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ORIGINAL ARTICLE

Experimental study of the effects of semi-elliptical defects on the API X52 pipeline and its reparation by welding

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ABSTRACT – The aim of the study is to investigate experimentally the influence of the semi-elliptical defect on the steel of grade API 5L X52 pipeline and its reparation by welding operation to keep the safety of hydrocarbons transport network. The tests have been performed on the specimens with/without semi-elliptical defects by using two ratios a/c and a/t, where the defects issue on the piping systems wall is treated by using the welding operation, which focuses on the filling the defected surface as same thickness of the base wall of the pipeline after removing the defects. The decrease of ultimate stress is mainly evident depending on the size of crack, where they compared to the base metal results. The experimental results showed that the reliability of the welding operation is proved especially in the ratio a/c =1, which is similar to that found in automatically welded. It is proved that the ratio a/t = 0.2 curve exhibits similarity to the base metal curve and their elongation conforms to API standard of steel X52 grade. Clearly, corrosion defects cause degradation of mechanical property in the order of 44% to 50% depending on the ratio of $0 < a/c \leq 1$ and from 20% to 80% according to the second ration of $0 < a/t \leq 0.8$. The obtained results proved that the enhanced of mechanical properties by welding reaches to ultimate stress is 559 MPa for the ratio a/t = 0.2 and 531 MPa for the ratio a/t = 0.5. Finally, the experimental results provided that the impact of semi-elliptical defect has effects on the safety of piping systems where welding became as one of among solutions to repair the piping systems.

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INTRODUCTION

Oil and gas companies have been sought to develop of the piping systems including the elbows, the valves and pipelines which have been become the great challenge to increase the lifetime for hydrocarbon transport structures, transport safety and security of energy taking into account the operating conditions including the temperature, the pressure and nature of pipeline materials. The transporting by piping system is one of most tools safety and security to arrive the energy to worldwide moreover, others tools have been used such as trucks, trains or oil tankers, which are less safety then the piping systems. In this strategy, the maintenance of the hydrocarbon transport system and the flow safety during all stages of transport and storage are very important. In addition, the many industrial company have been based on the international standards American Petroleum Institute API 5L [1], and American Society of Mechanical Engineers ASME B31G [2] to design and industry of piping systems the according on the suitable operating conditions to keep the mechanical characteristics for the long time. The small cracks on the piping systems are among dangerous reasons of failure which are often resulted from material (presence of impurities) and industrialization defects [3]. In addition, the prediction of defects became the challenge faced many companies, where some defects generate as a result of the operating conditions (velocity, pressure and temperature), nature of transported fluids (Non-Newtonian fluids) and vibrations (dynamic loading) of pipeline especially in the defective weld zones (elbows, valves) due to the insecure fluid flow (transitional regime) which lead to the fatigue during service [4]. Due to the effect of the cyclic loading (i.e., pressures, vibrations and external factors) on the safety of piping systems, the small cracks can propagate around of defected positions forming different shapes of cracks such as the semi-elliptical forms penetrate the wall of piping systems, thus it lead to fracture [3-5]. In order to continue operation, the integrity of the piping systems during hydrocarbons transport are very significant to assure quantity and quality on the one hand and to keep of the operating process on the other hand [5]. To avoid the corrosion problem, the process of design is usually based on the intern coating made of epoxy resin to isolate the internal wall in order prevent the chemical reactions on the one hand, and on the other hand on the extern coating made of polyethylene to protect from the strong conditions API RP 5L2 [6]. In fact, these criteria allow protecting the piping systems from the defects including external corrosion [7], hydrofluoric acid corrosion [8], sulfate-reducing bacteria on corrosion [9], friction wear, erosion and cracks due to the high pressure and temperature [10]. During operating of piping systems, the phenomenon corrosion can make the challenge faced many companies such as hydrocarbons. For these reasons many techniques were used to analyze the effect of crack for preventing from corrosion, where the corrosion is controlled and examined during operation of the lines using protective devices on the

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one hand [11] and on the other hand basing on the methods for evaluating the real information of operating conditions to predict the failure probability of a buried pipeline network [12,13].

In addition, the corrosion phenomenon which is one of the dangerous advanced steps, leads to weak of the structures of the piping systems and damaged under burst pressure of defects general corrosion [14,15], including the small cracks or different cracks that become critical zones [15,17]. Due to the occur of the complex chemical reactions, the corrosion issue in the piping systems influenced to loss of mineral represented by the brown layer and to decrease of the thickness in lifetime, where the pitting forms change and turn into semi-elliptical depth or length depending on the nature of materials and operating conditions [17-19]. These problems have become great obstacles on the piping systems including elbows [19-21], valves, and components of piping installations, where many studies were performed the impact of defects on the structures, which lead to change the mechanical characteristics, thus it must need to repair by welding [20-23] or by material composites [23-26].

The approximation techniques were used through a three-dimensional finite element to study on the semi-elliptical forms for length (superficial) defect or depth defect. I.S. Raju and J.C. Newman [27, 28] carried out an important study in this field where it was able to explain the crack phenomenon by results of stress intensity factors, which focused of many factors such asthe crack geometries on the wall of piping systems [29, 30]. The results of semi-elliptical cracks have been analyzed with more accurately conditions where many study have been performed by many researchers as Stefan Strobl and al [30-32]. In addition to all these researches the weight parameter was studied by K. Yuan et al [31-34], where these projects allow to study the behavior of cracks on piping systems by using finite element method to calculate the stress intensity factor [33-35]. Many researchers using the method of J-integral that is one an important technique to evaluatethe circular and semi-elliptical cracks over multiple rang and dimension types for steel pipes [35-37]. The improving of piping system materials is one of among major challenges to protect installations of hydrocarbon transport from corrosion defects and multiple-cracks at points of weakness. Depending on the results of many studies including L. Xu et al [35] who was based by using finite element method to analyze the effect of multiple cracks through the impact of mechanical properties on the safety of pipe steel such as the tensile and the bending stress with different crack depth ratios of shape semi-elliptical on the one hand and on the other hand the crack distance [37-41].

To analyze the cracks phenomenon of piping systems during the transport of hydrocarbons, the technique of S-version FEM was used to study the growth of semi-elliptical cracks for API X65 gas pipeline, where it is one of among an important methods to predict the behavior of crack taking into account the operating conditiond, nature of materials as well as the positions of crack at the critical zones. This method was utilized to calculate the stress intensity factors (SIFs) which are depended on the geometry of crack including the crack depth (a) and crack length (c) [42-45, 50]. The J-integral is one of among methods to study the behavior of cracks especially semi-elliptical shape which have strong relationship with several factors such as pipeline dimensions, defects type (circumferential, longitudinal), defect size, mechanical characteristics of piping systems, and the limit load of pipeline [46, 50-54]. To study the safety of structure, it can use Failure Assessment Diagram (FAD) which can classify the degree resistance of wall cracks and surface cracks through three zones including: safety, security, and failure [46-47].

The improving of the piping systems characteristics and repairing by the suitable patches such as the composite material are among solutions to prevent the propagation of cracks especially the semi-elliptical crack [48, 55-57]. In order to improve the mechanical characteristics due to the hydrogenation effect on the API X65 steel pipeline which occurs by transporting hydrocarbons taking into account the operating condition, where A. Magno et al [41,58] enabled to study this phenomenon depending on nature of fluid transported and in the mechanical properties of steel [58]. In addition, some experimental studies that were carried out to prove the hydrogenation issue were depended on tensile and Charpy operations, where this problem effects directly on the piping systems taking into account the effect of intensity of stress along of pipeline wall [59-61]. Depending on the complex chemical reactions and the operating conditions, during the hydrocarbons transport through the pipeline, can provide important information basing on the suitable conditions around the effect of the hydrogen mixture on the mechanical features of piping systems where this phenomenon leads to decrease of ductility and toughness on the one hand, and on other hand the degradation of the mechanical characteristics of high-strength steel pipelines, including API X70 [62, 63], API X80 [62, 63].

