed steel (CFS). During a compartment fire, steel structures typically go through heating and cooling stages, with the heating stage of steel corresponding to the growth and fully formed phases of a compartment fire and the cooling stage of steel corresponding to the decay phase of a compartment fire (Chen et al., 2020).

2.3.2 Systematic searching strategies

This phase consist of a strategy for searching and distribution of the scholarly sources (relevant documents). The search strategy helps establish the required search string and classify the correct databases to collect the relevant documents. Three sub-processes of systematic searching strategies are identification, screening and eligibility.

Identification is the first sub-process to search for synonyms, similar terms and variations of the keywords. It aims to include more options for the selected database to search for more relevant research articles. The appropriate keywords are first identified from the review topic, review objectives and review questions. Subsequently, the identified keyword need to enrich based on the online thesaurus, the keywords used in

past research, the keywords suggested by selected databases and the keywords recommended by the experts.

In this review work, the main keywords identified from the review objectives and review questions are enriched and shown in Table 2.1.

Table 2.1: Results of identification process

Section	Main Keywords	Enriched Keywords
RO1: To examine experimental and numerical investigations conducted in examining the mechanical properties of CFS sections at elevated temperatures and after cooling down	Experimental investigations Numerical investigations Examining Mechanical properties Cold-formed steel Elevated temperature Cooling down	- - Investigate, inspect Yield strength, ultimate strength, modulus of elasticity, ductility - High temperature, fire Low temperature
RO2: To examine the influence of elevated temperatures and cooling down on mechanical properties of CFS section	Influence Elevated temperature Cooling down Mechanical properties Cold-formed steel	Impact, effect, repercussion, consequence High temperature, fire Low temperature Yield strength, ultimate strength, modulus of elasticity, ductility -
RQ1: What are the mechanical properties of CFS sections without fire?	Mechanical properties Cold-formed steel Without Fire	Yield strength, ultimate strength, modulus of elasticity, ductility - Unescorted, absence High temperature, heat

RQ2: How the experimental investigations have been conducted in examining the mechanical properties of CFS sections at elevated temperatures and after cooling down?	Experimental investigations Examining Mechanical properties Cold-formed steel Elevated temperature Cooling down	- Investigate, inspect Yield strength, ultimate strength, modulus of elasticity, ductility - High temperature, fire Low temperature
RQ3: How the numerical investigations have been conducted in examining the mechanical properties of CFS sections at elevated temperatures and after cooling down?	Numerical investigations Examining Mechanical properties Cold-formed steel Elevated temperature Cooling down	- Investigate, inspect Yield strength, ultimate strength, modulus of elasticity, ductility - High temperature, fire Low temperature
RQ4: How elevated temperatures and cooling down process influence the mechanical properties of the CFS sections?	Elevated temperature Cooling down Influence Mechanical properties Cold-formed steel	High temperature, fire Low temperature Impact, effect, repercussion, consequence Yield strength, ultimate strength, modulus of elasticity, ductility -

The searching process was run on selected leading and supporting databases based on main and enriched keywords either by using advanced searching techniques which is by using Boolean operator, phrase searching, truncation, wild card, and field code functions separately, or by combining these searching techniques into a complete searching string. The search strings that have been created are then 'paste' in the selected databases which are leading database on Scopus and supporting database on Science Direct to search for relevant articles.

Science Direct is an online database of published scientific research and an online academic citation index run by the publisher Elsevier, while Scopus is an international database of peer-reviewed publications from all over the world (Mengist et al., 2020). Table 2.2 shows the full search string develop in this review work and was used selected database for the review objectives and review questions. The searching process in the leading and supporting databases have resulted in a total of 972 articles and after remove the duplicate between these two databases, the number of article become 548.

