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Experimental Behaviour of simple Bolted shear Connections in Steel Plates after high Temperatures

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

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CERTIFICATION

I certify that the thesis entitled " Experimental behaviour of bolted connections in thin-walled steel plates after elevated temperatures" is prepared by " Qahtan Adnan Sulyiman “ under my supervision at the Department of Civil Engineering-College of Engineering-Diyala University in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering.

Signature:

Supervisor:

Date: / / 2021

بسم الله الرحمن الرحيم

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سورة الكهف الاية(٩٦)

Dedication

To My Family

With Respect

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Abstract

Steel is widely used materials due to many advantages. It offers over other construction materials. These include high strength, ductility, ease of fabrication, and speed of construction. Steel joints are a major part of steel structures; it is responsible for the transmission of loads such as shearing, tension and bending and the stability of the building. The high temperature affects the mechanical properties of the steel. Therefore, the connections are considered as one of the affected parts if the building was exposed to fire. To maintain the safety of the building, there is a need to know the behaviour of the joint after exposure to high temperatures. This study deals with the effect of high temperatures on the mechanical properties of thin steel carbon plates (2mm , 4mm), and its behaviour in bolted connections after the fire. The experimental work includes testing of thin carbon steel plate bolted connections and coupons. They were exposed to a high temperature to simulate fire conditions, at different temperatures 400°C, 700°C, and 1000°C, in different durations time(30,60,90,120 min), and cooled in water or air. The specimens and coupons were tested in a tensile. The coupons were used to find the mechanical properties (yield stress, ultimate stress, and modulus of elasticity). The specimens were used to find the ultimate load, type of failure, axial displacement, and transverse displacement (curling). The results showed that after the steel was exposed to high temperatures there is a reduction in the thickness. The yield stress, ultimate stress, and modulus of elasticity for heated coupons dropped with increasing the duration of heating with cooled in air. The curling failure caused a reduction in the ultimate load when specimens of 2 mm thickness heated to 700 ºC and 1000 ºC and cooled in air. The ultimate stress for heated coupons drops with increasing the duration of heating to 400 ºC, 700 ºC, and 1000 ºC. For coupons of 2mm and 4mm thickness, it dropped by 10%, 13% and 14% and 4%, 11%, and 15% respectively after 120 minutes of heating and cooling in air. The load-carrying capacity of the bolted connections can increase with increasing the heating temperature to 700 ºC and 1000 ºC for specimens of 2mm thickness by 1% and14 % respectively after 120 minutes of heating and cooling in water. For the 4mm specimens, it improved in 400 ºC, 700 ºC and 1000 ºC by 2%,10%, and 9% respectively after 120 minutes of heating and cooling in water. To maintain the strength after the event of a fire in the steel structure buildings, it is recommended to use water to extinguish the fire to maintain the strength in the parts of the structure.

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Symbol	**Definition**
F_y	yield stress
F_{yt}	post fire yield stress
F_u	ultimate stress
F_{ut}	post fire ultimate stress
F_{yt}/F_y	Means Yield stress (Fyt) of the coupon subjected to heating to the yield stress (Fy) of coupon tested without heating.
F_{ut}/F_u	Means dividing the ultimate stress (Fut) of the coupon subjected to heating to the ultimate stress (Fu) of coupon tested without heating
F_u/ F_y	Means dividing the ultimate stress (Fu) of the coupon to the

	yield stress (Fy) of coupon
T_t / T	Means the thickness of plate after fire to thickness of plate without heating
P_y	Yield load of specimen
P_u	Ultimate load of specimen
P_{yt}	post fire yield load of specimen
P_{ut}	post fire ultimate load of specimen
P_c	load that initiates curling displacement
P_{yt}/ P_y	The ratio of load at which the heated specimen is subjected to load at which the specimen is subjected without heating
P_{ut} /P_u	The ratio of ultimate load of the heated specimen to ultimate load of the specimen without heating
P_c/P_u	The ratio is the ratio of load that initiates curling displacements to the ultimate load for same specimen
A_{ns}	Net shear fracture
A_{nt}	Net tensile fracture
$P_{u\ an}$	Ultimate strength for equation
P_{uexp}	ultimate strength for experimental

CHAPTER ONE

INTRODUCTION

1.1 Background

More than two centuries have passed since metals used for the first time in the construction sector. This sector was in continuous development until it became possible to use steel in many construction projects after the industrial revolution in the mid-nineteenth century. Besides, modern sections of steel that are produced in very sophisticated and accurate methods have achieved a great role in the renaissance of the construction sector. The modern steel materials and construction machines, with their high potential, widen the use of structural steel in the building industry. Steel structures are used in all types of construction including heavy industrial buildings, high-rise buildings, and bridges, towers, airport stations. (Al Manoufi, 2016) .Steel is widely used due to the many advantages. It offers over other construction materials. These include high strength, ductility, and speed of construction. A major hitch of steel construction is that steel structural members possess low fire resistance due to high thermal conductivity and low specific heat of steel, as well as faster degradation of strength with elevated temperature (Agustini, et al, 2017).

