Evaluation of Aspect Ratio on Tensile and Compressive Properties of Welded API X70 Steel

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Abstract-
Pipelines are fabricated by welding and are used for transportation of oil and gas products globally. These joints are prone to surface defects and sometimes deep cracks depending on types of loading they experience while in operation. Hence, it is necessary to understand the effect of defects on mechanical properties of welded pipeline joints for estimation of their service lives. In this study, a numerical approach was used to study the effects of aspect ratio on pipeline steel. Artificial cracks were created on API X70 steel tensile and compression specimens using different aspect ratios. ANSYS 2019 2R was used for modelling and loading of the specimens. Results show that the investigated mechanical properties were not only sensitive to materials type (weld and base) but also to aspect ratio. The maximum stresses obtained for tensile and compression specimens using various aspect ratios were discussed.

Keywords: Aspect ratio, API X70 steel, Tensile, Compressive

1 Introduction

Pipelines are generally used for the transportation of natural resources and fluids such as oil and gas over a long distance over the years and have been extended to the transportation of potable and industrial chemical products, water, sewage and even solid materials like coal and ores [1-3]. Damages in pipelines have been attributed to several factors such as third-party damage, manufacture and materials defects, corrosion and natural forces [4]. Pipelines are fabricated by welding and the joints are hot spots to crack initiation, propagation and eventual failure if proper monitoring is not deployed.

Welding is one of the most important techniques in the fabrication industries to join metals in different geometries and sizes with cost-effective and reliable assembly. There are several types of welding processes used in the petrochemical industry that have been around for many decades and new methods have also been developed in recent years [5]. Basically, these processes vary in setup, essential variables and non-essential variables, such as shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), etc. Each welding process has characteristics that affect its quality performance and the soundness of the weld. For example, a weld acceptable for one application, such as for a tank, may not meet the acceptance criteria for pressure vessels per applicable international codes. Welding imperfections such as cracks, porosity, lack of fusion, incomplete penetration, and spatter could be due to various causes, such as poor workmanship, design issues, incorrect material, improper weld procedure specifications, and/or an unfavorable environment. The impact of each defect varies from acceptable to not acceptable, and must be either repaired or cut-out [5].

It was stated that aspect ratio is the ratio of defects length to depth: smaller numbers indicate longer shallower defects while larger numbers indicate shorter deeper pits [6]. Research has been directed towards the deterioration of materials resulting from corrosion related failure especially in the pipeline industry. However, it was mentioned that weld failure and corrosive service environment result in about 60% of oil pipeline failure and 51% of natural gas pipeline with weld areas being considered the main stress raisers in a pipeline [7]. Research had been carried out using a plate with varying the aspect ratio between 0.25 and 1.5, where a series of elastoplastic large deflection analysis was performed [8].

At about 30 years ago, high strength X70 grade steel with minimum 70.3ksi/483MPa yield strength was brought into the pipeline industry and its development was rapid with the introduction of thermomechanical (TM) rolling practices. Currently, pipeline materials in the world market are now being regulated according to the American Petroleum Institute's (API) standard 5L [9], [11].As the world demand for energy increases, pipelines have been employed for use in the oil and gas industry. However, the oil and gas sector have continuously recorded huge economic losses due to pipeline failures, in terms of ruptures, explosion, leaks and spillage. It is therefore necessary to understand the causes the failures so that adequate maintenance measures can be deployed. In this paper effort was made to understand the effect of aspect ratio on parent API X70 and welded API X70 and their effect on the mechanical properties of the steel.

2. Experimental Methods

The material used for this research was API X70 pipeline steel plates of thickness 20.8 mm with equal width and length (304.8 mm). This material was obtained and sample preparation was carried out in the engineering Laboratory of the Pipe Construction Factory belonging to Shabiv Construction Company (SCC) Nig Ltd at Ushafa, Bwari, Abuja FCT. Equipment used for the preparation of the sample includes Milling Machine, Cutting Stone, Hack Saw, Bench Vice, Tape Rule, Vernier Calipers and Grinding Stone.