Focus on the numerical data and experimental results is one the solution to predict the behavior of piping systems where these methods enable for analyzing the defects phenomenon such as the cracks and the weakness positions related with welding processes on the walls and to present the solutions by using the finite element method at the tip of cracks depending on three-dimensional geometry [64-65]. Depending on the operating conditions including the pressure and temperature, which is taken into account to measure of stress concentration propagation at critical positions of piping systems. In addition, this process has been based by using the strain gauges which is one of methods to evaluate accurately the mechanical behaviour at near to tip of cracks including the form of semi-elliptical, H. Moustabchir et al. [66]. The comparison between the experimental and numerical results by using same boundary conditions leads to totally correspond of the solutions, which enable to analyze and to evaluate the behavior of defects especially the semi-elliptical cracks along of internal and external sides of piping systems, J. Lukács et al [67], where some projects were studied to enhance mechanical properties of the network systems [68-70]. To keep the safety of piping systems from many dangerous phenomena represented by defects such as cracks welded zones [71,72] and stress corrosion cracking which lead to explosion [73], where the solutions are became as challenges faced on hydrocarbons industries.

Using the composites materials especially the carbon fibers, as solutions tomaintain integrity improve transport systems especially the reinforce pipelines external surfaces[74-76], where these solutions can evaluate the effects of small cracks on the safety of needed energy supply [77, 78]. Meriem-Benziane et al. [79] confirmed that the using of patch from the composite materials for single and double layers is important solutions to repair API X65 pipeline cracks where they obtained results indicate a considerable decrease of the stress intensity factors (SIF) for different pressures at repaired cracks [80-81]. To avoid the failure issue of piping systems, the welding operation is still an important process to connect between two parts of pipeline. Indeed, the predominantly crack phenomenon is related with weak zones and small cracks under high pressure and high temperature [12, 46, 54, 81], where this domain has not evidenced precisely yet , due to the nature of hydrocarbons transported such as crude oil with/without aggressive compounds (naphthenic acid, sulfur compound and H_2S) and impurities on the wall as well as the nature of piping systems materials (ordinary or composite).

The aim of this project is to study experimentally the effects of semi-elliptical cracks on the API X52 pipeline and its reparation by welding operation, where two types of the specimens with/without defects were tested by tensile tests to evaluate the resistance of the piping systems with the presence of cracks defects which are represented by two principal configurations of the ratios (a/c) and (a/t). The tests focus on the studying of the mechanical properties behavior of structure containing defects on the wall, as well as structures reinforced by welding. However, the repair of pipeline systems by welding operation is necessary step to fill the surface defects of semi-elliptical shape in order to make the defected surface to same thickness and efficiency of base metal. The results purpose to evaluate the defects reasons, which lead to the influence of cracks on the piping systems material and on the energy transport on the one hand. On the other hand, the obtained results can provide the solutions of defects the semi-elliptical forms in the piping systems afterits reinforced by welding process which is one among of sustainably solutions of cracks.

MATERIAL AND EXPERIMENTAL METHODS

Material

The API X52 steel used in this project was supplied by company ALTUMET (in Algeria) to study the effect of defects on the surfaces of piping systems by using the traction machine. This project allows to analyze the crack phenomenon through the experimental study to show the effect cracks of semi-elliptical forms and their repaired by using welding operations to improve the mechanical characteristics. Table 1 summaries the physic-chemical characteristics of API X52 used in this study, where the tests were carried out in the laboratory of the ALTUMET company in Algeria. The impetus for the defected piping systems project especially the defects including semi-elliptical form has been become a great challenge to prevent the corrosion phenomenon as well as to control the safety of transport systems [82]. Considering that the form of defects phenomenon in piping systems is one of among reasons failure based on the ratios a/t and a/c which enable to understand and to analyze this issue.

Table 1. Chemical composition and mechanical properties of API X52 [1, 21, 90]

Chemical composition (%)	C	SI	Mn	P	S	Cr	Mo	Ni	AL
	0,038	0,258	1,12	0,0093	0,0019	0,0306	0,003	0,024	0,0214
	Cu	V	Nb	Ti	Pb	Sn	B	Ca	Co
	0,0188	0,0019	0,349	0,0018	0,001	0,004	0,0001	0,0002	0,0008

Mechanical properties	Young Modulus E (GPa)	Yield Strength, σ_Y (MPa)	Ultimate Strength σ_u (MPa)	Elongation [%]
	210	≥360	≥ 460	32

TEST SPECIMEN AND EXPERIMENT

Tensile Test Specimens

Through last few decades, piping systems exposed under major problems such as the corrosion due to the cracks, complex chemical reactions, nature of material and transported energy nature. Nowadays, there aren't any reports to study the semi-elliptical defects experimentally; this project has sought to analyze the effect of cracks such as semi-elliptical shape on the safety of pipelines. However, the second aim has focused on the provide the solutions by using the welding operation to repair and to reinforce the zones defects.In order to study the behavior of crack as semi-elliptical defect depending on ratios a/c and a/t which has been become a challenge faced on the pipeline industries under several operating conditions such as high pressure and temperature. Several of specimens (ASTM A370) [82-84] of steel pipeline API X52 were formed basing on semi-elliptical forms through length cracks (a/c) and profounder cracks (a/t).

All cuts of the same pipe were prepared of two types of the base metal specimens with/without the weld bead in the longitudinal direction of pipeline see Figure 1. In addition, basing on the milling machineis used to perform the real geometry where the defects put on the surface of piping systems through frieze hollowed to obtain the semi-elliptical shape (Figure 2(a)). Two forms distinguish the semi-elliptical defects: the first is characterized by the variation in defect length (c), and the second is characterized by the variation in depth (t) [83-85]. The results of test specimens for the semi-elliptical defects are summarized in Table 2.

Table 2. Results of tensile test for forms of specimens with/without defects

No	Specimens	*t* (mm)	*a* mm	C (mm)	*W* (mm)	*L* (mm)	L_0 (mm)	*B* (mm)	*R* (mm)
1	Base metal specimen without defect	10.3	-	-	38	340	100	55	20
2	Base metal specimen with welding	10.3	-	-	38	340	100	55	20
	First type : corrosion length								
3	Specimen with defect a/c = 01	10.3	5	5	38	340	100	55	20
4	Specimen with defect a/c = 0.7	10.3	5	7.5	38	340	100	55	20
5	Specimen with defect a/c = 0.4	10.3	5	14	38	340	100	55	20
6	Repaired specimen defect a/c = 01	10.3	5	5	38	340	100	55	20
7	Repaired specimen defect a/c= 0.7	10.3	5	7.5	38	340	100	55	20
8	Repaired specimen defect a/c= 0.4	10.3	5	14	38	340	100	55	20
	Second type : corrosion depth								
9	Specimen with defect a/t = 0.2	10.3	2	5	38	340	100	55	20
10	Specimen with defect a/t = 0.5	10.3	5	5	38	340	100	55	20
11	Specimen with defect a/t = 0.8	10.3	8	5	38	340	100	55	20
12	Repaired specimen defect a/t = 0.2	10.3	2	5	38	340	100	55	20
13	Repaired specimen defect a/t= 0.5	10.3	5	5	38	340	100	55	20
14	Repaired specimen defect a/t= 0.8	10.3	8	5	38	340	100	55	20