1.2 Connections in Steel Structures

Connections are one of the very important structural elements in steel structures. Having suitable connections can result in perfect structural performance. The failure in the connections can risk the unity of the whole structure and finally leads to collapse (Ketabdari, et al, 2019). The connections are mainly responsible for the transmission of loads and the stability of the structure. Connections are classified into two main classes, namely bolts and weld (Tamboli , 2009). The connections are important for assembling the parts of the steel structure, at the joints. The connection must be designed in such a way that there is no failure in the connecting area and the members because the failure of the joint is not ductile. Connections are usually the weakest components in steel structure; failure of which may cause the failure of the whole structure (Dowling, et al , 1988). Most structural failures are due to poor design or poor implementation since a large number of failures occur in the connection areas (Segua ,2007).

1.2.1 Bolt Types

Bolts are used to connect the structural elements as shown in Fig (1-1). Bolts are work for carriage Loading from beams to columns in bolted joints, Contribute to the fastness and safety of the structural system, and bearing both thermal and mechanical loads (Panga, et al, 2019). Bolts as either normal or high-strength bolts. Common bolts are graded A307 low-carbon steel with a minimum tensile strength of 60 ksi. High-strength bolts are typical of Grade A325 heat-treated medium-carbon steel with a minimum tensile strength of 120 ksi for bolts up to (1 in) diameter. (Williams , 2011).

Fig (1-1) Bolted connection. Williams , (2011)

1.2.2Welded Joints

Welding is a method to transfer loads from one member to the other. Welded joints are mostly made by melting the base metal from the parts to be joined with the weld metal, which became a connection after cooling presented in Fig (1-2). There are two major types of welds: groove welds, which are often called butt welds and fillet welds. For building structures in general, approximately 80% of the welds are fillet welds (15%) are butt welds. The presumption underlying the structural design of welds is that welds are homogeneous properties, residual stresses and stress concentrations in the welds are least, and the connecting parts are solid with minimal deformations. This means that the stress distribution is uniform in welding. The ductility of the material leads to redistribution of stresses from residual stresses and stress concentrations, leading to decrease stress in general. Fillet welds are often preferred over butt seams because they need less equipment, fewer operator skills and less item preparation to join. In contrast, butt welds require a bit more work and preparation (Manson , 2005).

Fig (1-2) Welded connection. Manson ,(2005)

1.3 Steel Properties after High Temperatures

Steel is used in building construction due to its main properties of weight to strength ratio, high strength and good flexibility. The mechanical properties of steel are described mainly through the stress-strain relationship. This relationship is for a standard sample under stresses at ambient temperature as shown in Fig (1-3). The steel structure are lost strength and rigidity if it exposed to fire (Fig 1-4), which leads to excessive deformation of the steel parts and collapse (Sarraj, 2007).

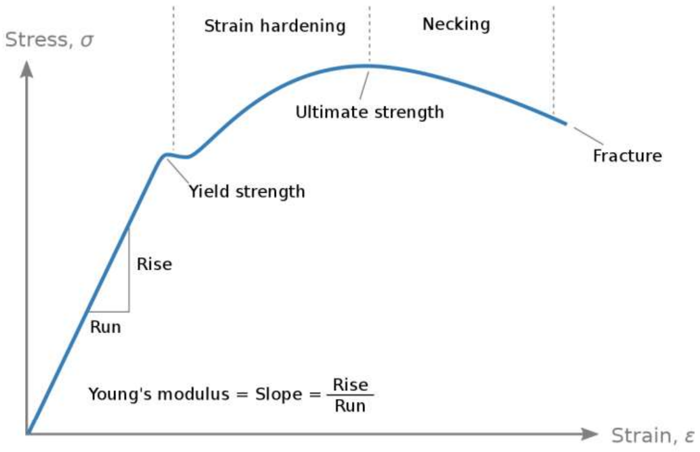
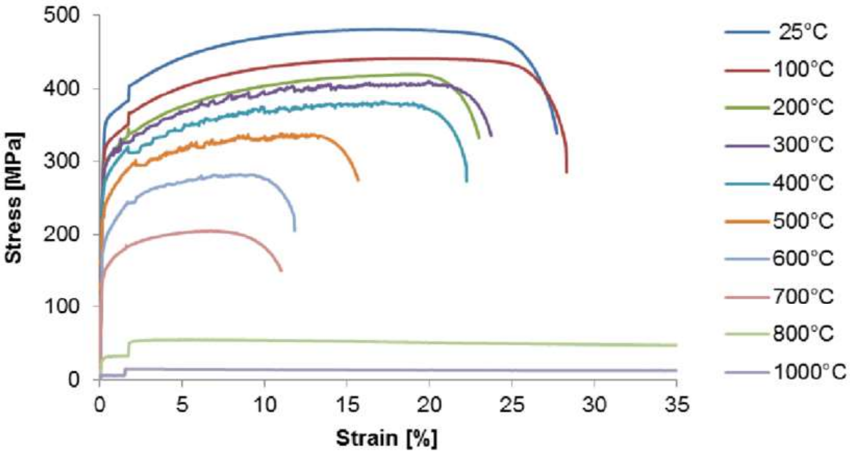


