Experimental investigation on the post-fire mechanical properties of the different weld metals

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Abstract

Nowadays, different types of welds and electrodes are used for welding in steel structures, each of which has different characteristics and performance. On the other hand, considering the general weakness of various steel elements such as welds in steel structures at high temperatures, it is very important to know their performance. Considering the insufficient research studies on the weld metals, in this study, the performances of weld metals made from welding with E6013, E7018, S2(EM12) and SG2(ER70S-6) after exposure to different temperatures are investigated. For this purpose, after welding the steel plates (ST37), the welds are turned into dumbbell-shaped specimens and then, exposed to elevated temperatures of 25, 100, 250, 400, 500, 700 and 900°C. afterward, when the specimens were naturally cooled to ambient temperature, tensile tests were carried out on them to obtain the stress-strain curves. The results indicate that in general, increase in the temperature undermines the mechanical properties (i.e. ultimate strength, yield strength and modulus of elasticity) of the weld specimens. It was found that the strength decreases more significantly at temperatures above 500 degrees. In addition, it was observed that ductility increases at temperatures above 700°C. Finally, comparison of the performance of the four weld metals, failure modes and energy absorption at various temperatures are the other results obtained in the present study. Accordingly, the temperature-dependent equations are proposed in order to predict the mechanical properties of the weld metals.

Keywords: Welding, Post-Fire Performance, Mechanical Properties, Weld Metal, Yield Stress, Ultimate Stress, Elasticity Modulus.

1- Introduction

Considering the widespread use of steel structures in the construction industry, it is very important to investigate the behavior of various elements of steel structures in fire conditions (due to their weakness at high temperatures) [1,2]. In recent years, many studies have been conducted to investigate the behavior of structural members during and post-fire and these studies are mainly divided into two groups. The first group deals with the overall performance of structural elements such as beams, columns, connections, etc. and in the second group, the performance of the structural components such as bolts and welds are explored.

In the first group, different studies have been performed. For instance, investigating the behavior of the beam-to-column connections exposed to fire [3], moment-temperature curve for the semi-rigid connections [4], the behavior of the welded and bolted beam-to-column connections [5-8], behavior and failure modes of the composite beams with pinned connections [9], etc. exposed to the elevated temperatures, can be pointed out.

In the second group, various studies have been done on the performance of bolts and welds. About bolts, they have done research such as experimental investigation of grade A490 and A325 bolts [10], experimental investigation of grade 45 bolts [11], experimental and numerical investigation of the behavior of grade 8.8 and 10.9 bolts with different sizes [12,13] exposed to different temperatures were carried out. Regarding welds, in 2011, Hanus et al investigated the behavior of welds at the Centro Sviluppo Materiali under the Heating-Cooling cycle [14]. The results of research on welds show that weld strength decreases by about 20% after heating to 800°C and cooling to the ambient temperature. In 2017, Zhang et al. studied the behavior of fillet and butt weld connections using Q345 steel base metal [15]. The results revealed that in butt weld connections, at temperatures higher than 400°C (under natural cooling) and 500°C (under water cooling), weld failure occurs, but in the fillet weld connections, at all temperature levels, failure occurs in the base metal. In another research in 2017, Liu et al. investigated the post-fire strength of Q235 and Q345 butt weld specimens [16]. The results of this research show that the temperature of 600°C is the critical temperature for the strength reduction of specimens. In 2019, Guo et al. tested the mechanical properties of the butt weldments made with E5515-G electrode at high temperatures. In this research, the results reveal that the welding heat-affected zone (HAZ) is vulnerable to fracture when subjected to reheating above 500 °C [17]. Moreover, at 500 °C and higher, the butt welds are considered unsafe relative to the recommendation of the current design standards. In another study, Guo et al. in 2020 investigated the mechanical properties of welds composed of E4303 and E5015 electrodes with Q235 and Q345B base metals by carrying out steady-state tensile tests at high temperatures [18]. The comparison of the results of this research with the current design standards such as Eurocode 3, showed that the recommendations of current codes are not fully applicable to the reduction of mechanical properties of welds, especially at 500 °C and higher. El-Ghor et al. in 2021, incorporated Two different loading rate scenarios (fast and slow) to examine the rate-dependent behavior of weld material in transverse welded lap joints at elevated temperatures under steady-state thermal conditions [19]. The results of this study indicate that the loading rate has a significant effect on the strength and deformation capacities of transverse welded lap joints for temperatures greater than 450°C. In 2022, Saedi et al investigated the post-fire performance of complete joint penetration welds [20]. In this study, plates with different sizes were used, and some of the results are obtaining mechanical properties and failure modes of specimens in welds or base metals. Qiang et al. investigated the mechanical properties of weld metal and base metal (Q345qD) in butt-welded joints at high temperatures, for this purpose, monotonic tensile tests were carried out. The results of this research show that elevated temperatures can decrease significantly the material performance of the Q345qD weldment, and the degradation of the mechanical properties of the base metal and weld metal differs with increasing temperature [21].

As mentioned, most of the research conducted in the field of the behavior of welds at high temperatures has focused on the investigation of different welding joints with different base metals and types of joints. Therefore, research in the field of weld metals and their post-fire performance is very important. In this paper, the post-fire performance of weld specimens composed of 4 different weld metals, E6013 electrode, E7018 electrode, S2 welding wire (EM12) and SG2 welding wire (ER70S-6) with ST37 base metal is investigated. For this purpose, the test specimens were exposed to seven temperature levels of 25, 100, 250, 400, 500, 700 and 900°C. In the next phase, the specimens were cooled down to the ambient temperature naturally, and then tensile tests were performed on the specimens. By performing 3 repetition tests for each specimen at each specific temperature level, the stress-strain curves are obtained and the mechanical properties of each specimen are examined in addition to their failure mode, ductility, and energy absorption.