The method used for this research is subdivided into two categories; analysis of the specimen and destructive test evaluation using ANSYS version 2019 R2 to simulate the experimental test. The most common shape factor is the aspect ratio; it is a ratio of crack length to crack depth of a defect. Aspect ratio is described in equation 1 and it is schematically shown in figure 1.

$$Aspect\ ratio = \frac{a}{c} \quad (1)$$

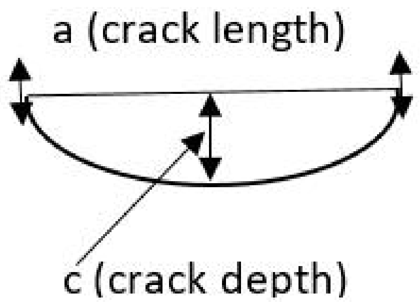

Figure 1: Schematic representation of aspect ratio

Five different lengths and depths were considered in creating the artificial surface defects on both the plain and the weld API X70 steel, 5mm, 4mm, 3mm, 2mm and 1mm dies were used to create the defects.

Chemical composition of the base metal plate being used API X70 was obtained by conducting a chemical analysis in the laboratory in Ushafa, Bwari FCT Abuja. The result obtained is set

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out in the discussion section. Tensile specimens of the base metal were produced with and without artificial surface defects. Similarly, weld samples were also produced with and without artificial surface defects. Depth and Length were varied for both plain and weld specimens with surface defects representing aspect ratio. Experimental test results are not reported in this paper due to closure of most test centers as a result of Covid-19 pandemic. The results that are discussed in this paper are those obtained numerically using ANSYS 2019 R2 software. The schematic diagram of the tensile test specimen designed according to ASTM D638 [10] is shown in Figure 2.

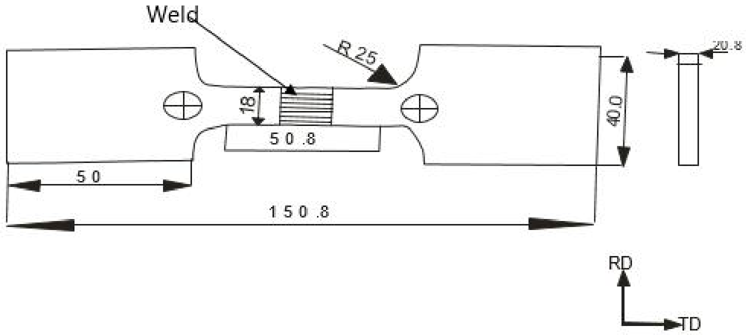


Figure 2: Tensile test specimen design

Compression specimens of the base metal and weld materials were produced with and without artificial surface defects. Depth and Length were varied for both plain and weld specimens with surface defects representing aspect ratio. In all, a total of thirty specimens for compression test were produced for testing. The schematic diagram of the compression test specimen designed according to ASTM D638 is shown in Figure 3.

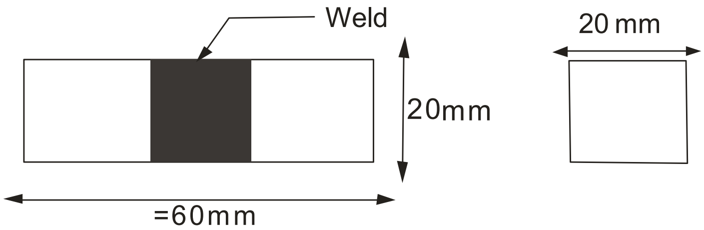


Figure 3: Compression test specimen design

3. Results and Discussion

The results that are presented and discussed in this section are those obtained numerically using ANSYS R2 as the modelling package. As mentioned earlier, experimental results of this investigation are not presented due to shut down of most test centres as a result of Covid-19 pandemic. Spectroscopic analysis revealed the chemical composition of the material as shown in Table 1.