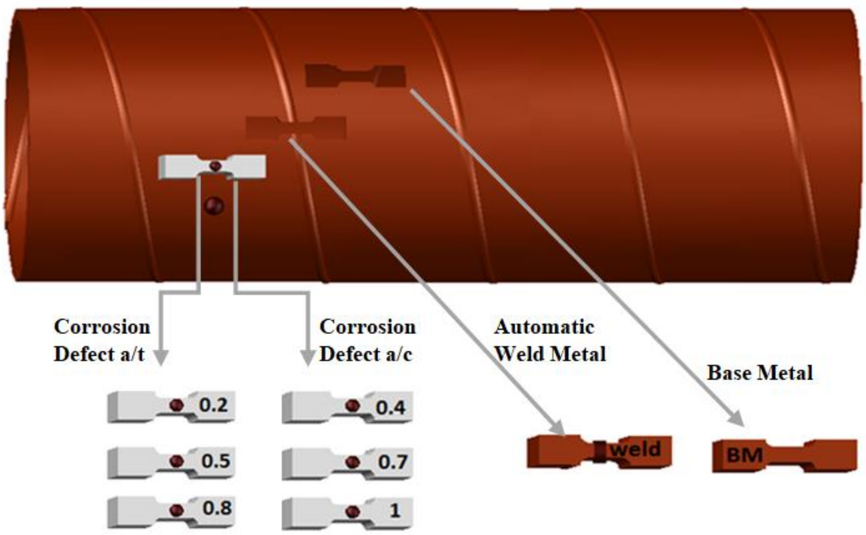
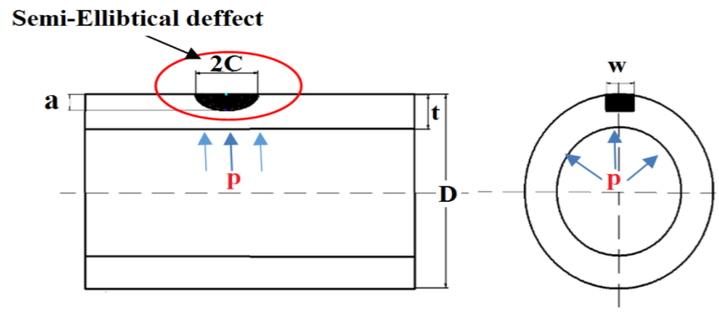
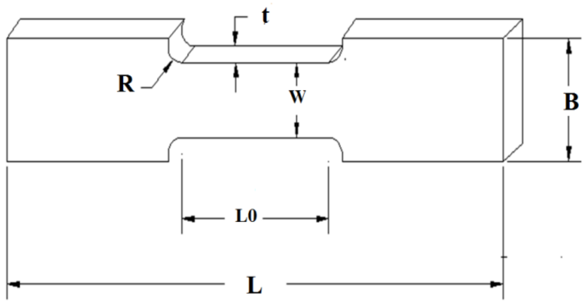


Figure 1. Location of tensile specimens in API 5L X52 pipe



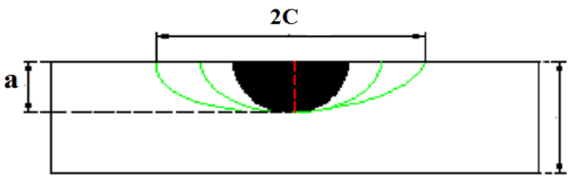
(a)



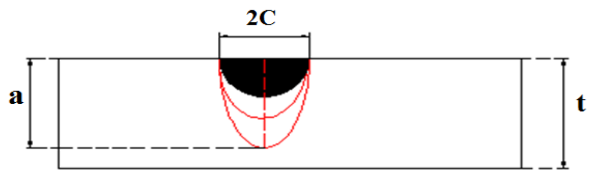
(b)

W:corrosion width, c: Corrosion length, a: Corrosion depth

Figure 2. (a) Geometry standards of semi-elliptical defects and (b) Dimension of the test specimen



(a) Length Semi-elliptical crack ratios basing on $0< a/c \leq 1$



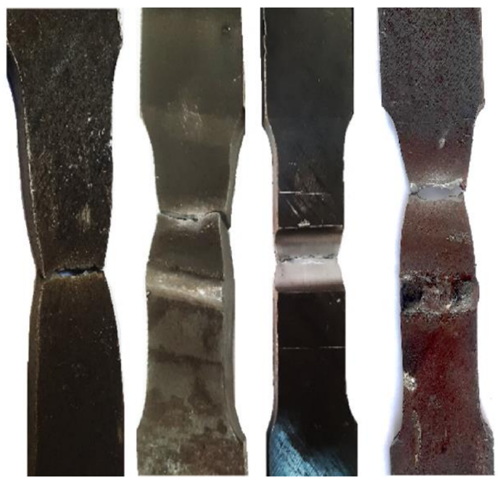
(b) Profounder Semi-elliptical crack ratios basing on $0<a/t\leq 0.8$

Figure 3. Forms of defect geometry used in the test tensile

Experimental Method

The main idea of this project about the safety of piping systems were carried out by using the test tensile to study the crack of semi-elliptical as well as the geometry of crack including longitudinal and depth forms, are necessary steps to find an accurately solutions through the study of structural integrity for the hydrocarbons transport as shown in the Figure 4. All performed experiments were tested at ambient temperature by using tensile test along the longitudinal axis of the pipeline.

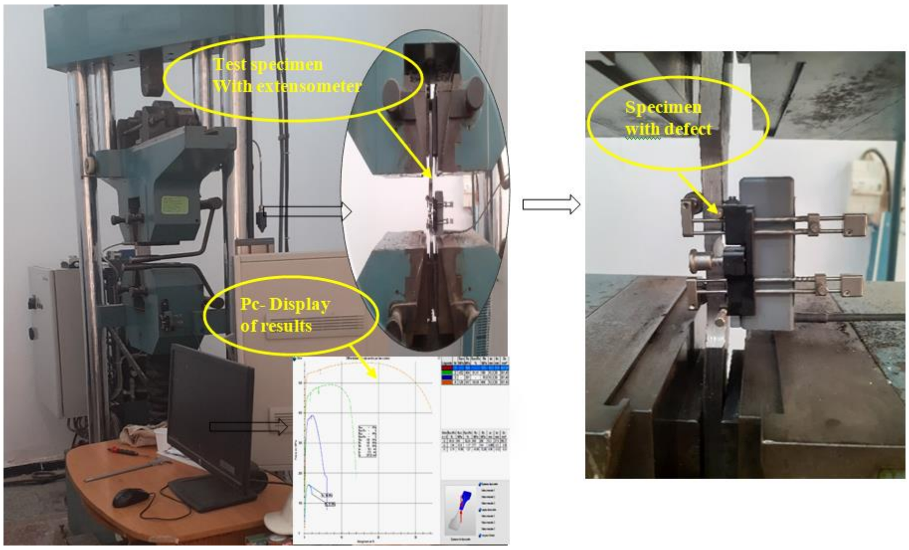
(a)



(b)

Figure 4. Experimental set up: (a) Before failure and (b) After failure

During the experiment, the specimens were put on the clamps of the machine (see Figure 5), than the flat specimen was withdrawn from both ends in tension until failure. The loading was applied under displacement by using an extensometer to monitor displacement. In addition, the obtained results were saved by using software on computer linked to measure instrument, which show the stress-displacement curves. To protect the pipeline transport systems from corrosion phenomenon, the specimens with semi-elliptical defects were repaired by process welding where these specimens were performed with same test steps above. Likewise, the specimens with an automatic welding was based considering submerged arc welded (SAW) bead that was prepared and tested to comparison with the specimens that had been repaired.



(a) (b)

Figure 5. (a) Zwick-Roell brand universal testing machine and (b) Specimen with defect and extensometer

TEST RESULTS AND ANALYSIS

Experimental Method

In order to understand the effect of semi-elliptical defect behaviour and it's repaired by welding process basing on the experimental values. It is noted from the experimental study that the semi-elliptical defect have been shown a considerable effect on mechanical characteristics of pipeline. The defect is evident from the Table 2 through ratios of a/c and a/t. The equipment used in this investigation is a test tensile machine to study the resist of material API X52. In addition, the ratios values of semi-elliptical shape a/c and a/t have been evidenced effects of these factors on the safety of piping systems. The obtained results are plotted in Figures 7 and 9, where the Figure 7 evidences the effect of the geometry of longitudinal defects on the safety of pipeline, and in Figure 9 shows the effect of geometry of depth defect on pipeline [15]. The obtained results in Figures 8 and 10 are provided as solutions of defects which lead to prevent from the corrosion issue in semi-elliptical defect. The results are shown mainly based on the variation of defects geometry longitudinal (a/c) and depth (a/t). The ration a/c is parameter which can influence on the safety of transport network, while changing the crack along of the longitudinal of pipeline [85, 86].