2-Experimental Program

2-1- Specimens Preparation

In this paper, the welded joints were made from the base metal of ST37 steel plates (Figure 1) and four different types of weld metals E6013 electrode, E7018 electrode, SG2(ER70S-6) welding wire and S2(EM12) welding wire. The welding process adopted for E6013 and E7018 electrodes was a shield metal arc welding (SMAW) process. The gas metal arc welding (GMAW) process with 100% CO2 was adopted for SG2(ER70S-6) welding wire and submerged arc welding (SAW) process was adopted for S2(EM12) welding wire. In Table 1, the chemical and mechanical properties of each weld metal are presented. As shown in Figure 2, the weld metals were cut from the welded joints and machined into dumbbell-shaped specimens according to the ASTM E8M standard [22] (Figure 3). The final shape of a weld metal specimen is shown in Figure 4. The specimens obtained from different welds are abbreviated as E6013, E7018, SG2 and S2 throughout the rest of this study.

Table 1: Chemical and Mechanical Properties of Weld Metals

Weld Metal	Welding process	Chemical Composition								Yield Strength	Tensile Strength	Elongation
		C%	Si %	Mn %	P%	S%	Cr %	Mo %	Ni%	MPa	MPa	%
E6013	SMAW	0.08	0.3	0.4	-	-	-	-	-	400	510	28
E7018	SMAW	0.06	0.5	1.2	-	-	-	-	-	445	540	29
SG2 (ER70S-6)	GMAW 100% SG2	0.06 - 0.17	0.70 - 1.16	1.30 - 1.76	0.2≤5	0.25≤				424	500	22
S2 (EM12)	S2	0.04 - 0.08	0.5 - 0. 8	1.2 - 1.6	-	-	-	0.45 - 0.50	-	500	500-650	22

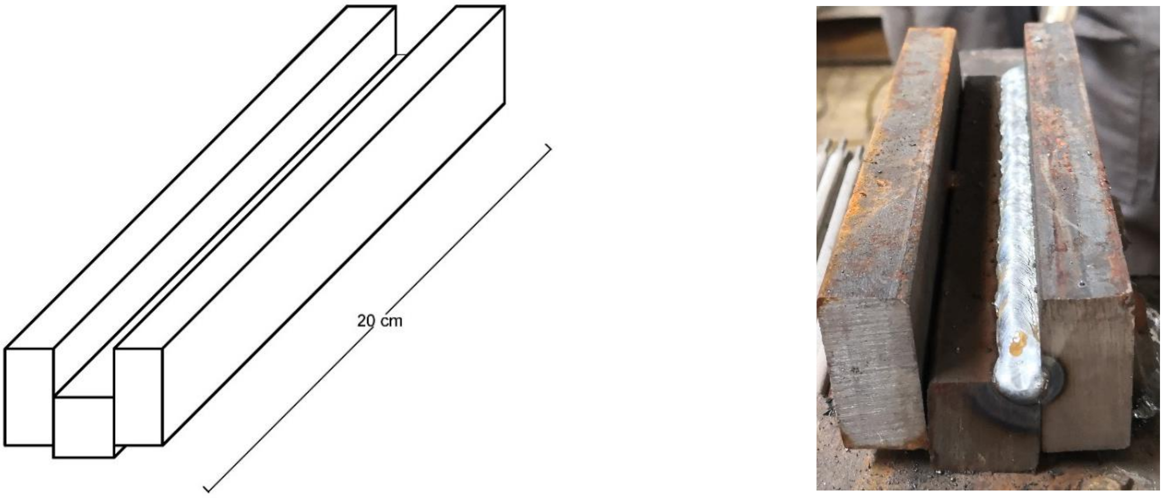


Figure 1: Preparation of Steel plates for Welding Process

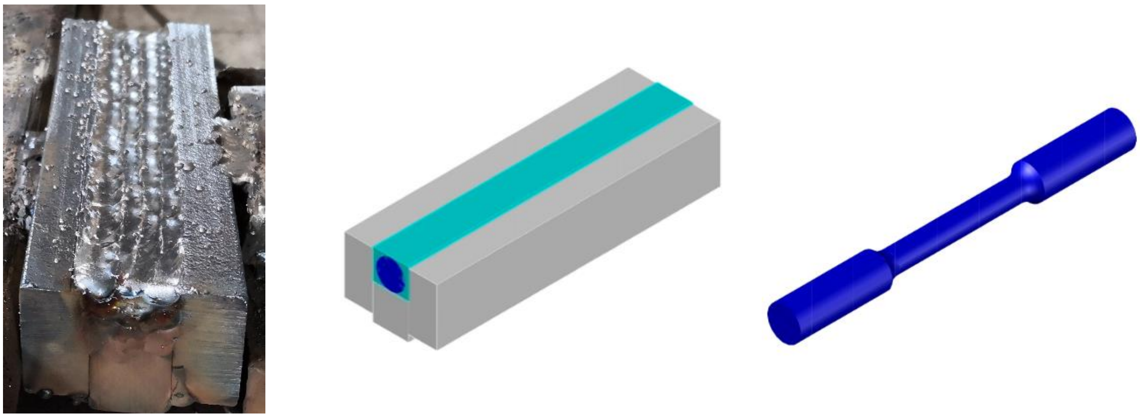


Figure 2: Manufacturing Process and Location of Weld Specimens

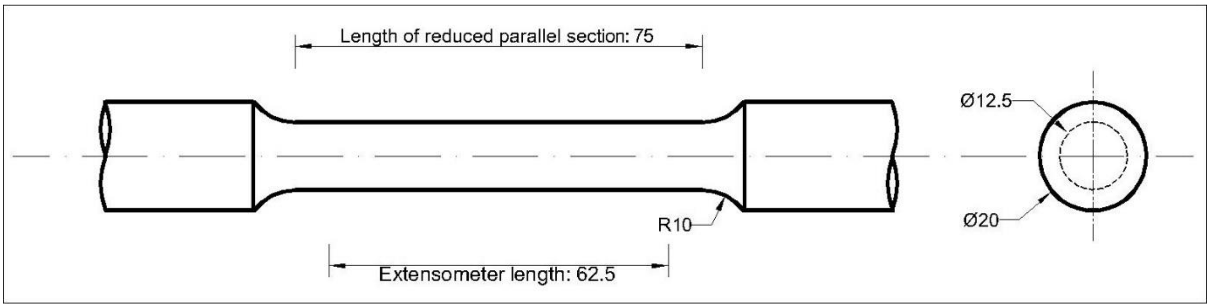


Figure 3: Dimensions of Specimens according to ASTM E8M (dimensions are in mm)

