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Investigation of Fracture behaviour of API X70 Pipeline Steel

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Abstract-

Oil and gas production has significantly increased over the years in order to meet future demands for oil and gas products, regardless of the unstable price being experienced by producing nations. The use of pipelines for the transportation of these products has been the globally recognized solution. These pipelines are fabricated by welding and their fracture properties depend on a number of factors which include temperature, particularly for pipelines operating in cold environment such as deeper water depths. Therefore, information of fracture behaviour of welded pipelines located in cold regions is therefore important for reliable design for service. In this paper, fracture behaviour of welded x70 pipeline steel was investigated using charpy v-notch specimens. Impact tests were carried out on weld and parent materials at temperatures -10^{o}C, -20^{o}C, -40^{o}C, -60^{o}C, -80^{o}C, -100^{o}C, -120^{o}C, -160^{o}C, 0^{o}C, 10^{o}C and 20^{o}C. Results revealed that higher energy was absorbed in the weld than in parent materials regardless of the test temperature used. results implied that the fracture behaviour of the material could be significantly influenced by temperature, welding and the notch sensitivity of the materials.

Key words: Oil and Gas, weld, pipeline steels, charpy V-notch, temperature

1. Introduction

The use of pipelines for the transportation of oil and gas products has been the globally recognized solution. The significant demand for these products necessitate the transportation of their production over a long distance from the crude oil reservoirs through the refining facilities to where they are demanded [1]. Based on the nature of the load and environment pipelines experience in service, there is a requirement for sufficient mechanical coupled with adequate fracture toughness and weldability [2]. During service, due to the nature of stress concentration, cracks can initiate from welded areas which are potential spots for crack initiation and subsequent propagation to sudden failure or collapse. As such, an understanding of the fracture toughness of pipeline is necessary in order to provide useful information to design Engineer regarding inspection, prediction or estimation of the service lives of pipelines in service.

Pipeline steel grades that are commonly used are those that are specified as API X52, X60, X65, X70, X80 and X100 [3]. The carbon content of these steels is reduced in order to

improve weldability, mechanical strength and fracture properties. Fracture properties depend on a number of factors which include temperature particularly for pipelines operating in cold environment such as deeper water depths. Under dynamic loads, crack initiates from the weld heat affected zone (HAZ) and propagate into the parent material. It is therefore important to have better understanding of the fracture properties of these steels under a low temperature for estimating of their lives in service. Due to industrialization globally, drilling in the cold reservoirs are being required [4]. The most commonly used tests for the determination of energy absorbed in a material is the Charpy impact test and the drop-weight tear test [3]. When charpy tests are carried out either on precracked or notched charpy test specimens, the energy absorbed are plotted with respect to temperature.

Some investigations have been carried out on mechanical and fracture properties of pipeline steels. Fracture properties of X70 and X80 pipeline steels were investigated [5]. It was found that the effect of material variation influenced the fracture properties of the steels. However, the only set back in the investigation was that the effect of temperature on the fracture properties of the material were not adequately investigated. The microstructure and mechanical properties of X60 and X70 base steel materials were compared in [2]. It was found that X70 steel has lower carbon content as well as better mechanical properties. Microstructure of some of the API steel grades has been investigated and it was found that X70 is ferrite-pearlite matrix, X80 is ferrite-bainite while X100 correpsonds to the bainite microstructure [6]. For API X70 steel, the reported types of grains was also similar to those investigated in [7]. Charpy tests were carried out on API X60, X70 and X100 high strength low alloy (HSLA) steels at temperatures of –196ºC, –100ºC, –70ºC, –40ºC, –20ºC and 21ºC [3]. Higher values of hardness, yield and ultimate strengths were reported for X70 steel that the other steels tested. Charpy impact tests were carried out on API 5L X60 at room temperature (25^0C) and at lower temperature of -196^0C which was achieved using liquid nitrogen [8]. The charpy energy values decreased from 210J to 5J when the specimens were cooled in liquid Nitrogen. A similar reduction in charpy energy was also reported in [9] as temperature was reduced from -20°C to -120°C.

However, the set back of most of the investigations that were discussed previously is that fracture properties of weld pipeline steels have not been adequately investigated under low temperatures for samples that are extracted from weld zones. In this paper, the fracture property of API X70 steel parent and weld materials was investigated. Tests were conducted on charpy V-notch specimens in cold environment.

2. Experimental Methods

The material that was used in this study was 20.8 mm thick API X70 pipeline weld steel. Impact tests were carried out using the Charpy V-notch impact tester belonging to the pipe testing facility of Shabiv Construction Company (SCC) Abuja, FCT., while the notch of the

specimens were prepared using Blacks Charpy V-notch preparation machine. The chemical composition of the material was carried out in a recent study [10].

