Ministry of Higher Education
and Scientific Research
University of Diyala
College of Engineering

Post-fire Behaviour of Stainless Steel Single Shear Bolted Connections

A Thesis Submitted to the Council of College of Engineering University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

By

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2022 A.D **IRAQ** **1444 A.H**

بِسْمِ اللَّـهِ الرَّحْمَـٰنِ الرَّحِيم

لَقَدْ أَرْسَلْنَا رُسُلَنَا بِالْبَيِّنَاتِ وَأَنزَلْنَا مَعَهُمُ
الْكِتَابَ وَالْمِيزَانَ لِيَقُومَ النَّاسُ بِالْقِسْطِ
وَأَنزَلْنَا الْحَدِيدَ فِيهِ بَأْسٌ شَدِيدٌ وَمَنَافِعُ لِلنَّاسِ
وَلِيَعْلَمَ اللَّهُ مَن يَنصُرُهُ وَرُسُلَهُ بِالْغَيْبِ ۚ إِنَّ
اللَّهَ قَوِيٌّ عَزِيزٌ

صدق الله العليّ العظيم

سورة الحديد - 25

Supervisor Certification

I certify that the thesis entitled "**Post-fire Behaviour of Stainless Steel Single Shear Bolted Connections"** presented by "**Salah Ganem Abbas**" was prepared under my supervision in Civil Engineering Department, University of Diyala, in partial Fulfillment of the Requirement for the Degree of Master of Science in Civil Engineering.

Signature:

Supervisor: **Asst. Prof. Dr. Mohammed Shihab Mahmood**

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We certify that we have read the thesis entitled **"Post-fire Behaviour of Stainless Steel Single Shear Bolted Connections"** and we have examined the student **"Salah Ganem Abbas"** in its content and what is related with it, and in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

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Date: / /2022

Dedication

I dedicate the fruit of my effort with a lot of love

- To the one who gave me life and had a shadow, help and support

(my dear father)

- To the one with whom I saw my life and drew my strength

(my dear mother)

- To whom was my shadow and strength at the time of my weakness to the beautiful butterfly

(my wife)

- To Whoever was a third hand and a bond all the time

(my children)

- To the companion of the path and the fragrance of friendship

(my friend)

Acknowledgements

I thank God Almighty who made my last supplications to be done by saying Alhamdulillah, Lord of the worlds.

I extend my thanks **Dr. Mohammed Shihab Mahmood** for taking on the task of scientific management of my thesis and for the effort and fatigue the gave me for the sake of scientific supervision throughout the research phase.

I extend my gratitude to all the teaching staff in the Department of Civil Engineering at the University of Diyala. I would also like to thank the construction laboratory staff for their support in completing this work. Thanks and appreciation to all the people that supported and helped me achieve this work.

And last but not least, I thank everyone who extended a helping hand to me from near or far, and every supplication that called for me in the back of the unseen, bless them all and may God reward them on my behalf.

Salah Ganem Abbas

Abstract

Post-fire Behaviour of Stainless Steel Single Shear Bolted Connections

By

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Asst. Prof. Mohmmed Shihab Mahmood, PhD

Stainless steel is used in many fields, including buildings, for its many advantages, including its resistance to corrosion, long life, high durability, low maintenance, and reuse. The high temperature affects the mechanical properties of stainless steel, and the joints are considered one of the most vulnerable parts in case the building is exposed to a fire risk. Therefore, there is a need to understand the behaviour of single shear bolt connections after exposure to high temperatures. This study deals with the effect of high temperatures on the mechanical properties of thin sheets of stainless steel and their behaviour in bolt connections after exposure to fire. The specimens were heated to high temperatures (600°C, 800°C and 1000°C) and cooled by air or water to simulate fire conditions and at different heating times (30, 60, 90 and 120) minutes. Coupons were used to find the mechanical properties (yield stress, ultimate stress, modulus of elasticity and elongation ratio) and specimens were used to find (ultimate load, failure type, axial displacement and curling displacement). The test results showed that after exposure to high temperatures there is a decrease in thickness. The yield stress improved for coupons of 2mm thicknesses when heating at a temperature of (600°C, 800°C and 1000°C) by 37%, 29% and 4%, and 31%, 22% and 10%, after the 120 min for the air-cooling and water-cooling, respectively, coupons of 4 mm thick that heated to (600 and 1000°C) were not affected and remained close to the reference coupon. The

elongation ratio of the 2mm and 4mm coupons increased when the heating temperature was increased to 1000°C. The failure of the curling had no significant effect on the ultimate load of the specimens. The effect of heating was limited on the specimens at a temperature of 600°C and 800°C. It became clear at a temperature of 1000°C, where the decrease was 15% and 10% for the specimen 2 mm, 12% and 8% for the specimen 4 mm specimen when cooling with air and water, respectively, at a heating time of 120 minutes. The strength of water-cooled specimens did not show significant difference from that of air-cooled specimens. The AISC approach for estimating the strength of the connection was lower than the experimental data.