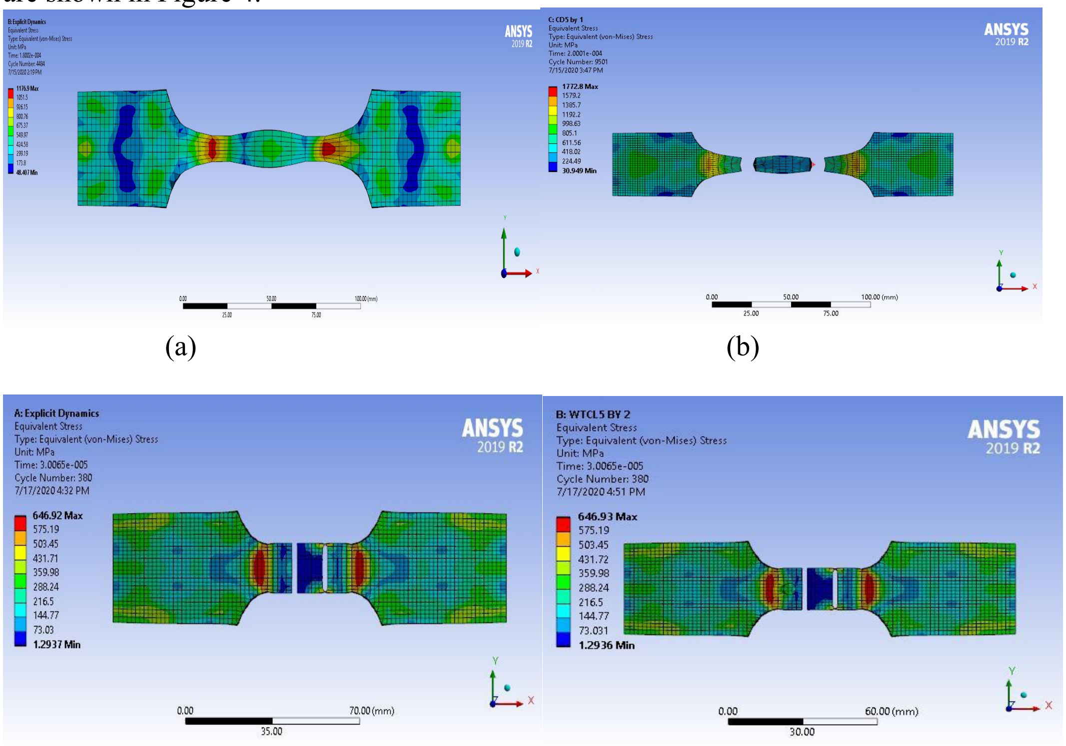
Table 1: Chemical composition of API X 70 steel

Element	%C	%Si	%S	%P	%Mn	%Cr	%Mo	%Ni	%V	%Cu	%Al	%Co	%Pb

Actual	0.051	0.210	<0.003	<0.005	1.500	0.239	0.118	0.017	0.012	<0.002	0.048	0.086	<0.003

The result of chemical analysis was in agreement when compared with those obtained in [12]. The chemical composition for the most common elements in steel as reported by [12] were 0.051%C, 0.210%Si, <0.003%S,<0.005%P, 1.500%Mn and 0.24%Cr; and these values are in close agreement with the ones obtained in this paper.

The tensile test results obtained for plain and weld materials with defects and without defects are shown in Figure 4.