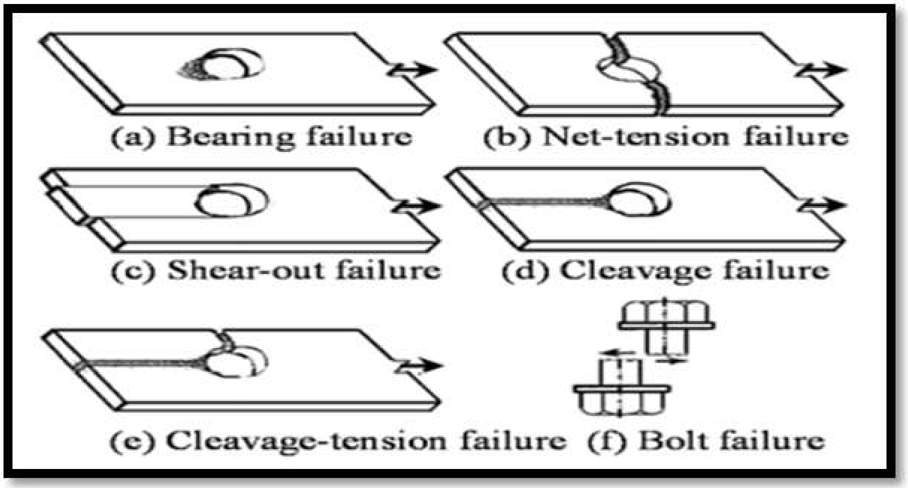
Fig (1-3) Stress –strain relationship of steel carbon. Sarraj, (2007)



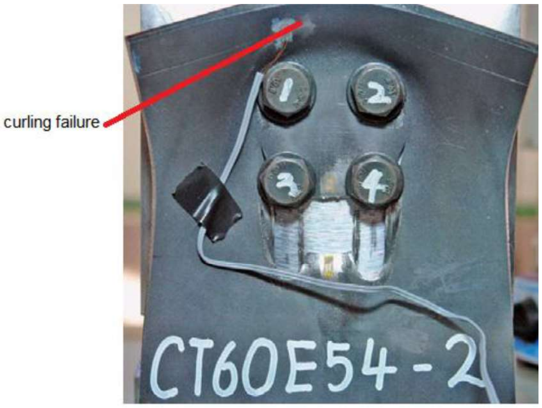
(Fig 1-4), Stress –strain relationship of steel carbon after a fire. Tao, et al, (2013)

1.4 Failure Modes of Bolted Connections

Failure modes of bolted tensile connections are fundamentally net tension failure, shear failure, cleavage failure, and block shear failure, as shown in Fig (1-5-a). Net tension occurs because the cross-sectional area is reduced by the bolt hole, Which causes the tensile strength reduced, so the plate fractures along the bolts line. Shear failure occurs when the plate becomes weak to resist shear and breaks along the shear direction. The failure of cleavage occurs in connections with a small end distance. Block shear failure occurs when shear fracture and net tensile fracture occur at the same time. In bearing failure, the bolt neck portion gradually pushes the plate as the member undergoes a load (Kim , et al , 2018). Finally In 2011, Kim reported that curling failure is shown in Fig (1-5-b) occurred in thin plates of a free edge from connection subject to tensile force. Curling accompanied by strength reduction at ultimate load (Kim ,et al, 2011).



a- Failure modes of single-bolt lap-joint in-plane connection, (Kim, et al, 2018)



b. Curling failure, (Kima and Kuwamura , 2011)

Fig (1-5) Failure modes of bolted connection

1.5 Aim and Objectives

The research aims at providing a fundamental understanding on the behaviour of thin bolted connections after being subjected to hit temperature. To achieve this aim, the following objectives were set:

1- Studying the state of the art to the research topic.

2- Design a comprehensive experimental programme to investigate the effect of the influential parameters on the connection behaviour.

3-Perform the experimental tests.

4- Analyze the experimental results and observations to quantify the effect of high temperature on the connection behaviour.

1.6 Outline of Study

The thesis was divided into six chapters, and a summary of each is presented below:

- Chapter 1. Gaves a general introduction on the research background and the thesis domain and outline.

- Chapter 2. This chapter contains a review of the literature that gives general introductions on the topic of the thesis. This chapter divides previous studies into three groups. The first presents specimens that tested at room temperature. The second group includes the specimens that tested at high temperatures (Fire representation). The third group presents the specimens tested after the fire.

- Chapter 3. This chapter describes the experimental programme including the dimensions of the samples (coupons and specimens). Then the chapter shows the method of heating and cooling. It also describes the instruments that were used in the experimental programme and the procedure that was adopted to record the results.

- Chapter 4. This chapter displays the changes in physical properties for coupons after heating and cooling (length, width and thickness). Comparison of coupons results after testing (yield stress, ultimate stress and elongation), at each heating temperature and different heating durations in the same cooling method with the results of coupon tested without heating were conducted.

- Chapter 5 Through this chapter, the effect of heating temperature, heating time and cooling method on the main aspects of the bolted connection is presented.

- Chapter 6. This chapter reports the conclusions and recommendations for future study.