Figure 4: Dumbbell-Shaped Specimens for Tensile Strength Tests

2-2- Test Method and Procedure

The heating of specimens was accomplished in a temperature-controlled electrical furnace, as shown in Figure 5. The specimens were heated from the ambient temperature to the target temperatures at a rate of 10°C/min. Six target temperatures (Tu) of 100, 250, 400, 500, 700 and 900 °C were selected. Each test specimen was heated to the target temperature in the furnace and then maintained at that temperature for 30 min. This 30 min time interval was considered to be enough to achieve temperature uniformity along the thickness of the specimens and to allow all possible transformations in the metal structure. Afterward, the furnace was turned off and the cooling phase started. The specimens were cooled naturally at a rate ranging from 5°C/min to 20°C/min to ambient temperature (Figure 6). Following completion of this step, tensile tests on the specimens were performed at ambient temperature. These tests were performed according to ASTM E8 [22]. Three repetitive tests were performed for each specimen under the same conditions to reduce experimental error.

The tensile test machine consists of the upper and lower grips, in which the specimen tabs fully engaged by the grips. An extensometer was attached to specimens to measure strain precisely. Figure 7 shows the placement of the specimens in the tensile test machine.

Figure 5: Specimens in Temperature-controlled electric furnace

The tension device also consists of the upper and lower jaws, in which the tested specimen is placed and fixed by the jack and support built into the jaw. The way the specimens are placed in the device can be seen in Figure 7.

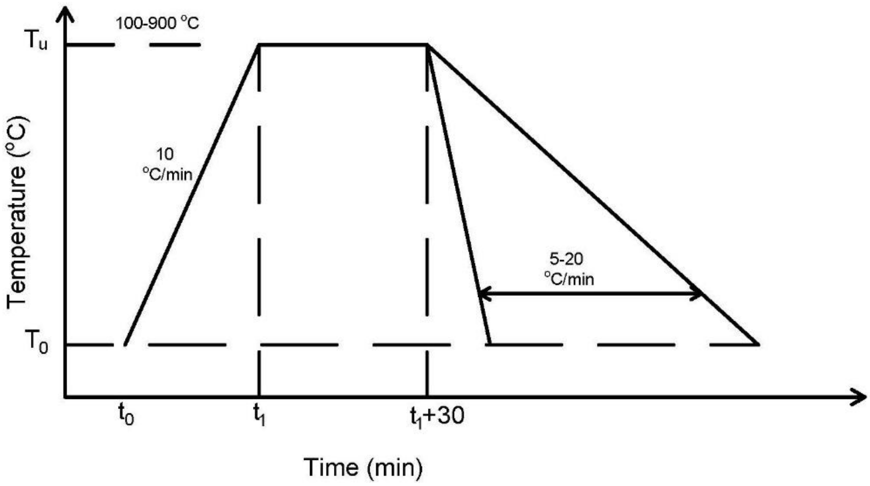


Figure 6: Heating and cooling procedures for test specimens

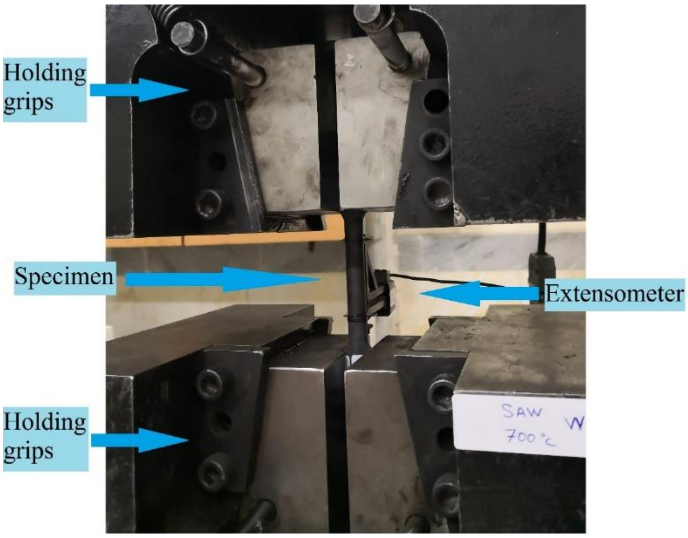
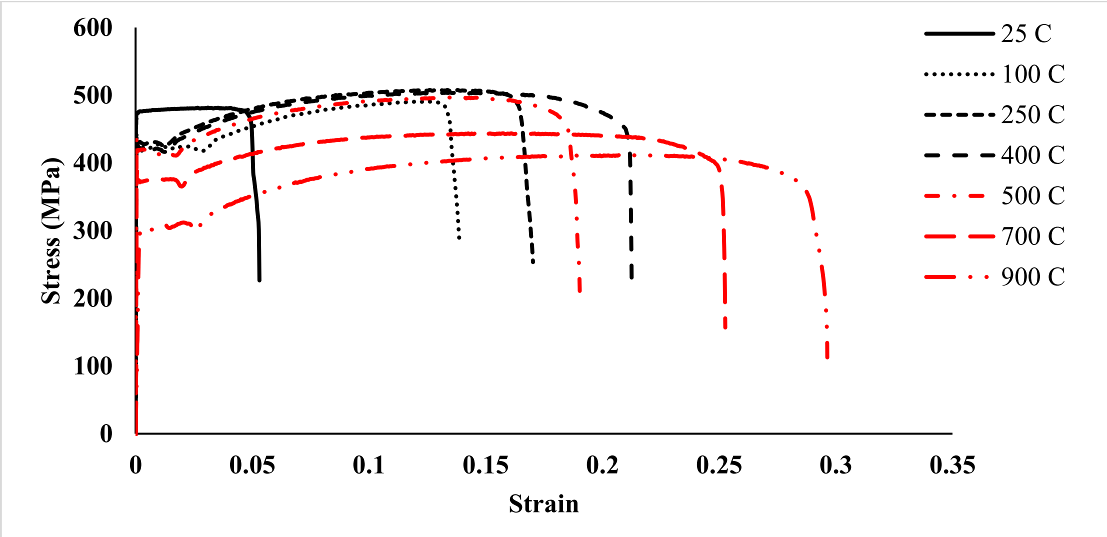