Table 2.2: Full search string used in selected databases (Scopus and Science Direct)

Section	Database	
	Scopus	Science Direct
Review Objective 1	TITLE-ABS-KEY (("experimental investigations") AND ("numerical investigations") AND ("examining" OR "investigate" OR "inspect") AND ("mechanical properties" OR "yield strength" OR "ultimate strength" OR "modulus elasticity" OR "ductility") AND ("cold-formed steel") AND ("elevated temperature" OR "high temperature" OR "fire") AND ("cooling down" OR "low temperature"))	("experimental investigations") AND ("numerical investigations") AND ("examining") AND ("mechanical properties") AND ("cold-formed steel") AND ("elevated temperature" OR "fire") AND ("cooling down")
Review Objective 2	TITLE-ABS-KEY (("influence" OR "impact" OR "effect" OR "repercussion" OR "consequence") AND ("elevated temperature" OR "high temperature" OR "fire") AND ("cooling down" OR "low temperature") AND ("mechanical properties" OR "yield strength" OR "ultimate strength" OR "modulus elasticity" OR "ductility") AND ("cold-formed steel"))	("influence" OR "effect") AND ("elevated temperature" OR "fire") AND ("cooling down" OR "low temperature") AND ("mechanical properties") AND ("cold-formed steel")
Review Question 1	TITLE-ABS-KEY (("mechanical properties" OR "yield strength" OR "ultimate strength" OR "modulus elasticity" OR "ductility") AND	("mechanical properties" OR "yield strength" OR "ultimate strength" OR "modulus elasticity" OR "ductility") AND

	("cold-formed steel") AND ("without" OR "unescorted" OR "absence") AND ("fire" OR "high temperature" OR "heat"))	("cold-formed steel") AND ("without") AND ("fire")
Review Question 2	TITLE-ABS-KEY (("experimental investigations") AND ("examining" OR "investigate" OR "inspect") AND ("mechanical properties" OR "yield strength" OR "ultimate strength" OR "modulus elasticity" OR "ductility") AND ("cold-formed steel") AND ("elevated temperature" OR "high temperature" OR "fire") AND ("cooling down" OR "low temperature"))	("experimental investigations") AND ("examining") AND ("mechanical properties") AND ("cold-formed steel") AND ("elevated temperature" OR "fire") AND ("cooling down")
Review Question 3	TITLE-ABS-KEY (("numerical investigations") AND ("examining" OR "investigate" OR "inspect") AND ("mechanical properties" OR "yield strength" OR "ultimate strength" OR "modulus elasticity" OR "ductility") AND ("cold-formed steel") AND ("elevated temperature" OR "high temperature" OR "fire") AND ("cooling down" OR "low temperature"))	("numerical investigations") AND ("examining") AND ("mechanical properties") AND ("cold-formed steel") AND ("elevated temperature" OR "fire") AND ("cooling down")
Review Question 4	TITLE-ABS-KEY (("elevated temperature" OR "high temperature" OR "fire") AND ("cooling down" OR "low temperature") AND ("influence" OR "impact" OR "effect" OR "repercussion" OR "consequence") AND ("mechanical properties" OR "yield strength" OR "ultimate strength" OR "modulus elasticity" OR "ductility") AND ("cold-formed steel"))	("elevated temperature" OR "fire") AND ("cooling down" OR "low temperature") AND ("influence" OR "effect) AND ("mechanical properties") AND ("cold-formed steel")

Screening is the second sub-process in the systematic searching strategy process, which sets out the inclusion and exclusion criteria for the articles to be evaluated. All the articles listed need to be screened based on inclusion and exclusion criteria. This scan

can be done automatically from the sorting feature available in the selected databases. Some of the basic requirements considered for inclusion and exclusion are timelines, publication types and language.

Regarding the timeline, since it is almost impossible for researchers to review all of the currently published papers, (Okoli, 2015) proposed that researchers could assess the range of timelines they should review. On the other hand, (Higgins & Green, 2020) in the Cochrane Handbook claimed that timeline publication limitations should only be activated if it is understood that similar studies may only have been published during a given period. In addition, only articles with empirical evidence and published in journals, research articles, or review articles are included to ensure the quality of the analysis. Besides, only papers written in English and Bahasa Malaysia are included in the study to prevent misinterpretation of the content. Table 2.3 shows the inclusion and exclusion criteria set in this review work. This process had excluded 31 articles as they did not fit the inclusion criteria and the remaining 517 articles were used for the eligibility process.