Table 3. Tensile mechanical properties of processed specimens

Specimen	Yield Stress (MPa)	Ultimate Stress (MPa)	Strain Elongation (%)	Yield Ultimate Ratio	Toughness (KJ m^{-3})
Specimen of base metal	452	558	40.86	0.81	20646.47
Specimen of welded metal	456	572	25.56	0.79	12465.14
First configuration					
Specimen with defect a/c = 1	-	311	07.36	-	1895.72
Specimen with defect a/c = 0.7	-	306	07.12	-	1914.94
Specimen with defect a/c = 0.4	-	259	07.90	-	1696.42
Specimen repaired a/c = 1	455	531	25.36	0.85	12374.17
Specimen repaired a/c = 0.7	452	533	24.67	0.84	11125.60
Specimen repaired a/c = 0.4	418	480	16.62	0.87	6736.38

Table 3. Tensile mechanical properties of processed specimens (cont.)

Specimen	Yield Stress (MPa)	Ultimate Stress (MPa)	Strain Elongation (%)	Yield Ultimate Ratio	Toughness (KJ m^{-3})
Second configuration					
Specimen with defect a/t = 0.2	448	488	12.71	0.92	5912.10
Specimen with defect a/t = 0.5	-	311	07.36	-	1895.72
Specimen with defect a/t= 0.8	-	160	01.98	-	274.59
Specimen repaired a/t= 0.2	520	559	33.62	0.93	17729.03
Specimen repaired a/t = 0.5	455	531	25.36	0.85	12374.17
Specimen repaired a/t = 0.8	330	399	05.18	0.83	1704.68

Tensile Test of Different Specimens

Figure 6 has been shown that the obtained stress-deformation curves by using the tensile tests for the base metal and of the weld bead of API 5L X52, could indicate the stress as a function of the deformation in first stage by a linear elastic reach to value of 452 MPa, which corresponds to strain values of 0.5%. In the second stage occurs the plastic deformation through the parabolic form of the stress reach to a maximum value of 558 MPa for the base metal specimen and of 572 MPa for the automatic welding specimen. Finally the third stage is distinguished by increasing plastic deformation to rupture state through the following values 41.86% of the raw metal specimen and of 25.56% for the specimen with automatic weld beads. The tensile test results and the stress-strain curve correspond with the industrial standards [1] and existing literature for pipeline steels, type API X52 [86-88].

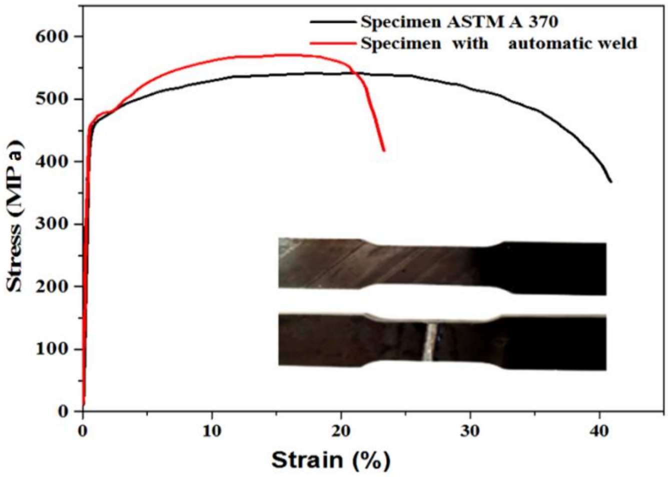


Figure 6. Stress-Strain curve for API X 52 pipeline steel when tested with specimen automatic weld and without weld

Tensile Test of Specimen with Defect Through Ratio 0 <a/c≤1

The tensile tests were performed on specimens with semi-elliptical defects. Three forms of defects were experimented by varying the length of the defect (c) and retaining the fixed depth (a) which enter in the framework of the conditions of the ratio 0<a/c≤1, as displayed in the Table 2 [28, 29, 30]. Figure 6 proved that the degraded external and internal wall has been reused due to the presence of the semi-elliptical defects of the API X52 pipeline, where this phenomenon is featured by a marked diminution in ultimate stresses as shown at the values 259 MPa for a/c = 0.4 which are compared by the values of the base metal specimen 558 MPa, moreover the elongation values decreased from 40.86% to 7.12% [87-89].

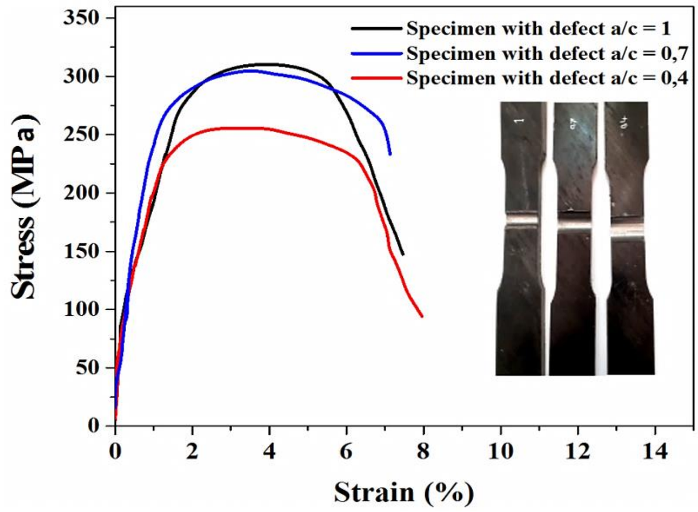


Figure 7. Stress-Strain curve for API X 52 pipeline steel when testedwith the various defects tensile specimen of 0<a/c≤1

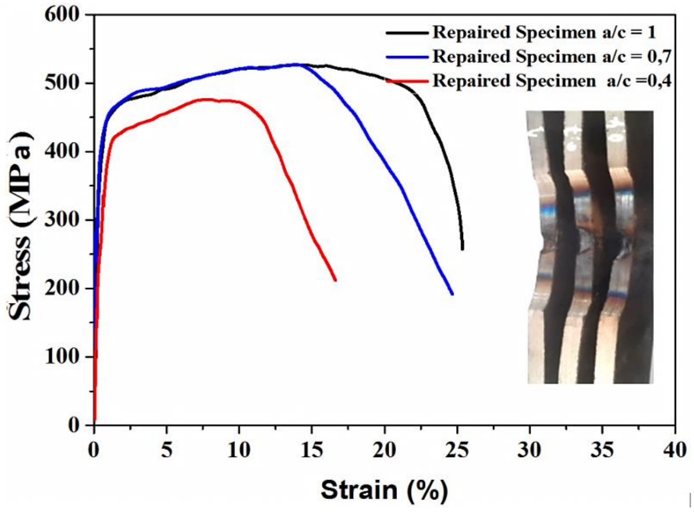


Figure 8. Stress-Strain curve for API X 52 pipeline steel when tested with the repaired welding tensile specimens of 0<a/c≤1

However, the diminution of mechanical characteristics values change from 40% to 50% for the three forms which are compared with the base metalas shown in the Figure 7, Hence, the obtained results proved that the variation of the form length (c) leads to decrease the safety of piping systems on the one hand. On the other hand, in the Figure 8 the obtained results have provided that the repair by welding through the test specimens have become one of the most solutions which have a great efficiency on the keeping the mechanical properties by their comparing by defected specimens [84-87]. Consequently, the keep the mechanical characteristics of pipeline by weld repairing is consideredas challenge for many companies basing on the nature of piping systems and kind of transported liquids, for the first specimen when the ratio a/c =1. The maximum value of stress reaches to 531MPa and the elongation to 25.36% , for the second specimen when the ratio a/c = 0.7, the values of stress reaches to 533 MPa and the elongation to 24.67% and, for third specimen when the ratio a/c = 0.4, the value of stress reaches to 480 MPa and the elongation to 16.62%.