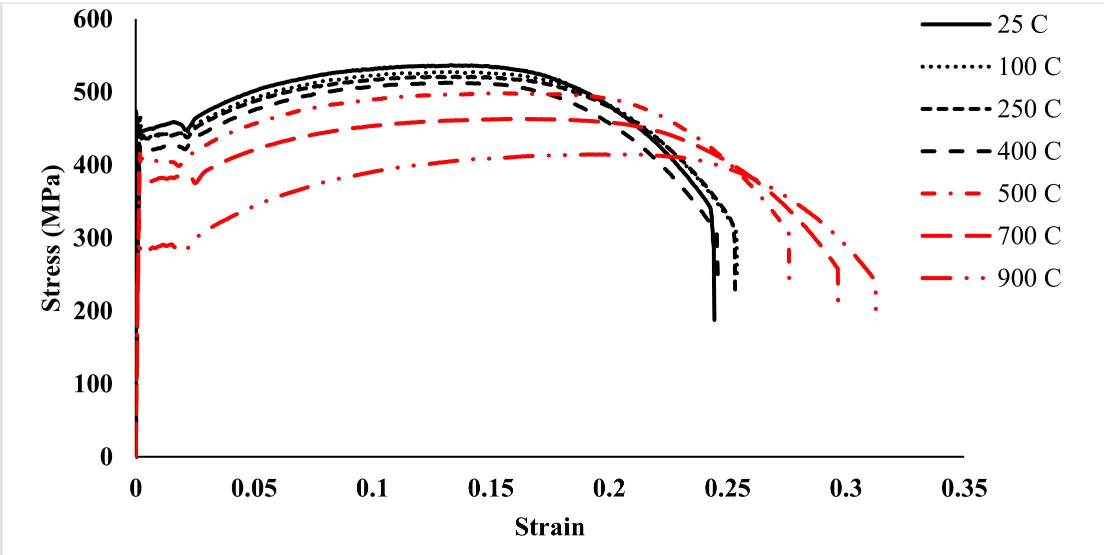
Figure 7: Placement of the specimen in the tensile test machine

3- Results of the Tests

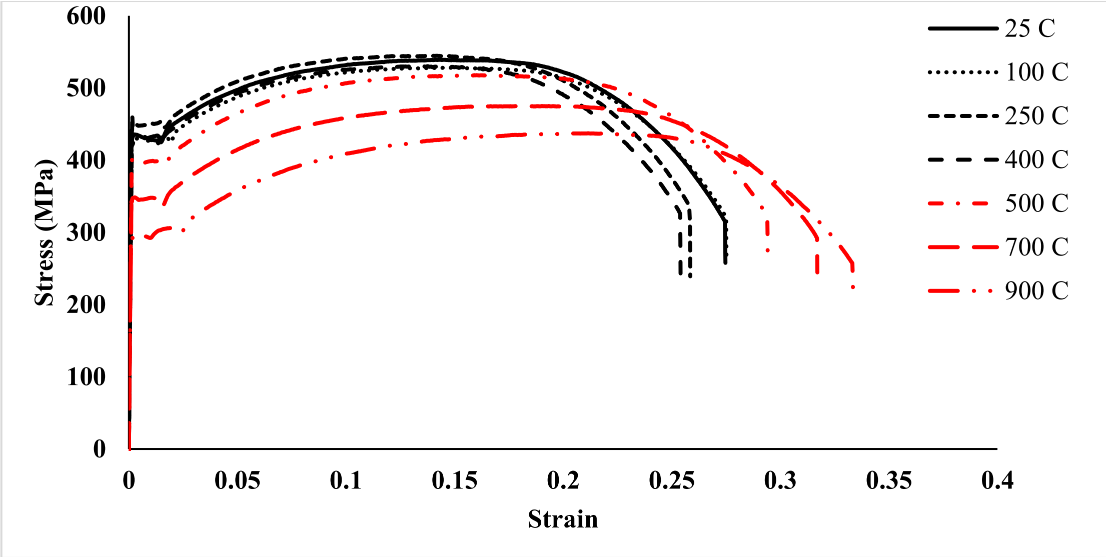
Based on the results of the tests, the stress-strain curves after exposure to different temperature levels and natural cooling are in accordance with Figure 8.