Table 2.3: Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Timeline	2005-2021	Before 2005
Publication Type	Journal, Research article, Review article, Books, Conference proceeding, Chapter in Book	Newspaper
Language	English, Bahasa Malaysia	Other than English and Bahasa Malaysia

Eligibility is the third sub-process in which the retrieved articles were examined manually to ensure that all the remaining articles are aligned with the criteria after the screening process. This can be achieved by reading the title and abstract of the papers. If

there is still no clear understanding of the relevance of the articles listed for the review, the content of the articles needs to be reviewed. This process excluded 487 articles due to the main content of article that not related to the mechanical properties of cold-formed steel (CFS). Most of the excluded article related to the buckling analysis, fire performance, seismic performance, finite element analysis, bending behaviour and flexural behaviour. Overall, there were 30 selected articles to be reviewed.

2.3.3 Data extraction and synthesis

Once all the articles have been listed to be included in the systematic review, the next step would be to extract and analyse the data found in those articles. Many methods used for data extraction and synthesis frameworks have been discussed in the literature, but the most commonly used are non-meta-analysis as qualitative analysis and meta-analysis as quantitative analysis. A summary of the findings tables will be generated for a non-meta-analysis. Meanwhile, a meta-analysis involves data pooling and advanced statistical analysis.

Another main issue in data extraction and synthesis is that, with the latest creation of machine learning models, electronic text searches can now be carried out, which provide valuable help in finding information within an article (Higgins et al., 2019). Despite recent advances in machine learning models for automating data extraction in systematic reviews, data extraction is still largely a manual process.

2.4 Reporting the SLR

All processes carried out must be reported at this phase. All the number of articles retrieved from identification to screening and, lastly, in eligibility, should be recorded appropriately. The number of articles retrieved is recorded using the PRISMA flow diagram, as shown in Figure 2.2.