Tensile Test of Specimen with Defectfor Ratio 0 < a/t ≤ 0.8

The second type of semi-elliptical geometry which is represented by the ratio a/t which is based on the variation of depths (a) and fixed length (c) depending on the condition of 0 <a/t ≤0.8 [28-30]. Figure 9 shows the curves of the tensile test results of the specimens with presence of defects as displayed in the Table 2 of the a/t ratio.

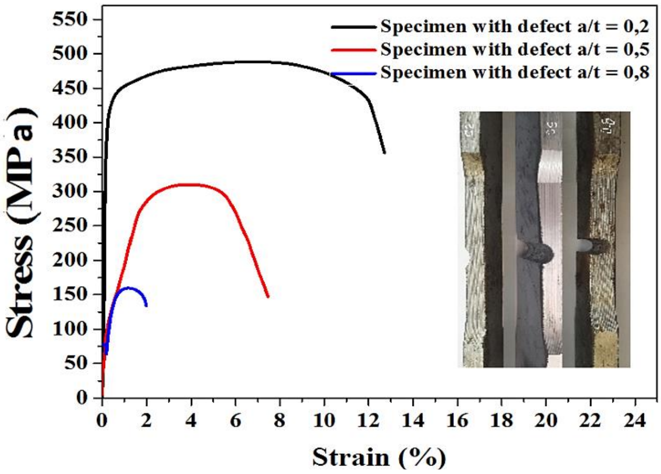


Figure 9. Stress-Strain curve for API X 52 pipeline steel when testedwith the various defects tensile specimen of $0<a/t\leq0.8$

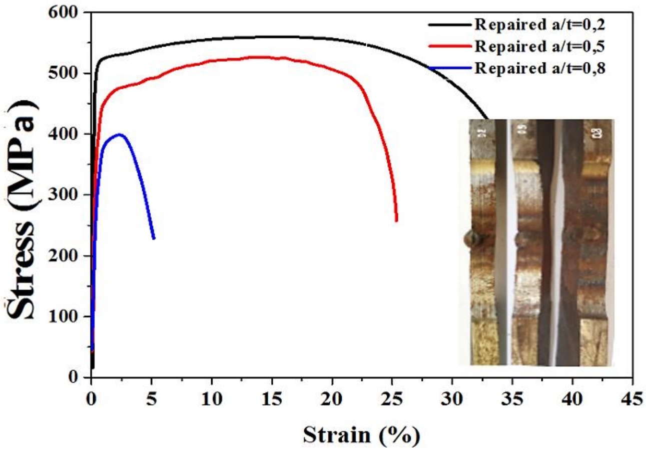


Figure 10. Stress-Strain curve for API X 52 pipeline steel when testedwith the repaired welding tensile specimen of $0 < a/t \leq 0.8$

At the semi-elliptical form a/t = 0.2 as the first casewhere the maximum value of stress reached to 488 MPa and its elongation 12.71%, in the second form is considered by the ratio of a/t = 0.5, where the stress is 311MPa and its elongation 7.36%, in the third form a/t = 0.8, where the stress is 160 MPa and its elongation 1.98 %. The obtained results explain that the crack phenomenon with semi-elliptical form lead to crack API X52 pipeline which characterized by a reduction of the ultimate stress from the value of 558 MPa for the base metal specimen to 160 MPa for the cracked specimen [17-19]. Depending on these characteristics, which have directly relationship with specimen with defect of the depth (a), where the elongation value decreased from 40.86% to 1.98% led to degradation of piping systems. In addition, the Figure 10 obviously shows that the repairing by the welding process is considered a great challenge where these solutions have a valuable effect on the safety of piping systems through compared to results of the specimens with defects [21-23]. Basing on the increasing of the mechanical characteristics, the first form of ratio a/t = 0.2 the maximum value of ultimate stress is become 559 MPa and its elongation value 36.62%. Then in the second form of semi-elliptical for a/t=0.5, where the maximum value of ultimate stress is become 531 MPa and its elongation value 25.36%, with regard to the third form of defect a/t = 0.8, the maximum value of ultimate stress 399 MPa and its elongation value 5.18%. This study provided many solutions and more explanations about the crack of semi-elliptical form, where the strategy of solutions is basing on the operation welding through reinforcing the structure at the point of the defect depending the ratios of geometry a/c and a/t. Basing on the criterion to the API [1] standard of steel X52, the increasing of ultimate stresses and elongations have been indicated by depending on the geometry and with different crack depths ratios of semi-elliptical forms, except for the third figure, which is characterized by the lowest depth (a), which is more than half the thickness. The adopted criterion exhibits a potential dependence on defect geometry and possibly on material's strain capacity [88-90]. For this purpose, it cannote that the repairing by welding has a good resultswhen the value of ratio a/t is greater than 0.5. The obtained results proved that the welding process is one of among methods to improve and to increase the degree of safety where these solutions lead to increase the efficiency from 80% to 98% depending on the size of the defects through the ratio $0.5 < a/t \leq 0.8$. It has been shown that the stress-strain curve of a/t= 0.2 was identical to the base metal curve including its elongation, where the results agreed with the standard of steel pipe API X52.

AUTOMATICALLY AND MANUALLY WELDING OPERATIONS

Results of Repaired Pipes and Compared

In order to show the importance of welding operationsin the safety of piping systems, the comparison between stress versus strain for two tests specimens related with welding operation through two cases allow to reinforce of the piping systems resistance taking into account the mechanical characteristics of materials. It is necessary to study the efficiency of welding, where the first specimen was carried out automatically and the second specimen was carried out manually for repairing the semi-elliptical defect depending on the ratio a/c =1 as shown in Figure 11.

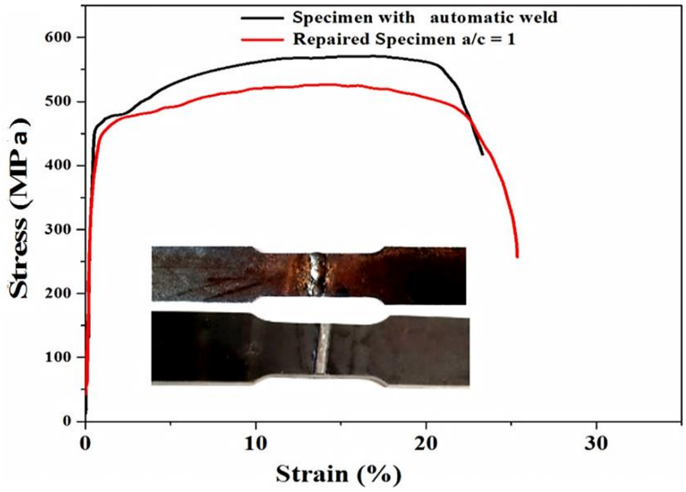


Figure 11. Stress-Strain curve for the compared to different withrepaired specimen of a/c =1 and with specimen automatic weld

This strategy provided the solutions valuable which led to increase the efficiency through the stress increases for the manually welding, which is agreement with automatically welding, i.e. the difference of 7% for the ultimate stress and of 1% for the elongation. Repairing by welding is one of the important techniques to treat the corrosion phenomenon and to develop the mechanical characteristics in order to reinforce the piping systems, where they obtained results summarized in the Table 3. Automatically welding is one of the important operations, which are carried out on the specimen of pipeline where this technique is featured by the maximum value of ultimate stress 572 MPa and its elongation value 25.56%. Manually welding was carried out on the specimen of semi-elliptical defect to repair and to reinforce, where it is characterized by the maximum value of ultimate stress 531MPa and its elongation value 25.36%. The experimental results proved that the values of ratio a/c =1 for two cases: the automatic and the manual welding are almost identical in efficiency which can keep the safety of piping systems [90].