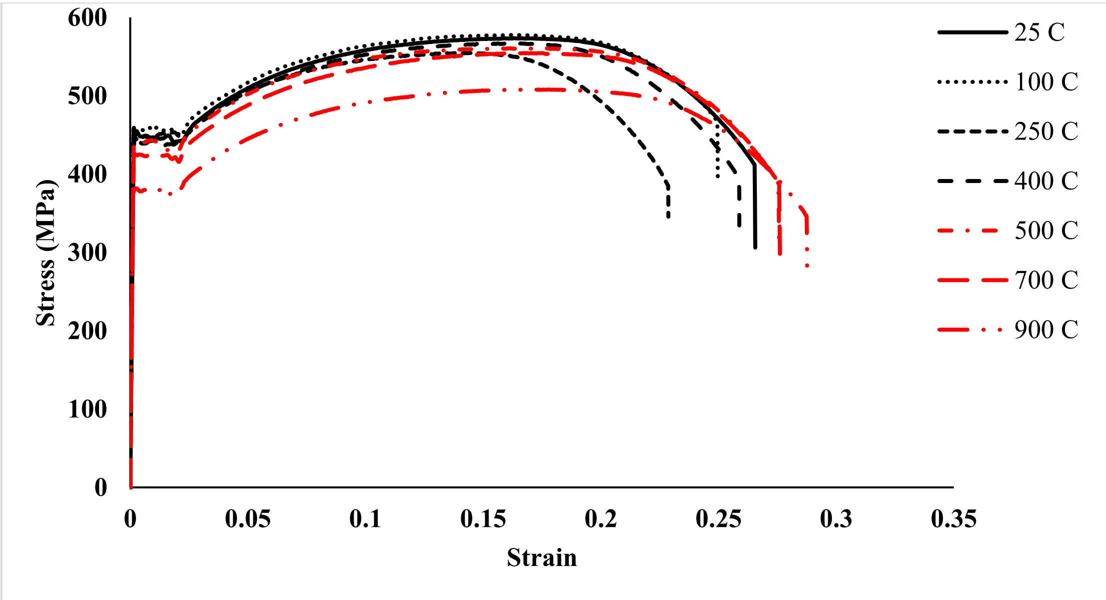
6013 Specimen



7018 Specimen



SG2 Specimen



S2 Specimen

Figure 8: Comparison of the stress-strain diagram of different specimens with varying temperatures

According to the stress-strain diagram of the specimens, in all the specimens except the E6013, at first the behavior is linear-elastic up to the yield point, then, non-linear behavior with high plastic deformation rate is observed. In the E6013 specimen at 25°C, unlike other specimens, the failure of the specimen was brittle, as can be seen in all the results, the strength of the specimens is significantly recovered before the temperature of 400°C, but with increasing temperature and exceeding from 500°C, a decrease in mechanical properties is observed. Therefore, the temperature of 500°C is the critical temperature which significant loss of strength will happen for various weld specimens. Moreover, the ductility of the specimens increased gradually when the temperatures exceeded 500 °C. At 900 °C, maximum ductility is observed in all the weld specimens. Based on the obtained stress-strain curves, the yield strength (F_y), ultimate strength (F_u) and elastic modulus (E) of the specimens are also calculated. The reduction factors (R_F), calculated as the ratio of the test value of specimens after cooling down from an experiencing an elevated temperature to the original value of specimens at ambient temperature.

3-1- Post-Fire Ultimate Strength

The ultimate strength is determined according to the maximum stress experienced by the specimens during the tensile strength test. Figure 9 and Table 2 show the ultimate strength reduction of the specimens after being exposed to elevated temperatures up to 900°C The results show that when E6013 specimens are exposed to high temperatures below 400°C, their ultimate strength increases slightly after cooling down. Then, the ultimate strength gradually decreased by 15% after exposure to temperatures up to 900 °C. The greatest deterioration of the ultimate strength is observed in the 7018 specimens so that the ultimate strength reduction reaches 23% at 900°C. In S2 and SG2 specimens, the maximum reduction in ultimate strength continued to 11% and 19%, respectively.

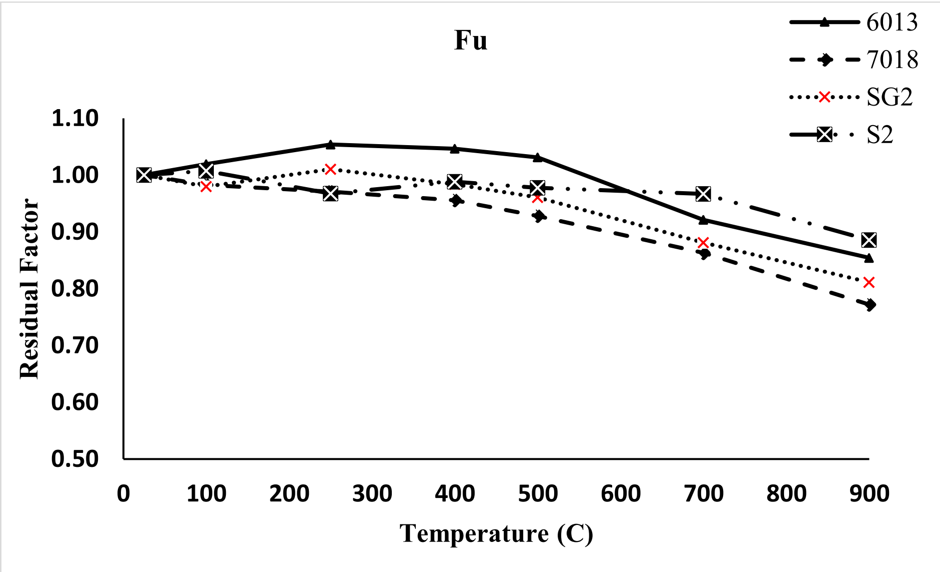


Figure 9: Diagram of ultimate strength reduction of weld specimens

Table 2: Ultimate strength recovery values of weld specimens

T (ºC)	6013		7018		SG2		S2	
	Fu (MPa)	RF	Fu (MPa)	RF	Fu (MPa)	RF	Fu (MPa)	RF
25	481.63	1.00	536.59	1.00	538.99	1.00	573.36	1.00
100	490.83	1.02	527.40	0.98	528.20	0.98	577.56	1.01
250	507.61	1.05	521.00	0.97	544.58	1.01	554.78	0.97
400	504.02	1.05	512.81	0.96	530.20	0.98	566.77	0.99
500	496.62	1.03	498.02	0.93	517.81	0.96	560.57	0.98
700	443.66	0.92	463.05	0.86	475.04	0.88	554.38	0.97
900	411.49	0.85	414.28	0.77	437.27	0.81	507.81	0.89

3-2- Post-Fire Yield Strength

The yield strength is determined by the stress method related to the strain of 0.2%, in this way, the yield stress value is determined from the intersection of the line corresponding to the strain of 0.2% with the point on the stress-strain curve. Figure 10 and Table 3 show how the yield strength of the specimens decreases after exposure to elevated temperatures.