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List of Symbols

Symbol	Definition
F_y	The yield stress of the coupon.
F_{yt}	The yield stress of the coupon after post fire.
F_u	The ultimate stress of the coupon.
F_{ut}	The ultimate stress of the coupon after post fire.
t	Thickness of plate.
t_t	Thickness of plate after post fire.
P_y	The yield load of the specimen.
P_{yt}	The yield load of the specimen after post fire.
P_u	The ultimate load of specimens.
P_{ut}	The ultimate load of specimens after post fire.
P_c	The initial load curling displacement.
P_{ut}	The net tensile fracture strength
P_{ys}	The net shear yielding strength
P_{yb}	The net bending yielding strength
A_{nt}	The net tensile fracture area
A_{ns}	The net shear yielding area
A_{nb}	The net bending yielding area
P_{usc}	The ultimate strength of the connection.
P_{uexp}	The ultimate strength for experimental

CHAPTER ONE

INTRODUCTION

1.1 Background

Stainless steel's durability and aesthetic appeal have inspired architects and designers for over 100 years and first introduced in 1912–1913 by (Brearley in the UK and Maurer and Strauss in Germany). Ernest Stuart, a cutlery manager, popularised the term stainless steel is currently used as a generic term to indicate corrosion-resistant iron alloys containing at least 10.5% chromium (Gardner, 2005). Stainless steel usage in buildings has recently increased because of its resistance to corrosion, high durability, low maintenance needs, and it is long life. The long life and low maintenance of stainless steel over its lifespan cover its high cost, as well as the aesthetic advantages of architecture. Stainless steel has been utilized in construction since the early twentieth century. It was used for decorations and construction coverings. The usage of stainless steel as a structural element thereafter became highly widespread. It was also utilized in historical structures because of its superior structural performance, beauty, corrosion resistance, and durability (Baddoo, 2008). The most popular grade is the austenitic grade 1.4301 (AISI 304), containing 18% chromium and 8% nickel. This grade has excellent corrosion resistance and is highly ductile. In the construction domain, this grade is available in the following forms: sheet, plate, welded mesh, bar, and sections. More specific alloy additions enhance the corrosion resistance. Because stainless steel is more cost than its carbon steel equivalent, there aren't many instances of it being utilized in buildings for reasons like higher strength, higher ductility, or better retention of strength and stiffness at high temperatures. For example, in the construction domain, stainless steel was mainly used as cladding (inside or outside), thanks to its aesthetic expression. The Francois Mitterand Library in Paris, where stainless steel mesh was used for the interior ceiling, the Torre Caja in Madrid covered with patterned stainless steel cladding, the New Justice Palace in Anvers characterized by a shiny stainless steel roofing, the cable-stayed construction of Hong Kong's Stonecutters Bridge, where stainless steel was utilized for the outer shell of the bridge towers' top parts, the Science City structure in Paris, the Metro Station Sainte-Catherine structure in Brussels, the Saint-Pierre station structure in Ghent, the Luxembourg Chamber of Commerce composite floors, the Parliament House structure in Helsinki, and the Cala Galdana bridge structure. (Rossi, 2014).

1.2 Types of Connections in Steel Structures.

Bolted joints are commonly employed in steel buildings for several reasons. They provide rapid and simple structural element assembly and transmit bending, shear, and axial stresses (Kulak et al., 2001). High-strength structural bolts transfer loads from beams to columns in a bolted connection, helping structural stability and integrity and withstanding thermal and mechanical stresses from a fire (Wang et al., 2010). Steel connections are one of the most important structural components as a result, having proper connections may result in good structural performance. Furthermore, any failure in the connections might risk the overall structure, ultimately leading to its collapse (Ketabdari et al., 2019).

1.2.1 Bolted Connections

Bolts are essential components for the detachable assembly of components in construction. Bolts apply the needed axial or preload forces to the components. The axial load or preload of a bolt must be carefully regulated to guarantee the safety and dependability of structures. Insufficient or excessive preload is a common cause of bolt joint failure (Wang et al., 2013). Bolts carry loads from beams to columns in bolted connections, thus enhancing the structural system's stability and safety by carrying both thermal and mechanical stresses (Pang et al., 2019). Connections are significant because their reaction may affect the linked member's structural behaviour and the overall system (Quan et al., 2022). Bolts may be standard or high-strength and typically made of A307 low-carbon steel with a minimum tensile strength of 60 ksi. In addition, bolts having a minimum tensile strength of 120 ksi for bolts up to 1 in diameter are typical of Grade A325 heat-treated medium-carbon steel (Williams, 2011), as shown in Figure (1-1).