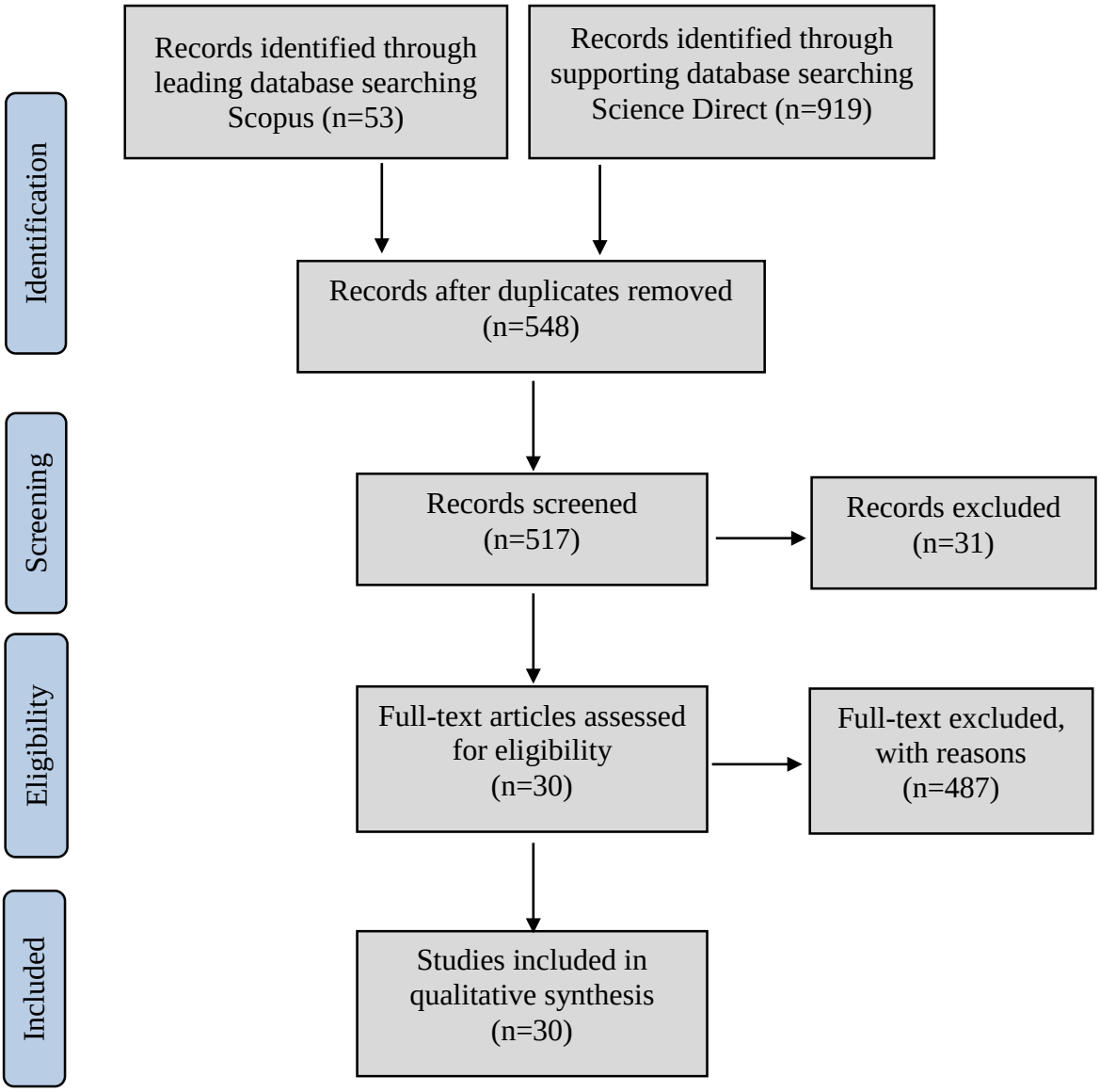

Figure 2.2: Flow diagram of the retrieved articles

2.5 Summary

After conducting the phase of define searching strategy, there are 30 retrieved articles will used for the next phase due to the main content that are related to the mechanical properties of CFS at elevated temperature and after cooling down. This 30 articles will be used on define data extraction and define data synthesis.

CHAPTER 3

DATA EXTRACTION AND DATA SYNTHESIS: A METHODOLOGY

3.1 Introduction

The extraction and synthesis phases include classifying and analysing the relevant information from the selected articles. The data extraction procedure entailed identifying and extracting relevant information from the selected articles. The analysis and synthesis phase comprised examining the synthesised data, extracting useful information, and drawing conclusions from the selected articles.

In order to meet the objective of the SLR, The variable was sorted based on the basic characteristics of the articles and the primary criteria used for evaluation. The papers' general information include the years of publication, the type and scope of the study, and the country or area in which the study was performed. The data relevant to each selected article was extracted and entered into an Excel spreadsheet for processing. The categorisation stage involved the categorization and processing of the obtained data in order to prepare it for further study, with the final result displayed using charts and other types of graphs.

At the analysis and synthesis phase, the questions formulated for the review work are to be answered. It includes a qualitative overview of the findings, a discussion, and an indication of the way forward for future research work and a conclusion. The data from the final list of selected papers can be summarised in a descriptive form.

3.2 Data extraction

Data extraction is the process of bring out the relevant data (information) from the selected scholarly sources and saved in one single format. Usually, the process involves reading the full text of each article selected for inclusion in the analysis and bring out the relevant data using a standardised data extraction form/table. The development of the data extraction form or table should be based on the review objectives and the review questions formulated in the first step of the SLR. In this review work, data extracted from the selected articles are divided into two, i.e., descriptive data and analytical data. Table 3.1 and Table 3.2 summarised descriptive data and analytical data, respectively, extracted from the retrieved articles.

The extraction of qualitative evidence is usually an iterative procedure. Review authors can switch between reading primary articles, data extraction, and synthesis/interpretation in several cycles, as key themes and questions emerge from the synthesis (Noyes & Lewin, 2011).