According to the results, the yield strength of the specimens decreases with the increase in temperature in all specimens, and this decreasing trend should be greatly increased at temperatures above 700 °C. In the E6013 specimen, the yield strength at 700 and 900 °C decreases by 22 and 37%, respectively, which is the lowest percentage of yield stress compared to other specimens. In the E7018, the process of reducing the yield strength is equal to 14 and 37% for temperature levels of 700 and 900 °C. In the S2, which has performed better than others, the strength reduction at 700 and 900 °C is 6 and 16%, respectively, and this strength reduction for SG2 is 20 and 32%.

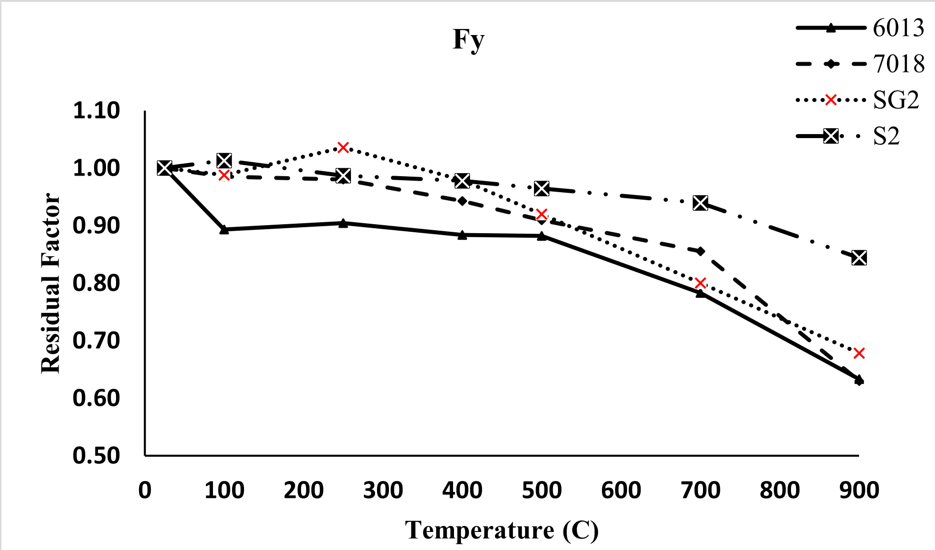


Figure 10: Graph of reduction in yield strength of weld specimens

Table 3: Summary of yield strength recovery values of weld specimens

T (ºC)	6013		7018		SG2		S2	
	Fy (MPa)	RF	Fy (MPa)	RF	Fy (MPa)	RF	Fy (MPa)	RF
25	475.64	1.00	446.26	1.00	435.07	1.00	451.26	1.00
100	424.88	0.89	439.55	0.98	429.87	0.99	457.25	1.01
250	430.07	0.90	437.47	0.98	450.66	1.04	445.26	0.99
400	420.48	0.88	420.66	0.94	426.08	0.98	441.26	0.98
500	419.68	0.88	405.89	0.91	400.30	0.92	435.27	0.96
700	372.52	0.78	381.71	0.86	348.14	0.80	423.88	0.94
900	301.17	0.63	281.19	0.63	295.17	0.68	380.91	0.84

3-3- Post-Fire Modulus of Elasticity

The slope of the linear part of the stress-strain diagram represents the modulus of elasticity of the specimens. Figure 11 and Table 4 indicate how the modulus of elasticity of the specimens decreases after exposure to elevated temperatures.

In the E6013 specimen, the reduction of modulus of elasticity at temperatures of 700 and 900 degrees is 18 and 29 percent, respectively. The modulus of elasticity in the specimens created by electrode 7018 is also reduced by 27 and 28% when exposed to 700 and 900 °C, respectively, which indicates a sharp decrease in the modulus of elasticity at temperatures higher than 700 °C. For S2 and SG2 specimens, which have the highest and lowest performance in regaining the modulus of elasticity at elevated temperatures, the reduction ratio reaches 15% and 24% at 900°C, respectively.

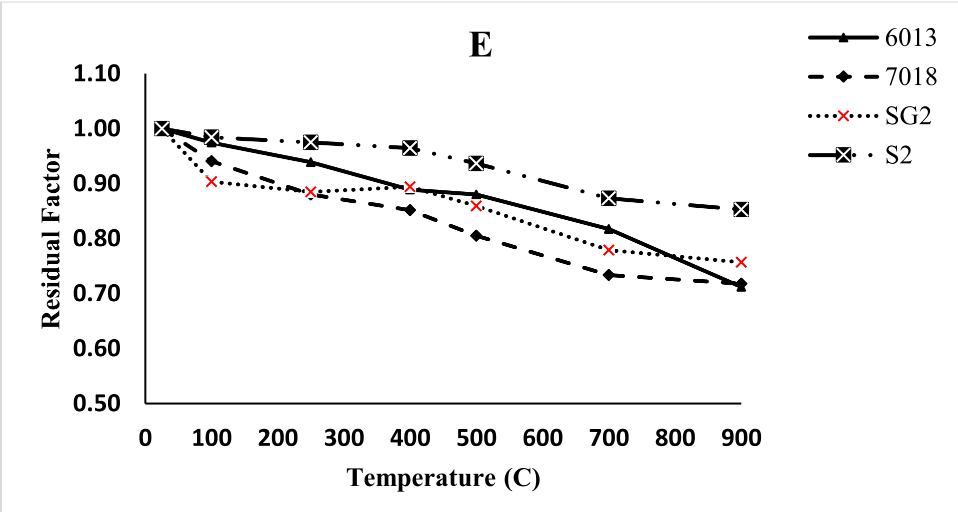


Figure 11: Diagram of reduction of modulus of elasticity of weld specimens

Table 4: Summary of modulus of elasticity recovery values of weld specimens

T (°C)	6013		7018		SG2		S2	
	E (GP)	RF	E (GP)	RF	E (GP)	RF	E (GP)	RF
25	216.20	1.00	250.81	1.00	249.28	1.00	243.15	1.00
100	210.61	0.97	235.97	0.94	239.19	0.96	239.38	0.98
250	202.97	0.94	220.78	0.88	237.69	0.95	237.04	0.97
400	192.22	0.89	213.63	0.85	223.30	0.90	234.51	0.96
500	190.31	0.88	201.99	0.81	214.24	0.86	220.47	0.91
700	176.72	0.82	184.03	0.73	206.51	0.83	211.93	0.87
900	153.93	0.71	180.04	0.72	188.66	0.76	207.35	0.85

3-4- Failure Modes

After the heating and cooling procedure, changes in the appearance of the specimens such as darkening, color change, surface oxidation and peeling are observed. These changes can be seen in Figure 12.