DISCUSSION OF RESULTS

Results of Ultimate Strength

Ratio of 0 < a/c ≤1

In order to show the effect of crack on the piping systems through the ratio $0<a/c \leq 1$, where the experimental results clearly explain that the various forms of semi-elliptical of the defected specimens are lower resist than the base metal specimen. Figure 12 clearly explained that the difference between the both results of the ultimate stresses are very significantly, where three ratios (a/c) for 1, 0.7 and 0.4 of defected specimens gave values of 311 MPa, 306 MPa and 259 MPa, respectively which compared with the base metal specimen of 558 MPa [17-19].

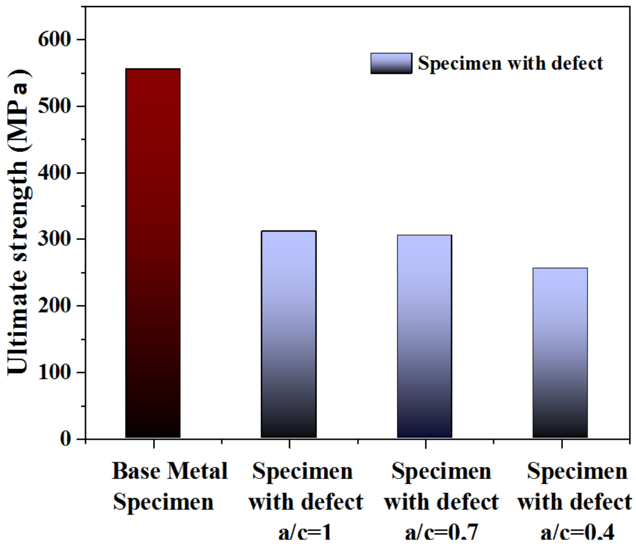


Figure 12. Results of ultimate strength when testedwith the defect specimens 0<a/c≤1

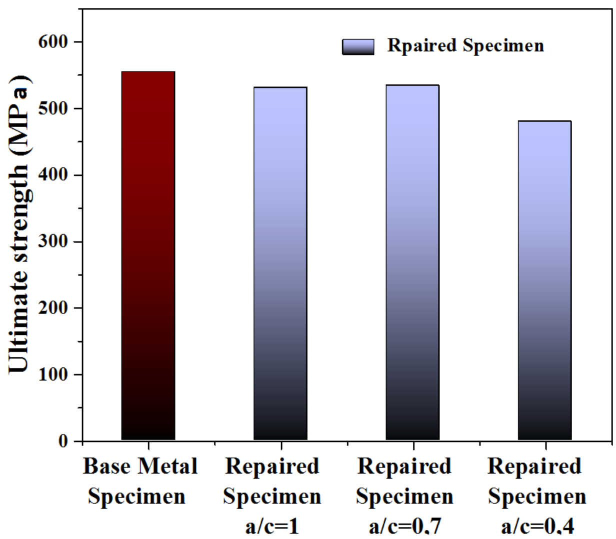


Figure 13. Results of ultimate strength when testedwith the repaired welding specimens 0<a/c≤1

In order to reach an explanation of the semi-elliptical defects through the ratio a/c that the experimental results of the ultimate stresses for three shapes of 0<a/c≤1 are lower than the experimental result of the base metal specimen as shown in the Figure 12. It can be noted that the obtained results proved the importance of welding operation as shown following.It is worth to mention that three ratios (a/c) for 1, 0.7 and 0.4 of repaired specimens gave values 531 MPa, 533 MPa and 480 MPa respectively which compared with the base metal specimen of 558 MPa, as shown in the Figure 13.

Ratio of 0 < a/t ≤ 0.8

It is interesting to remark that Figures 14 and 15 indicated the effect of the defects of ratios (a/t) on the transport systems security through of the ultimate strength compared to the base metal specimen result. The results of Ultimate strengths appear that the specimen base metal is greater than the specimens with defects. Experimental tests were performed by base metal specimens and defected specimens of ratio a/t at different values of semi-elliptical geometry (0.2, 0.5 and 0.8).

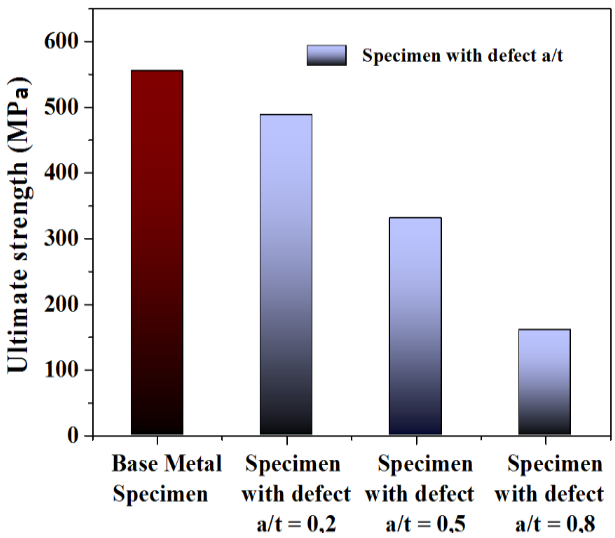


Figure 14. Results of ultimate strength when testedwith the defect specimens 0<a/t ≤0.8

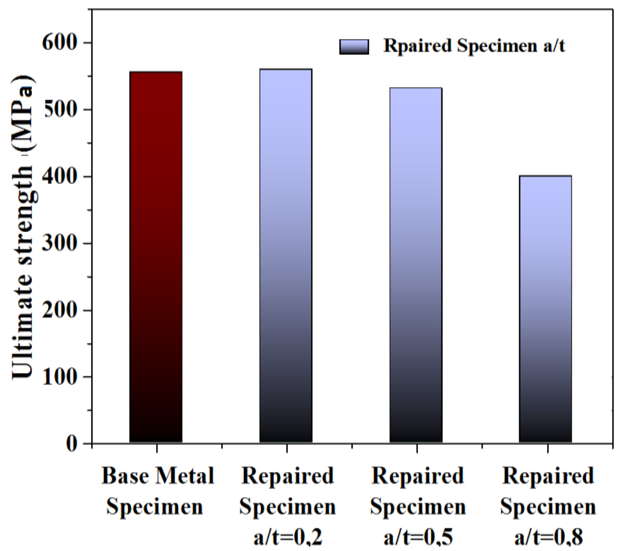


Figure 15. Results of ultimate strength when testedwith the repaired welding specimens 0< a/t ≤ 0.8

The results of ultimate strength measured for the different defects of semi-elliptical through the ratios a/t were: 0.2 for 488 MPa, 0.5 for 331 MPa and 0.8 for 160 MPa. In summary, in order to investigate the effect of defects, the presence of semi-elliptical defect reduces the mechanical characteristics especially at the ratio a/t=0.8. Depending on the ultimate strength the maximum value of the ultimate stress of the defect at the ratio a/t = 0.2 almost conforms to API 5L standard andas mentioned above. Thus the results of ultimate strength of a/t = 0.2 and a/t = 0.5 can explain that the variation of the depth shape (a) for semi-elliptical geometry has great effect on the behavior of defects and security of piping systems [14-16].

Elongation Test Tensile of Base Metal, Defect Metal and Repaired Metal

Experimental Results for Ratios 0 < a/c ≤1 and 0 < a/t ≤ 0.8

The defect of piping systems along on the pipeline especially in the critical zones such as the elbows and the welded zones which are considered as challenge faced on the hydrocarbons companies, where the defects take many forms such as the semi-elliptical shape althrough two Ratios 0<a/c≤1 and 0<a/t≤0.8.