2.1 Charpy test specimens extraction and testing

The extracted Charpy V-notch samples were designed according to ASTM E23 [11], with a notch radius of 0.25mm. Samples were extracted from parent plates as well as from the weld zones. Weld samples were prepared with their notches aligned on the weld zone of the plate. The dimensions of the designed charpy V-notch specimens are given in Figure 1. The sample was 55 mm in length and with a thickness of 10 mm, while the depth of the V-notch was 2 mm with a radius of 0.25 mm.

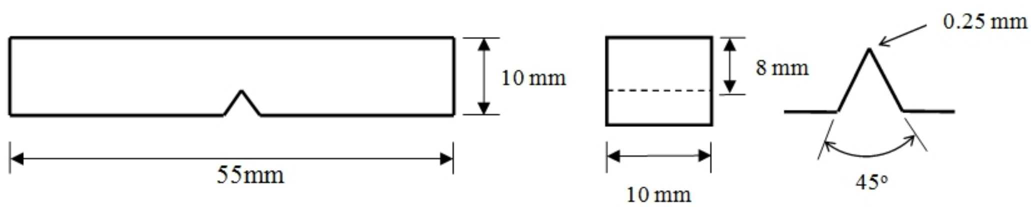

Figure 1: Charpy V-notch geometry

The impact tests were carried out according to the specifications set out in the ASTM E23 [11] using the impact testing machine. Impact tests were carried out at temperatures of -10°C, -20°C, -40°C, -60°C, -80°C, -100°C, -120°C, -160°C, 0°C, 10°C and 20°C. The lowest temperature that could be achieved by the liquid nitrogen was -160°C and this informed the choice of range of temperatures used for testing. At a temperature of -160°C, the specimen was removed from the liquid nitrogen and was placed on the impact testing machine. The machine pendulum was released to strike the specimen after a desired temperature had been achieved. The energy that was absorbed by the specimen after breaking was recorded from the gauge of the machine. The energies absorbed by the specimens were plotted against the corresponding temperatures.

3. Results and discussion

Figure 2 shows the plot of charpy V-notch test results against the corresponding test temperature for parent materials. The obtained charpy energy reduced from 145.6 J to 12.3 J when the test temperatures were reduced from 20°C to -160°C. The charpy energy trends obtained from the present material agree with the fracture behaviour reported in previous studies. These include the investigations carried out by [3], [8], [9], [10] and [12]. In [9],

charpy impact energy reduced form 216 J at a temperature of 20°C to 16 J at a temperature of -120°C while in [12], charpy energy reduced from 210 J at a temperature of 25°C to 5 J at a temperature of -196°C.

In the present study charpy impact energy in parent material reduced from 145.6 J at a temperature of 20°C to 12.3 J at a temperature of -160°C. This implies that temperature has a significant effect on fracture behaviour of materials which can be seen by the significant reduction in charpy energy values. Reduction in charpy energy was also observed to be pronounced at lower temperatures compared to higher ones. The obtained charpy energy in the present material were higher than those obtained in [3]. The sensitivity of the specimen notch may be responsible for the difference. In [3], the specimens used were precracked before charpy tests and it was mentioned previously that the effect of the notch is minimized by precracking and hence the correponding data [13]. In this study, the specimens were not precracked; therefore the notch sensitivity would have influenced the absorbed energy. A similar behaviuoir was also observed for API X60 steel as higher energy was obtained in unnotched specimens than in notched ones [8].

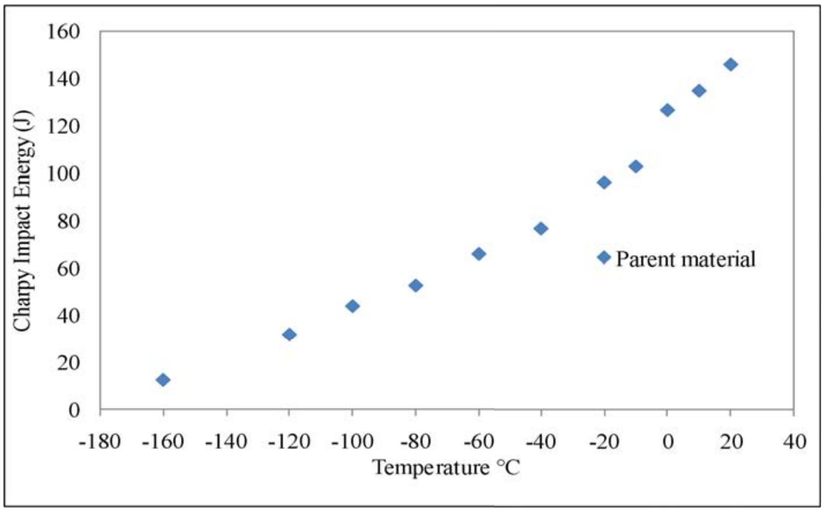

Figure 2 **:** Charpy V-notch energy absorbed in parent materials

Figure 3 presents the charpy energy absorbed from weld materials with respect to test

temperature. Similarly, the energy values reduced with reduction in temperature across the range of temperature used for testing. It was found that the change in charpy energy with respect to temperature in weld has a similar trend with those obtained in parent material (Figure 2).

