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Investigating the Fatigue Fracture Morphology of 0.28%C Pipeline Steel with Strain Induced Cavities.

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ABSTRACT

The study of fatigue is very important because it can lead to failure of line pipes, structural components and other engineering systems at load levels far below the original design. This intends to assess the effect of strain induced cavities on the fatigue fracture morphology of 0.28%C low alloy steel. The samples were machined into notched tensile samples. Some of the notched tensile samples were fractured to obtain three different prestrain levels. Strain level 0.77, 3.3 and 5.5 respectively. The notches were thereafter machined out and then converted to fatigue samples. The fatigue analysis was carried out and the fractured surfaces were examined to observe the effect of the strain levels on the fatigue fracture surface. The fatigue fracture surface was found to have multiple crack propagation origins. These origins increase with increased prestrain values. The fatigue striations at the fatigue fracture surfaces were found to become clearer with increased prestrain. The secondary cracks also increased with increased strain level too. It was observed that as a result of the high level of strain, the crack quickly propagated through the samples and there was no visible smooth zone that usually denotes the first stage and most times the beginning of the second stage of fatigue crack propagation. This study therefore shows that the cavities resulted in a quick spread of crack quickly through the material skipping the first stage to the beginning stage of the second stage of fatigue crack propagation. Therefore, adequate care should be taken to avoid too much deformation of the pipeline before they are put into use.

1. Introduction

Fatigue is a process of structural degradation that is usually caused by fluctuations or cycles of stress or strain [1]. Fatigue is a major problem in the oil and gas industry, since over 90 percent of mechanical failures occur due to fatigue failure [2]. Fatigue research is critical because it can lead to structural component failure at load levels significantly below the original design values. It is therefore very important that the risk of fatigue be properly understood and characterized correctly in order to prioritize responses and minimize the chance of fatigue impacting the integrity of engineering systems including line pipes. As part of understanding and characterizing the risk associated with cyclic fatigue, it is important for a line pipe operator to understand what scenarios may lead to fatigue and what scenarios can reasonably be expected to pose no fatigue risk.

Fluctuations or cycles of stress or strain are usually concentrated locally by structural discontinuities, geometric notches, surface irregularities or damage, defects, or metallurgical non homogeneities. Plastic deformation has been widely reported to affect static and cyclic properties of steel [3, 4] Plastic deformation occurs to line pipes during the manufacturing and machining process and also during transportation from one place to another. This results in a lot of damages to the pipes, creating stress concentration sites which can result in the onset of fatigue. [5-9]. It is necessary to understand the mode of damage in the fracture surface to ascertain the degree of damage as a result of the cavities.

In fatigue fractures, there are usually two or three zones, which can be identified on each fractured surface. Around the region of origin of the crack, the surface often has a smooth appearance showing beach markings [10,11]. This is usually the area over which the fatigue crack has spread relatively slowly. A second less smooth zone can sometimes be distinguished across which the crack has extended more rapidly, perhaps in several at once, such that the fracture surface is irregular. [12] The third zone is the area on which the final fracture occurs when the section is reduced so much that the metal is unable to withstand the last application of load. [13-15] Following crack initiation, these macro cracks expand with each fatigue cycle and leave a detectable signature on the fracture surface. Therefore, a very important tool given to designer, that is often forgotten, is the post mortem examination of failed piece. [16-18] The entire story of its fate is inscribed on the fracture surface. What is genuinely desired is a key to decipher and interpret the distinguishing features visible with our eyes alone and, more significantly, those visible with advanced equipment such as high-definition optical microscopes and scanning electron microscopes (SEM) that we cannot see with our naked vision. Each stage of the fatigue fracture surface tells us the story from the beginning. It is therefore important to examine the fracture surface on the pipeline steel to ascertain the extent of the damage as a result of the induced cavities to enable us guild against the extent of plastic deformation a pipeline can undergo before they are discarded.