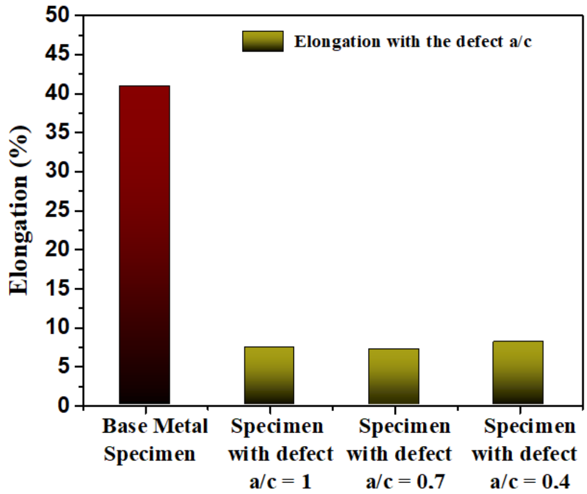


Figure 16. Results of elongation in tensile specimen of base metaland with defect specimens of 0<a/c≤ 1

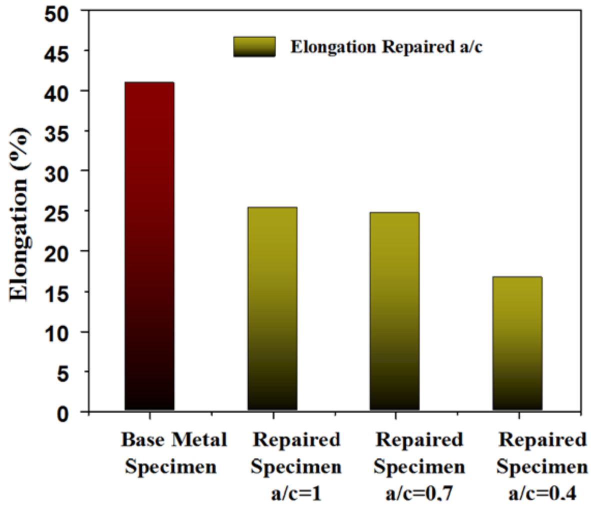


Figure17. Results of elongation in tensile specimen of base metaland repaired welding specimens of 0<a/c≤ 1

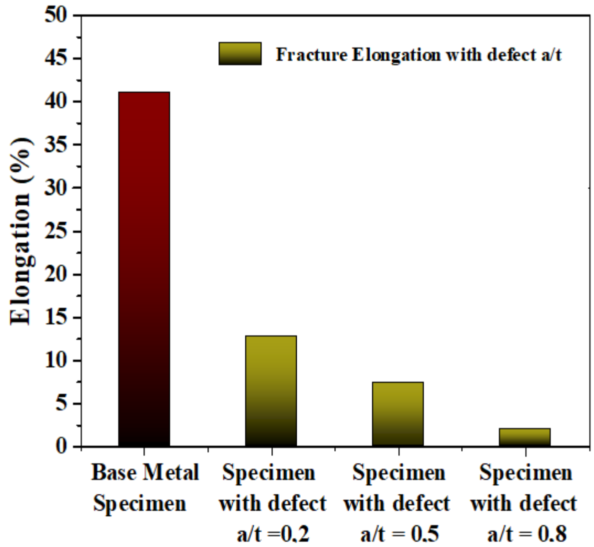


Figure 18. Results of elongation in tensile specimen of base metaland with defect specimens of 0<a/t≤0.8

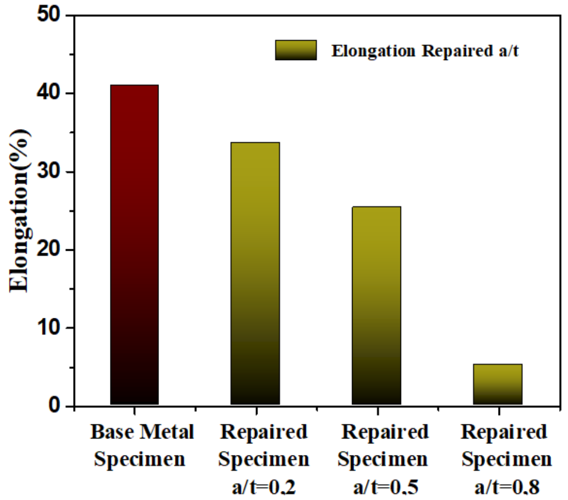


Figure 19. Results of elongation in tensile specimen of base metaland repaired welding specimens 0<a/t≤0.8

Based on the experimental results of the elongation of metal with/without defects to study the resistance of material, the Figures 16 and 18 show that the tensile tests of the defected specimen by semi-elliptical forms where the ratio a/c lost almost the average of 80% and the ratio a/t lost from 67% to 95% compared to base metal. Depending on the obtained experimental results in order to understand this phenomenon, the effect for different ratios a/c and a/t for the semi-elliptical defect on the safety of piping systems are important factors to analyze the behavior of crack and security of transport systems. The experimental results of elongation show the variations of effect of ratio a/c and ratio a/t on the defects phenomenon , where the percentage of semi-elliptical for the ratios a/c varied from 7.36% to 7.9% which are considered as a simple change. However, the high difference of elongation according on the variation of the ratios (a/t) indicates to effect of defect on the mechanical characteristics by percentages from 12.36 % up to 1.98%. It is interesting to mention that the experimental results, for considered phenomenon explained the behavior of defects of semi-elliptical through ratios a/c and a/t, which effect on the size of defects. In view of the experimental results, the values which highly percentages were accepted where the ratios a/c=1 and a/c=0.7 gave the elongation values of 25.36% and 24.36% respectively. The same for theratios a/t=0.2 and a/t=0.5 gave the elongation values of 36.36% and 24.36% respectively. From the values obtained in the Figures 17 and 19 show that the repaired specimens showed the improve in the elongation results, thus it explains the develop of the mechanical characteristics according on the accepted elongation value which is greater than 24% depending on the standard required. In order to find accurately solutions and sufficient, the values of ratios a/c=0.4 and a/t=0.8 are not agree with the API 5L standard to keep the mechanical characteristics.

Toughness: Test Tensile of Base Metal, Defect Metal and Repaired Metal

In order to measure the toughness factor which was applied to the critical sections of pipeline to estimate the absorb energy and plastically deform without fracturing. Toughness can be calculated by integrating the stress-strain curve it is energy of mechanical deformation per unit volume prior to fracture where it based on the equation mathematical as following:

$$W = \int_0^{\varepsilon} \sigma d\varepsilon \tag{1}$$

where, ε is the strain, σ is the stress, W is the toughness, energy absorbed to fracture of material in tension.

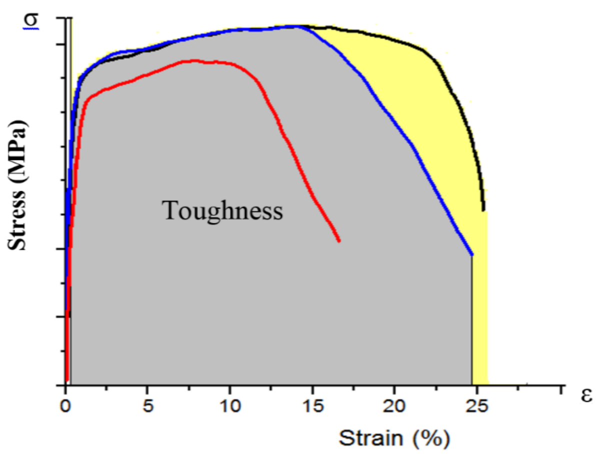


Figure 20. Toughness is bycalculating the areas under the stress-strain curves

Toughness Results for Ratios 0< a/c ≤1 and 0<a/t≤0.8

Figures 21 to 24 proved that the effects of the semi-elliptical of corrosion defect on toughness and the energy absorbed during fracture related with the mechanical properties including the nature of materials. The energy absorbed is become important factor to measure the capacity of material where it is calculated by the integration of the areas under the stress-strain curves through per unit volume. Figures 21 and 23 compare the toughness results of specimens with/without defects which is based on two ratios (a/c, a/t), where the maximum values of toughness and the energy absorbed of defect a/c = 1 and a/t = 0.2 are 1895.72 kJ m^{-3} and 5912.10 kJm^{-3} respectively. As it is observed that the defected specimen can propagate very low energy where it can't occur any bruit during internal rupture (slamming). Contrary, the test specimen of base metal features to propagate high internal energy which is reached to value of 20646.47 kJ m^{-3} and the same of ratio a/t = 0.2 proved better toughness results for the repaired specimen where the value of this operation reached to 17729.03 kJ m^{-3}.