(a) (b)

(c) (d)

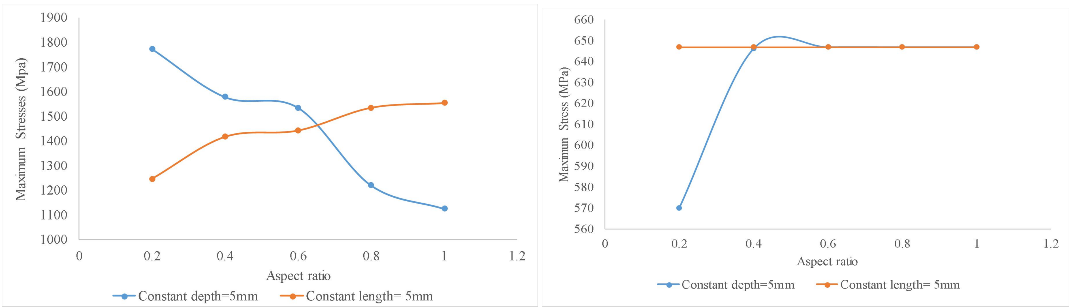
Figure 4: Tensile test result for (a) plain material, (b) Plain material with defect, (c) weld material, (d) weld material with defect

The maximum stress obtained for plain material was 1176.9 MPa while for specimens with defects, the maximum stress for an aspect ratio of 0.2 was obtained to be 1776.9MPa. However, for plain material with defect the lowest value of maximum stress was obtained at an aspect ratio of 1.0 to be 1124.6Mpa. This implies that for tensile specimens, the lower the aspect ratio, the higher the stress. For weld material without defect (Figure 4c), the maximum stress obtained was 646.92MPa, while for weld material with defect, the maximum stress was obtained to be 646.93 MPa at aspect ratios of 0.6 to 1.0 which agrees with the result obtained from [12]. The lowest value of the maximum stress for weld tensile specimen was obtained to be 569.75Mpa at an aspect ratio of 0.2. It can be observed that there was no significant effect of aspect ratio compared to plain tensile specimens. For weld materials, for increased defect length, likely weld repair could be experienced in the materials causing no observed effect of aspect ratio on damage scenario. In Table 2, the various aspect ratio and maximum stress obtained are set out.

Table 2: Result of Aspect Ratio and Maximum Stresses for Plain and Weld Tensile specimen with Artificial Surface Defects

Aspect Ratio	Maximum Stresses (Mpa)			
	Plain Material (MPa)		weld material (MPa)	
	Constant Depth=5mm	Constant Length=5mm	Constant Depth=5mm	Constant Length=5mm
0.2	1772.8	1246.9	569.79	646.92
0.4	1578.1	1417	646.08	646.92
0.6	1534.8	1442.2	646.92	646.93
0.8	1219.9	1534.8	646.92	646.93
1	1124.6	1553.9	646.92	646.93

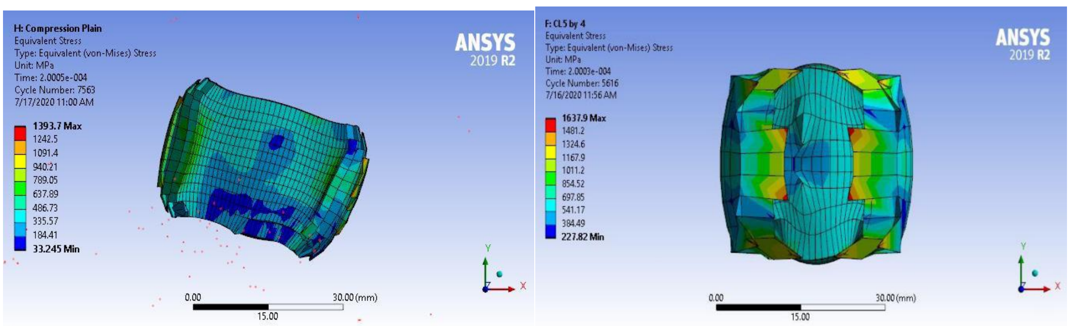
In Figure 5, the values of aspect ratios are plotted against the corresponding maximum stresses.



(a) (b)

Figure 5: Maximum stress against aspect ratio for (a) plain tensile specimens, (b) weld tensile specimen

The results of compression tests carried out on plain and weld materials with and without defects are shown in Figure 6. The maximum stress obtained in plain and weld material without defect were 1393.7 MPa and 1902.1 MPa respectively. For the plain and weld materials with defect, the maximum stresses were obtained to be 1637.9 MPa and 1929.9 MPa at aspect ratios of 1.0 and 0.2 respectively. Table 3 shows the result of aspect ratio and maximum stresses for plain and weld compression specimen with artificial surface defects.