Several researches have been done in this area. Branco et al., [19] investigated the effect of tensile pre-strain on low-cycle fatigue behaviour of 7050-T6 aluminium alloy. They discovered that the heterogeneous distribution of dislocations, such as dislocation stacking at slip bands and grain boundaries, was caused by pre-tensile deformation of the 7050-T6 aluminum alloy, which accelerated damage accumulation at the grain boundaries and reduced its fatigue life after pre-tensile deformations by <8%. Al-Rubaie et al. [20] evaluated the influence of pre-strain on the fatigue life of an aluminum alloy 7050-T7451. They discovered that sliding grains and persistent slip bands (PSBs) caused by 1-7% pre-straining deformations were deleterious to the fatigue life of a 7050-T7451 aluminum alloy plate, and that the reduction in fatigue life increased with the extent of pre-straining. Mrozinski et al., [21] examined the Influence of Pre-Strain on Static and Fatigue Properties of S420M Steel. They observed that no effect of pre-strain on the basic strength parameters of the S420M steel was found. Low-cycle fatigue tests showed that the pre-strain of the specimens causes a change in the cyclic properties of the steel and a slight increase in fatigue life compared to that of the as-received specimens. They also observed that the greatest increase in durability was observed at the lowest strain levels. Though several studies have been done on the effect of prestrain on the fatigue of materials. They remain few works done on the effect of these induced cavities on the fracture surfaces of the fatigue sample. This study therefore examines the extent of damage strain induced cavities can cause by examining the fracture surfaces of line pie steel. (0.28%C)

2. Materials and Method

This research was done using a 32mm diameter low alloy steel bar. The 0.28%C API 5L Grade B steel was gotten from Renda Steel Group Company Limited, China. The chemical composition was done by using spark spectrometer metal analyser (NCS lab spark 750B) at the quality control laboratory of Renda Steel Group Company Limited. Table 3.1 displays the statistics data from the low alloy steel

Table 1. Chemical Composition of the Investigated Steel

Elements	**C**	**Cr**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Fe**
% Composition	0.28	0.50	1.20	0.030	0.030	0.50	0.50	0.15	96.81

2.1 Heat Treatment

2.1.1 Normalizing

Normalizing was chosen because it has been shown that normalizing improves the fatigue life of a material. Fine grain structure which is obtained when normalizing have also been shown to improve fatigue life. [22,23]

Sixty-nine (69) samples from the pipeline low alloy steel were subjected to normalizing heat treatment. The specimens were heat treated to an upper critical temperature of 870℃ and then cooled in air.

2.2. Notched Tensile Specimens.

A circumferential V- notch of angle 60° was machined to a depth of 1.5mm at the centre of the Tensile specimens. The notch radius was as small as possible (0.075mm). The machining of the V-notch on the specimens was carried out by using a programmable lathe machine. The load was focused at the centre of the notch, as is usually done in tensile specimens with notches. Some notched specimens were fractured to failure and the actual strain point of the 3 different pre-strain levels before fracture was observed. The values obtained were 0.77, 3.3 and 5.5 respectively.
This procedure aligns with Wu et al [25] and Unueroh and Awheme. [26]

Figure 1. A picture of the notched specimen used for this research

2.3 Pre-straining

Some of the notched samples were prestrained based on the three different strain levels obtained from the fractured notched samples.

2.4 Re-Machining the Control Specimens into Fatigue Specimen

The notches in the samples not prestrained and prestrained were remachined into fatigue specimen. size with a throat diameter of 4mm. This was to enable it fit into the Wohler rotating fatigue apparatus for onward testing. When assembled, the sample was at 125.7mm from the load at the end of the cantilever.

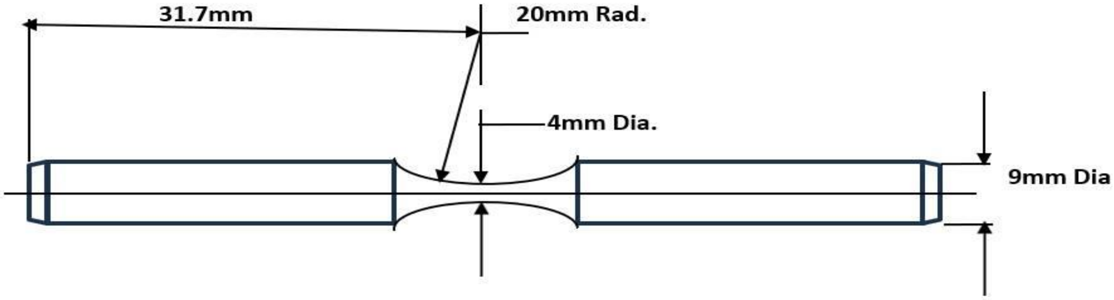


Figure 2. Drawing and dimension of the Fatigue Test Specimen used for this research