6013

7018

SG2 S2

Figure 12: Color change and fracture of specimens at different temperatures

According to the observations of the specimen after the fracture in Figure 12, in the welded specimens obtained from the 6013 electrode, brittle fracture occurred at low temperature (25 degrees), but ductile failure occurred with the increase in temperature. These are formable fractures of the slant fracture type. The fracture in the rest of the specimens at different temperature levels was ductile and of "cup and cone" type. The most probable example of ductile failure is that in uniaxial tension, "cup and cone" failure occurs. Upon reaching the maximum load, the plastic deformation in a cylindrical tensile test piece becomes macroscopically inhomogeneous and concentrated in a small area which is called necking. The final fracture occurs in this area and has a characteristic appearance such as a cone-shaped area at the edge caused by the cut and a central flat area caused by the holes created there. In fact, when the total plastic strain reaches a critical level, voids form a core and grow inside the specimen. The voids grow until they merge. At first, they are coaxial, and their shape changes according to the overall stress field. As the holes merge, they spread to the adjacent areas due to the stress concentration effect. Once the center of the specimen is essentially detached, the fracture will grow outward. As the elastic-plastic limits change, the plane of maximum shear (approximately 45° to the tensile axis) is favored and most growth occurs along these planes, which form the sides of the cup. [23,24].

3-5- Toughness and Energy Absorption

Toughness is the ability of a material to absorb energy and change its shape before failure. In other words, it is the amount of strain energy per unit volume that a material can absorb before fracture. Toughness can be calculated using the area under the stress-strain curve up to the breaking point. Its explicit description in mathematical form in terms of (J/m3) is as follows [25]:

$$U_T\left(\frac{Energy}{Volume}\right) = \int_0^{\varepsilon_f} \sigma d\varepsilon \qquad (1)$$

Where:

ε : strain

ε : failure strain

σ : stress

According to equation (1), the amount of strain energy absorption obtained from the specimens at different temperatures is presented in Figure 13.

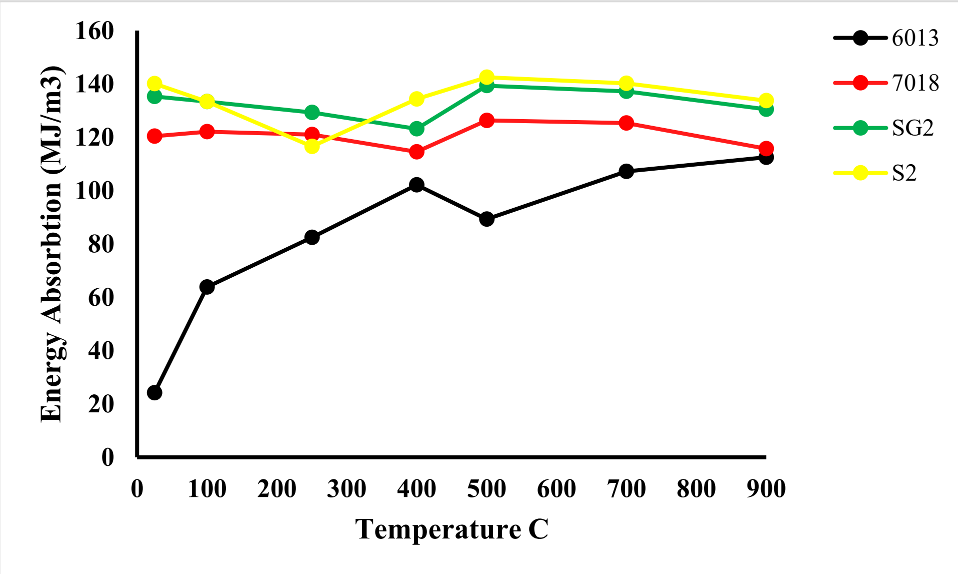


Figure 13: Energy absorption rate of specimens at different temperatures

As can be seen, in the E6013 specimens, at low temperature due to brittle fracture, there is lower energy absorption than at the other temperatures. As the temperature increases, the amount of energy absorption also increases. In the case of other specimens, the highest amount of energy absorption occurred at a temperature of 500 °C. As mentioned before, the temperature of 500 °C is the critical temperature of the beginning of the reduction of strength and also the increase of ductility.

4- Comparison between the Results of this Sturdy and Other Research

In this section, the comparison of the type of test, the number of tests and the summary of the results obtained from this research and other studies are discussed.

By performing 39 different tests on butt welded connection specimens made of Q345 steel that were exposed to elevated temperatures and then cooled to ambient temperature, it was shown that these specimens regain 88% of their strength at 800 °C, and when heated to above 400 °C attain failure in the weld region [15]. In 78 fillet welded connection specimens made with Q345 base metal, failure occurred in the base metal throughout 20–800 °C exposure range [15]. In another study, 18 of each Q235 and Q345 butt weld specimens were examined, and the post-fire ultimate strength at 800 °C decreased to 91% and 87%, respectively [16]. further, the post-fire performance of complete joint penetration welds made of ST37 base metal was investigated by performing tests on 168 specimens [20]. The results of this study indicate that the strength of the specimens decreased by 20% after exposure to 900 °C and cooling down to the ambient temperature. Also, failure occurred in the base metal [20].