(a) (b)

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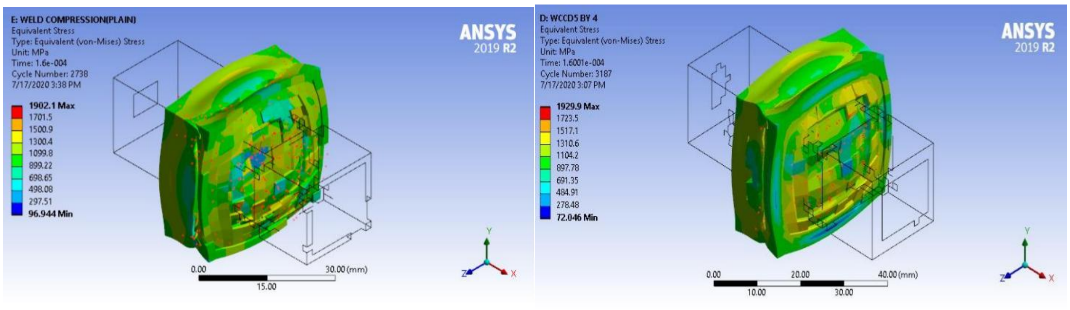


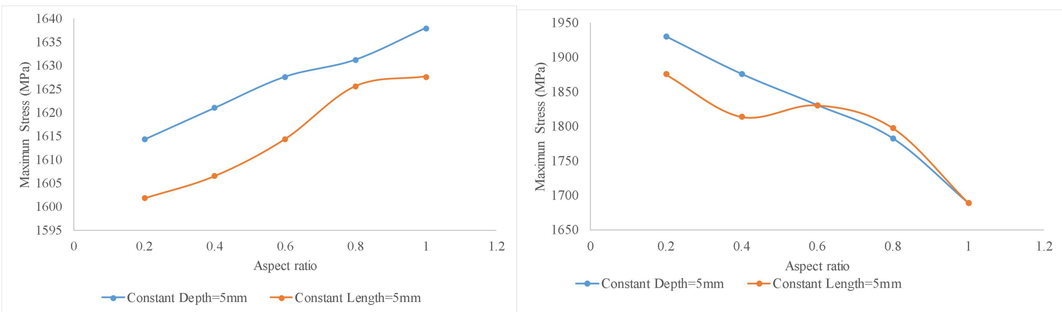
(c) (d)

Figure 6: Compression test result for (a) plain material, (b) plain material with defect, (c) weld material, (d) weld material with defect

Table 3 Result of Aspect Ratio and Maximum Stresses for Plain and Weld compression specimen with Artificial Surface Defects

Aspect Ratio	Maximum Stresses (MPa)			
	Plain Material		Weld Material	
	Constant Depth=5mm	Constant Length=5mm	Constant Depth=5mm	Constant Length=5mm
0.2	1614.3	1601.8	1929.9	1875.5
0.4	1621.0	1606.5	1875.5	1813.6
0.6	1627.6	1614.3	1830.4	1830.4
0.8	1631.2	1625.5	1782.4	1797.7
1.0	1637.9	1627.6	1688.8	1688.8

The plots of maximum stresses obtained from plain and weld materials with defects are shown in Figure 7.



(a) (b)

Figure 7: Maximum stress against aspect ratio for (a) plain compression specimens, (b) weld compression specimens

4. Conclusion

The effect of aspect ratio on tensile and compressive properties of API X70 steel was investigated for both plain and weld materials. The following conclusions can be drawn: for weld material, aspect ratio proved to be insignificant on both tensile and compressive specimens compared to the significant effect revealed for plain materials. Numerical method by ANSYS has shown to be cost effective methods for estimating maximum stresses experience in structures subjected to different surface cracks or defects.

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