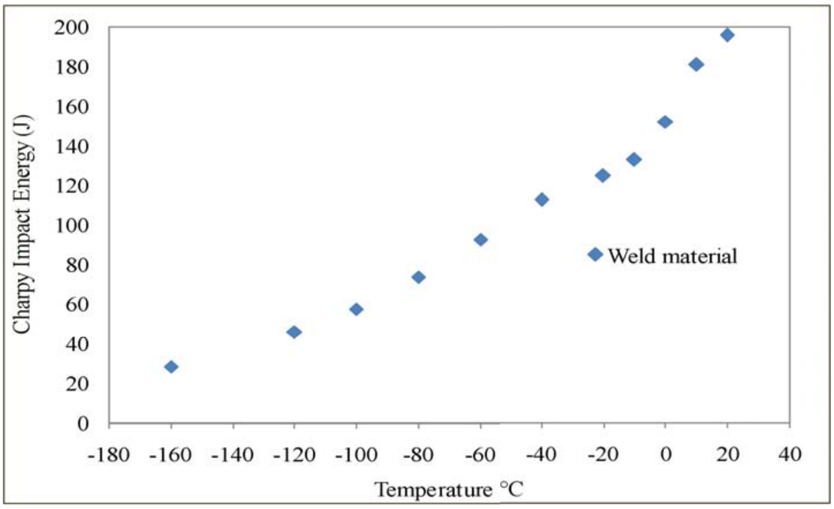

Figure 3 **:** Charpy V-notch energy absorbed in weld materials

In Figure 4, the charpy energy obtained in parent materials is compared with the weld ones. The weld materials absorbed more energy than parent materials irrespective of the test temperatures as shown in the Figure. At temperatures of 20^{o}C and 10^{o}C, the percentage difference of absorbed energy in parent compared to in weld was found to be 20% while at temperatures of -10^{o}C and -20^{o}C, the percentage difference in the absorbed energy was found to be 18%. Also at temperatures of -40^{o}C, -60^{o}C and -80^{o}C the percentage difference in the absorbed energy was approximately 23%, while at a tempearture of -160^{o}C the percentage difference in absorbed energy between the parent and weld material was obtained to be 36%. However, the differences in the higher energy observed in the weld compared to in parent materials may be contributed by the effect of welding which is characterized by different microstructural changes.

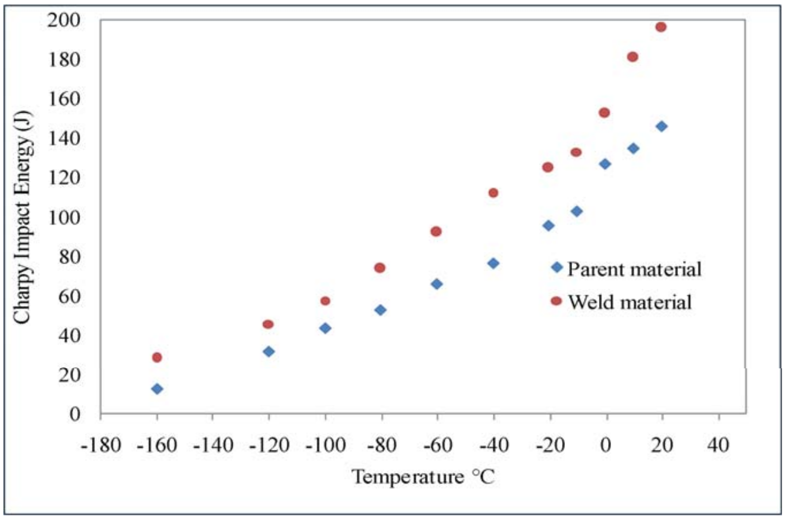

Figure 4 **:** Comparison of Charpy energy absorbed in parent and weld materials

A similar effect of microstructure was given in [14] as different energy values were obtained in HAZ, parent and seam weld material extracted from X70 steel. It was also mentioned that microstructure influenced the fracture properties of X 70 and X80 steels significantly in base materials [5]. Contribution of the filler material used for welding is another factor that could influence material properties as it is possible to alter the amount of individual elements in the composition of the material during welding.

4. Conclusions

Fracture behaviour of API X70 pipeline steel has been investigated at low temperatures in order to represent the behaviour of the steel operating at cold regions. The following conclusions can be drawn:

1. Fracture behaviour depends on material type as charpy V-notch energy were higher in welds that in parent materials regardless of the test temperature. However more tests are needed on evaluation of the material microstructure.
2. The behaviour of material is more sensitive at lower temperatures than in higher ones. Fracture of API X70 steel could be influenced significantly by both notch sensitivity and welding.
3. The mean of the difference in charpy energy absorbed in weld and parent materials provides useful information that could be applied for use in inspection or monitoring

of pipelines operating in cold environments.

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