As mentioned in the introduction section, most of the experimental research conducted is related to welded joints, and limited research has examined weld metal to have an accurate understanding of the during and post-fire behavior of different weld metals. By manufacturing 57 specimens of butt weldments composed of Q420B base metal and E5515G electrodes, the performance of specimens up to 800 °C was investigated by performing steady-state tensile tests and transient-state tests [17]. By manufacturing 21 specimens for each of the E4303 and E5015 electrodes, the behavior of the specimens was evaluated by performing steady-state tests at elevated temperatures up to 800 °C [18]. The results indicate that the strength of the specimens decreases by more than 90% at 800 °C. In another study, 8 weld metal specimens and 8 Q345qD base metal specimens were manufactured to evaluate the degradation of Q345qD weldment under elevated temperatures. The test data indicate that the yield strength reduction in the weld metal and base metal specimens at 700°C compared to 20°C is 78% and 75%, respectively [21].

According to the mentioned data and comparison with this study, it can be seen that the following points distinguish the current study from others and illustrate the innovation and importance of the results of this paper:

- ❖ Conducting research on weld metal according to the limited studies done in this field
- ❖ Types of weld metal specimens (E6013, E7018, S2 and SG2)
- ❖ Number of test specimens (84 specimens)
- ❖ Post-fire evaluation of specimens
- ❖ Failure modes of specimens

5- Predictive Equations

In this section, based on the test data, predictive equations are proposed to describe its temperature-dependent mechanical properties at elevated temperatures which can be utilized in finite element analysis. In Table 5, the predictive equations of the yield strength, ultimate strength, and elasticity modulus for four types of welds are presented. Also, R^2 values (square of the correlation coefficient) are presented. The results indicated that the predictive equations are appropriate to use in future studies.

Table 5: Temperature-dependent equations

Weld Type	Proposed Equation	R^2
6013	$\frac{f_{y-T}}{f_{y-20^o}} = -(2e-14)T^5 + (4e-11)T^4 - (4e-8)T^3 + (2e-5)T^2 + 0.0029T + 1.0609$	0.94
	$\frac{f_{u-T}}{f_{u-20^o}} = (3e-12)T^4 - (4e-9)T^3 + (1e-6)T^2 + 0.0001T + 0.9968$	0.96
	$\frac{E_T}{E_{20^o}} = -0.0003T + 1.0138$	0.96
7018	$\frac{f_{y-T}}{f_{y-20^o}} = -(6e-7)T^2 + 0.0002T + 0.9806$	0.96
	$\frac{f_{u-T}}{f_{u-20^o}} = -(3e-7)T^2 + (9e-6)T + 0.9923$	0.98
	$\frac{E_T}{E_{20^o}} = (2e-7)T^2 - 0.0005T + 1.0023$	0.97
SG2	$\frac{f_{y-T}}{f_{y-20^o}} = (1e-12)T^4 - (2e-9)T^3 - (3e-7)T^2 + 0.0008T + 0.9835$	0.94
	$\frac{f_{u-T}}{f_{u-20^o}} = (2e-12)T^4 - (3e-9)T^3 + (1e-6)T^2 - 0.0002T + 0.998$	0.95
	$\frac{E_T}{E_{20^o}} = -(1e-14)T^5 + (3e-11)T^4 - (3e-8)T^3 + (2e-5)T^2 - 0.0028T + 1.0612$	0.93
S2	$\frac{f_{y-T}}{f_{y-20^o}} = -(5e-10)T^3 + (4e-7)T^2 - 0.0002T + 1.0125$	0.96
	$\frac{f_{u-T}}{f_{u-20^o}} = -(8-10)T^3 + (9e-7)T^2 - 0.0003T + 1.0154$	0.97
	$\frac{E_T}{E_{20^o}} = (4e-10)T^3 - (6e-7)T^2 + (1e-4)T + 0.9902$	0.96

6- Conclusions

In this study, the post-fire behavior of various weld metal specimens obtained from E6013 electrode, E7018 electrode, S2 welding wire and SG2 welding wire was investigated. For this purpose, the tensile tests of 84 experimental specimens were performed after exposure to different temperatures and cooling naturally. The most notable results are as follows:

- ❖ The stress-strain curves of the specimens along with the mechanical characteristics of the specimens such as yield strength, ultimate strength and modulus of elasticity were obtained.
- ❖ According to the examination of the mechanical characteristics of the specimens, the temperature of 500°C was observed as the critical temperature where the strength drop is faced with a more severe trend. This decreasing trend is more obvious at temperatures above 700°C.
- ❖ The ductility of all weld specimens increased at temperatures higher than 500°C, which is very evident at temperatures above 700°C.
- ❖ The recovery percentage of the ultimate strength after exposure to 900°C of E6013, E7018, S2, and SG2 specimens was 85, 77, 89, and 81%, respectively.
- ❖ The yield strength reduction of E6013, E7018, S2 and SG2 specimens after exposure to 900°C was 37, 37, 26 and 32%, respectively.
- ❖ The amount of post-fire elasticity modulus recovery of specimens E6013, E7018, S2 and SG2 was achieved 71, 72, 85 and 76%, respectively.
- ❖ The failure mode of the E6013 specimen at the ambient temperature was brittle fracture and slant ductile fracture in the other specimens. Moreover, the failure mode of the E7018, S2 and SG2 specimens exposed to all temperatures was observed to be ductile and cup and cone fracture occurred at all temperature levels.
- ❖ According to the failure mode of the E6013 specimens, increasing the temperature has a significant effect on increasing the amount of strain energy absorption. In the case of other specimens, the increase in temperature did not affect the amount of absorption rate.
- ❖ The predictive equations have been proposed for the yield strength, ultimate strength, and elasticity modulus of the weld metals at different temperatures. The results indicated that the proposed equations are accurate to use in the finite element modeling.
- ❖ This study provides preliminary data that can support the development of design guidelines of welded connections after fire exposure.

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