Figure (1-1) Bolts connections .(Williams, 2011)

1.2.2 Welded Joints

Welded connection; welding is a fabrication process whereby two or more parts are fused together using heat, pressure, or both forming a join when the parts cool it can transfer loads from member to the other, as shown in Figure (1-2). Welds are classified into two types: groove welds and fillet welds. In general, fillet welds account for around 80% of all welds in building structures, whereas butt welds account for 15%. The structural design of welds is based on the assumption that welds have homogenous qualities, that residual stresses and stress concentrations in the welds are small, and that the connecting components are solid with minimum deformations. This indicates that the stress distribution in welding is uniform. The ductility of the material causes the transfer of stressors from residual stresses to stress concentrations, resulting in an overall reduction in stress. Fillet welds are often favoured over butt seams because they need less equipment, operator expertise, and item preparation. Butt welds, on the other hand, need a little more effort and planning (Manson, 2006).

Figure (1-2) Welded connections . (Manson, 2006)

1.3 The Difference between Carbon Steel and Stainless Steel

The high cost is one of the most important differences between stainless steel and carbon steel due to its chemical composition, where the percentage of carbon is less than 8%, 18% chromium, and 8% nickel in stainless steel, according to ASTM 240. This increases its corrosion resistance. The difference in mechanical properties is the carbon steel has a yield point while stainless steel does not have a yield point where the yield stress is known as stress causing permanent stress at 0.2 percent, as shown in Figure (1-3) (Williams, 2011). Because of the appearance of stainless steel, it is used to cover the facades of buildings.

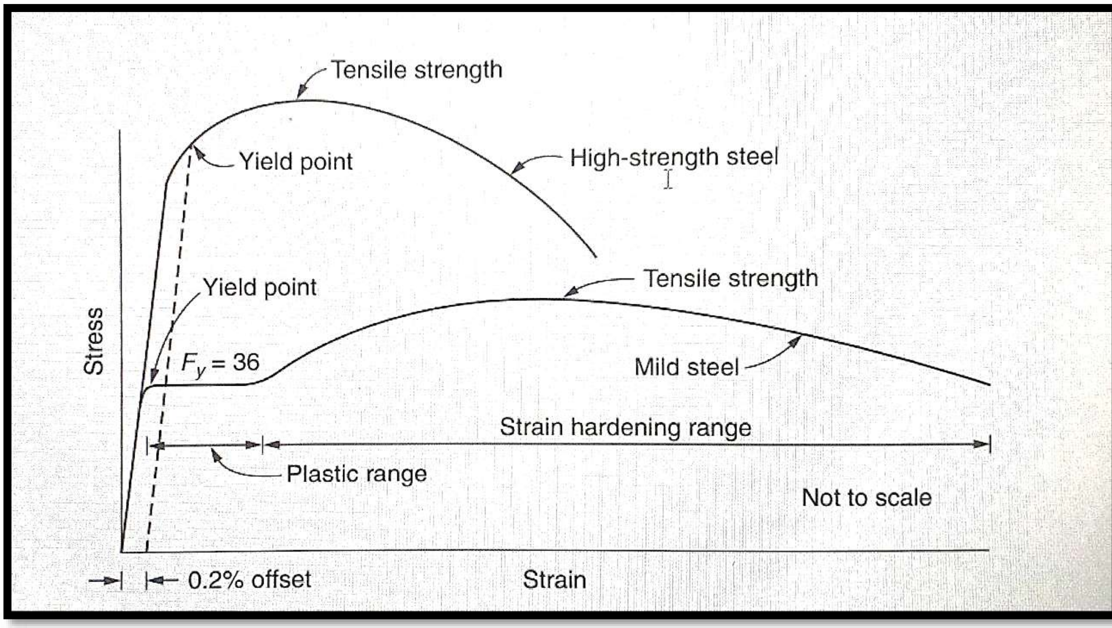

Figure (1-3) Stress-strain curves for steel. (Williams, 2011)

1.4 Failure Types in Bolted Connection.

Figure (1-4) shows failure types is net tension failure, shear failure, cleavage failure, and block shear failure are the most common failure mechanisms of bolted tensile connections. Net stress occurs because the bolt hole reduces the cross-sectional area, causing the tensile strength to decrease and the plate to fracture along the bolt's line. Shear failure happens when the plate's resistance to shear deteriorates, and it breaks along the shear direction. Cleavage failure occurs in connections with a short end distance. When shear fracture and net tensile fracture occur simultaneously, block shear failure occurs. When a bearing fails, the bolt neck section progressively pulls the plate out when the member is loaded (Kim et al., 2018).