Table 3.1: Table of descriptive data

No	Title and Author	Year of Publication	Types of Publication	Country	Research Objectives	Research Questions	Research Scope	Brief Description
1	Mechanical Properties of Steels for Cold-Formed Steel Structures at Elevated Temperatures (Zhen Nie, Yuanqi Li and Yehua Wang)	2020	Hindawi Advances in Civil Engineering	China	To determine the mechanical properties of steels (S350, S420 and G500) for CFS structures at elevated temperatures.	RQ2, RQ3 and RQ4	S350 and S420 steel and proposed stress relieving annealed steels G500 for CFS structures with thickness of 1.0mm and 1.2mm	50 tensile tests were carried out by steady-state test method for temperatures ranging from 20°C to 700°C.
2	Post-fire mechanical properties of advanced high strength cold-formed steel alloys (Xia Yan, Yu Xia, Hannah B. Blum and Thomas Gernay)	2021	Thin-Walled Structures	USA	To determine the post-fire mechanical properties of advanced high-strength cold-formed steels of the dual phase steel and martensitic steel types with nominal yield stress up to 700MPa and 1200MPa	RQ2, RQ3 and RQ4	Advanced high-strength steel (AHSS)	Tensile specimens made of two dual-phase steels and two martensitic steels with nominal yield stress from 340MPa to 1200MPa were tested after exposure to temperatures up to 700°C.

No	Title and Author	Year of Publication	Types of Publication	Country	Research Objectives	Research Questions	Research Scope	Brief Description
3	Experimental Investigation of Post-fire Mechanical Properties of Q345 and G550 Cold-Formed Steel (Wei Chen, Jihong Ye, Jixian Peng, and Bin Liu)	2019	Journal of Materials in Civil Engineering	China	To determine mechanical properties of Q345 and G550 CFS after cooling down from the elevated temperatures	RQ2, RQ3 and RQ4	Q345 and G550 CFS with thicknesses ranging from 0.75 mm to 1.9 mm	Q345 CFS (with nominal thicknesses of 1.9 mm, 1.5 mm, and 1.0 mm) and G550 CFS (with nominal thicknesses of 1.0 mm and 0.75 mm)
4	Elevated temperature mechanical properties of cold-rolled steel sheets and cold-formed steel sections (M. Rokilan and M. Mahendran)	2020	Journal of Constructional Steel Research	Australia	To determine the mechanical properties of cold-rolled steel sheets, cold-formed steel (CFS) channel sections and floor decks at elevated temperature	RQ1, RQ2, RQ3 and RQ4	0.8 mm and 1.0 mm low strength (G300) and 0.55 mm, 0.75 mm and 0.95 mm high strength (G550) cold-rolled steel sheets 0.75 mm and 1.2 mm high strength (G550) CFS lipped channel sections and 0.75 mm and 1.0 mm high strength (G550) CFS floor decks	Low and high strength cold-rolled steel sheets and high strength CFS lipped channel sections and floor decks were tested in the temperature range of 20°C - 700°C under isothermal conditions

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5	Experimental investigation of post-fire mechanical properties of Q235 cold-formed steel (Chong Ren, Liusi Dai, Yuner Huang and Wenfu He)	2020	Thin-Walled Structures	China	To obtain post-fire mechanical properties of Q235 cold-formed steel channel section	RQ2, RQ3 and RQ4	The specimens are of grade Q235, with section thicknesses of 1 mm and 2 mm	The test specimens were cut from flat portion and corners of cold-formed channel sections, which were exposed to temperatures ranging from ambient temperature to 800°C, and then cooled with water and air
6	High-temperature material degradation of Q345 cold-formed steel during full-range compartment fires (Wei Chen, Jihong Ye, Lei Jin, Jian Jiang, Kun Liu, Meng Zhang, Wenwen Chen, and Hua Zhang)	2020	Journal of Constructional Steel Research	China	To reveal the degradation law of Q345 CFS during the rising and falling temperature periods	RQ2, RQ3 and RQ4	The test materials were Q345 CFS studs and the nominal thicknesses of 1.0 mm	The test specimens were taken longitudinally at the flat part of stud flange and web without considering the corner part. The surface has the zinc coating as the protective layer with a single-sided average thickness of approximately 0.02 mm. Maximum temperature is 500°C and the first load testing temperature is 300°C