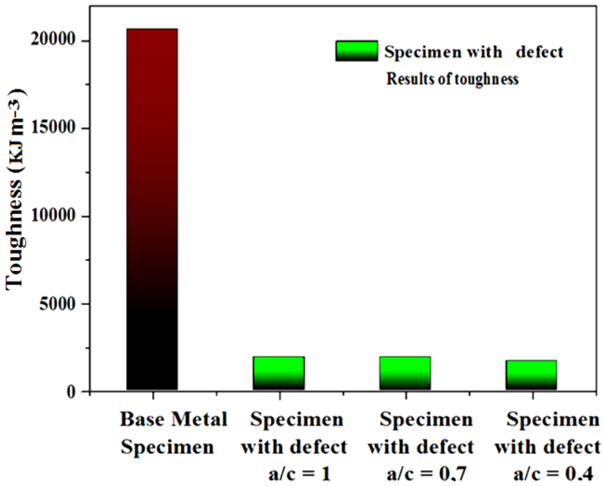


Figure 21. Results of toughness in tensile specimen of base metaland with the defect specimens of 0<a/c≤1

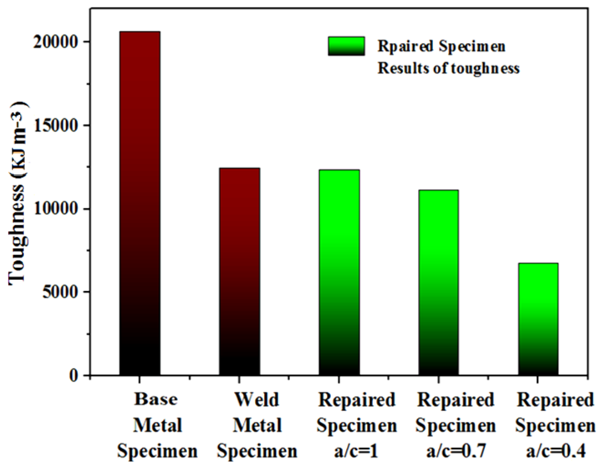


Figure 22. Results of toughness in tensile specimen of base metal, weld metal specimen and repaired welding specimens of 0<a/c≤1

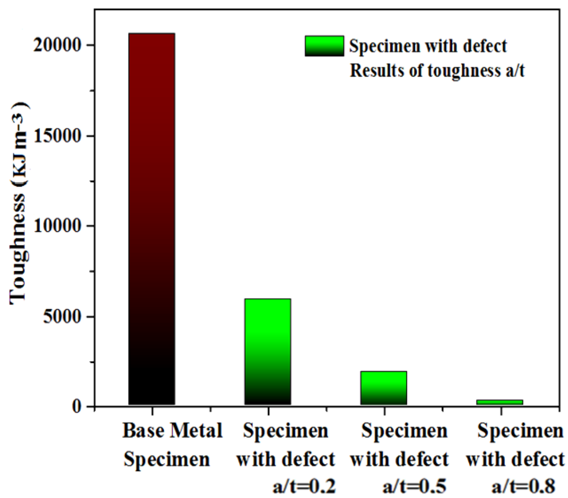


Figure 23. Results of toughness in tensile specimen of base metaland with the defect specimens of 0<a/t≤0.8

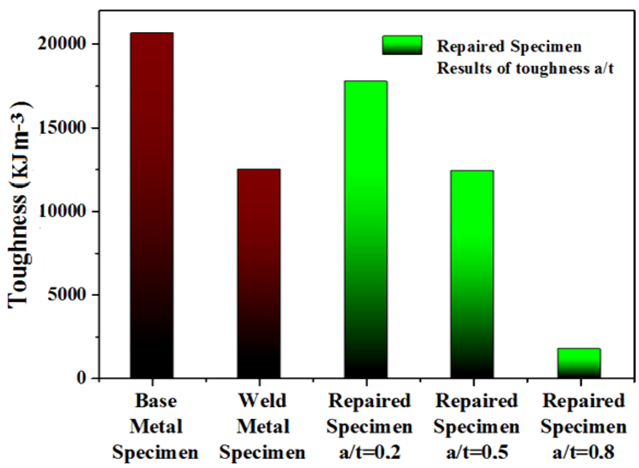


Figure 24. Results of toughness in tensile specimen of base metal, weld metal specimenand repaired welding specimens of 0<a/t≤0.8

In addition, this solution proves that the corrosion of semi-elliptical defect in the depth is more dangerous than the defect length and its repair less efficient in API X52 pipe, where the value of ratio a/t = 0.8 is the lowest value which is reached to 274.59 kJ m^{-3}. Figures 22 and 24 have shown that the ratios a/c and a/t of toughness of tensile are important to show the impact of defect of semi-elliptical along the piping systems such as the refinery stations, elbows and welded zones, where the maximum value of the toughness for the repaired specimen at the ratio a/c = 1 is approximately equal to the toughness of the automatically welded specimen. The welding operation is one of among an important solutions to avoid the crack phenomenon which are occurred under the external/ internal stresses concentration effects, the bending load and the manufacturing defects, where these reasons can influence on the safety of piping systems [5, 49-57].

CONCLUSION

The experimental results obtained by using the tensile test allow to analyze the effect of semi-elliptical defects through two ratios a/c and a/t on the safety of API X52 piping system. The welding operation has been become one of solutions to safety the piping systems taking into account the geometry of defect. Depended on the experimental results, it is clear that the complex behavior of semi-elliptical defects through the ratios a/c and a/t became the challenge faced the piping systems safety. The decrease of ultimate stress is mainly evident depending on the size of crack, where they compared to the base metal results. The obtained results shown that the ultimate stress have been clearly decreased through the comparison to the base metal results which reached to 558 MPa compared with 259 MPa of defected specimens of ratio a/c 0.4 and 160 MPa of defected specimens of ratio a/t = 0.80. It is clear that the elongations results of base metal decreased from 40.86% to 7.12% for the ratio a/c on the one hand, and to 1.98% for the ratio a/t on the other hand. This study proved that the defects on the specimens lead to weak of the structure of API X52 material through two ratios of semi-elliptical defects a/c and a/t. Based on the size of cracks which is led to the corrosion phenomenon has directly relationship with the variation of depth (a), where it is considered as one of caused factors which led to depredate the mechanical characteristics in the rate of 44% depending on the ratio (a/c) and 80% depending on the ratio (a/t). However, the repairing strategy of the specimens by welding process leads to confirm that this solution allows improving mechanical properties of the welded specimens which have been well reinforced by comparing with the basespecimen. Finally, the reparation by welding process is one of among important methods, where this process can increase the lifetime of the pipeline through the improving of the mechanical properties for strength and ductility. In addition, the results proved that the repairing efficiency of piping systems for semi-elliptical defected can be reached to 98%, if the defect ratio for different cracks does not exceed 50% of thickness wall pipe. Thus, the repairing process by welding method is one of solutions to reinforce the mechanical characteristics in order to increase the performance and less maintenance cost of pipelines of the API X52 type.

ACKNOWLEDGEMENT

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