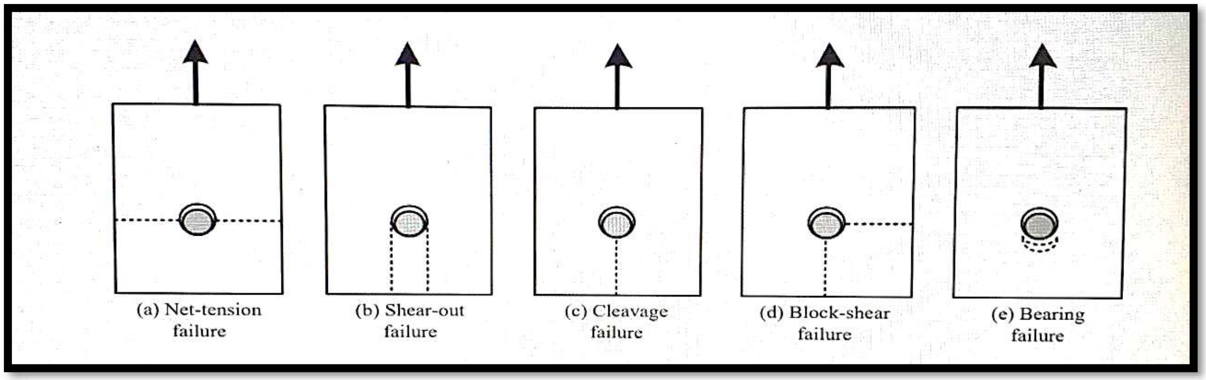

Figure (1-4) failure types (Kim et al., 2018).

Curling failure occurs in thin plates that are affected by tensile forces. The failure of the curling reduces the ultimate strength of the plate, as shown in Figure (1-5), (Kim et al., 2011)

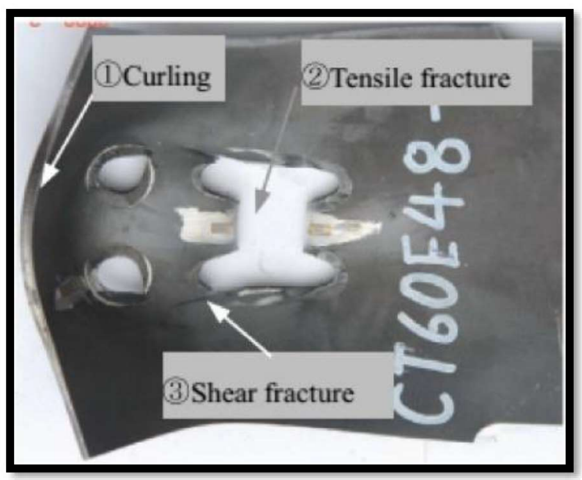

Figure (1-5) curling failure (Kim et al., 2011).

1.5 The Aim of the Study

Fire in buildings causes a significant increase in temperature up to 1000°C (Beitel et al., 2008). The residual strength and behaviour of the connections can be significantly affected after the high temperature. Limited researches have been conducted on the behaviour of stainless steel bolted connections after elevating temperatures. Therefore, this study aims to provide a fundamental understanding to the post-fire behaviour of stainless steel single shear bolted connections.

The following objectives were established to attain these aim:

1- Studying state-of-the-art to investigate the subject.
2- Design a complete experimental programme to study the influence of important factors on connections behaviour.
3- Conduct the experimental tests.
4- Analyze the experimental data and observations to quantify the influence of high temperature and heating time on the bolts connections behaviour.
5- propos analytical models to estimate the bolts connections strength.

1.6 Program of Study

The thesis was divided into six chapters, each of which is summarised below:

- ❖ Chapter one: Provides an overview of the research background as well as the thesis topic and outline.
- ❖ Chapter two: This chapter contains a literature review that provides an overview of the thesis topic. This chapter is divided into three sections of the literature. The first section presents specimens tested at normal temperature (room temperature), the second section presents specimens tested at high heating temperature (representation fire), and the third section presents specimens that were tested after the fire (returning the temperature of the specimens to the normal temperature).
- ❖ Chapters three: This chapter explains the experimental program that was used in the study and includes measuring the dimensions of the models (coupons and specimens), the method and time of heating and cooling methods, the devices and tools that were used in the test, and the procedures that were followed in recording the results.

- Chapter four: This chapter presents the changes in the physical and chemical properties of the coupons before and after heating, which includes changes in the physical properties (length, width, and thickness) and changes in colour and shape as a result of exposure to heat, and heating time for each cooling method and compare it with the results of coupons without heating. As for the changes in the chemical properties, the samples were examined at a temperature of 1000 °C and a heating time of 120 min for both cooling methods and compared with the results of the sample without heating using EDX and SEM.
- Chapter five: This chapter presents the results of the effect of temperature, heating duration, and cooling method on the main aspects of a bolt connection.
- Chapter six: This chapter presents conclusions and recommendations for future studies.