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7	High-temperature steady-state experiments on G550 cold-formed steel during heating and cooling stages (Wei Chen, Kun Liu a, Jihong Ye, Jian Jiang, Changzheng Xu, Lei Jin and Meng Zhang)	2020	Thin-Walled Structures	China	To investigated the material properties on G550 CFS during the heating and cooling stages	RQ2, RQ3 and RQ4	G550 CFS, with a nominal thickness of 1.0 mm and a nominal yield stress of 550MPa	G550 CFS studs with a nominal thickness of 1.0 mm. All of the test specimens were cut from the flat part of the stud web and flange in the longitudinal direction
8	Sensitivity of resistance of cold-formed steel tubular columns to elevated temperature mechanical properties (M. Imran, M. Mahendran and P. Keerthan)	2018	Applications of Fire Engineering (Conference Paper)	Australia	To emphasize the importance of elevated temperature mechanical properties in the fire design of cold-formed steel tubular members	RQ2, RQ3 and RQ4	Tensile coupons extracted from Grade 350 Square Hollow Sections (SHS), Rectangular Hollow Sections (RHS) and Circular Hollow Sections (CHS) were tested	The tensile coupons extracted from SHS and RHS were not straightened in the longitudinal direction. The coupons extracted from CHS sections had a curvature in the transverse direction due to their section radius

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9	Mechanical properties and creep strain of Q355 cold-formed steel at elevated temperature (Xuhong Zhou, Jingjie Yang, Weiyong Wang, Lei Xu and Yu Shi)	2021	Journal of Constructional Steel Research	China	To investigate the mechanical properties and thermal creep of Q355 cold-formed steel (CFS) through tests	RQ2, RQ3 and RQ4	Q355 CFS with a thickness of 3 mm	Study on the thermal creep of Q355 CFS with a thickness of 3 mm was conducted to overcome this knowledge gap
10	Mechanical properties of hot-rolled and cold-formed steels after exposure to elevated temperature: A review (Yujie Yu, Lifeng Lan, Faxing Ding and Liping Wang)	2019	Construction and Building Materials	China	To determine the mechanical properties of hot-rolled and cold-formed steels after exposure to elevated temperature	RQ4	The post-fire properties of cold-formed steels are also discussed here. Available post-fire test data for different cold-formed steels are sorted, and a summary introduction is given.	Test data on the residual properties of different kinds of structural steels after exposure to elevated temperatures were collected. Post-fire residual property discussions address normal strength steel, high strength steel and cold-formed steels

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11	Mechanical properties of YSt-310 cold-formed steel hollow sections at elevated temperatures (Tekcham Gishan Singh and Konjengbam Darunkumar Singh)	2019	Journal of Constructional Steel Research	India	To determine the mechanical properties of YSt-310 cold-formed steel hollow sections under steady state elevated temperatures	RQ1, RQ2, RQ3 and RQ4	Two SHSs and a RHS, namely 50 mm × 50 mm × 2.9 mm, 60 mm × 60 mm × 2.6 mm and 80 mm × 40mm × 2.6 mm were considered	Experimental investigation into the mechanical properties of YSt-310 cold-formed steel hollow sections, under steady state elevated temperatures ranging from approximately ambient to 800°C
12	Post-fire mechanical properties of YSt-310 cold-formed steel tubular sections (Tekcham Gishan Singh and Konjengbam Darunkumar Singh)	2019	Journal of Constructional Steel Research	India	To study the post-fire mechanical properties of YSt-310cold-formed steel	RQ2, RQ3 and RQ4	One square (SHS) 50 mm × 50mm × 2.9 mm and two rectangular tubular/hollow sections (RHS), 66 mm × 33mm × 2.6 mm and 60 mm × 40 mm × 2.9 mm are considered	The flat coupon specimens extracted from the flat regions of YSt-310cold-formed steel sections were exposed to nine preselected elevated temperatures ranging from 300°C –800°C