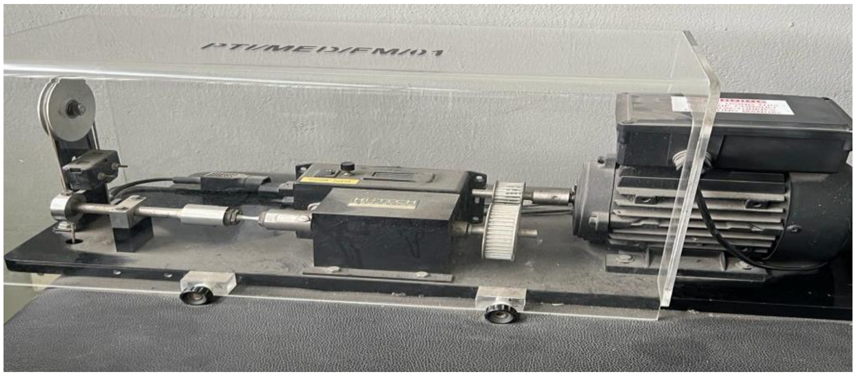
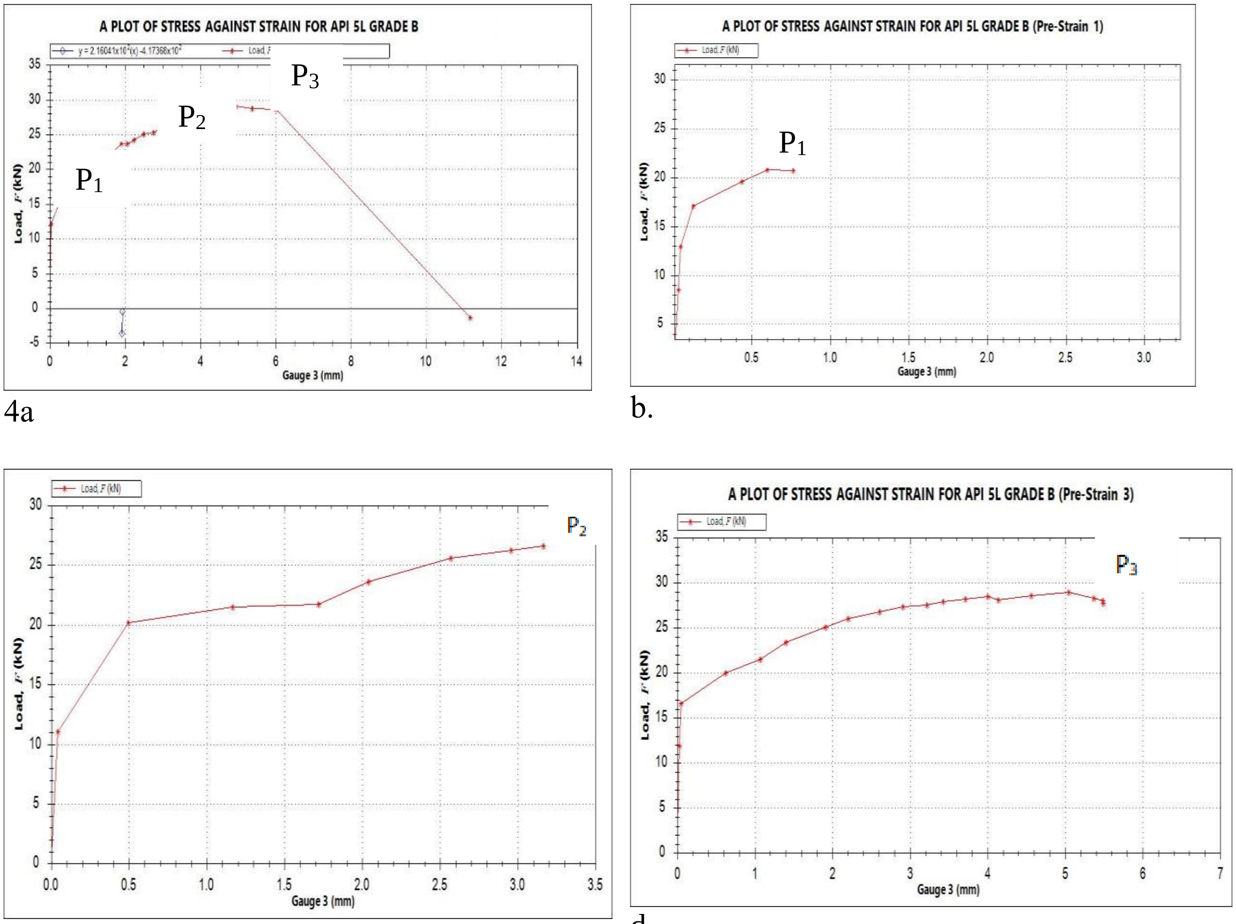


Figure 3. A picture of Wohler Rotating Fatigue Testing Machine used for this research

3. Result and Discussion

3.1. Fractured Notched Samples

The notched 0.28%C low alloy steel samples were fractured to ascertain the following parameters yield, UTS, and fracture points as shown in Figure 4. Between the yield and ultimate tensile strength, three different plastic strain levels were identified as shown in Figure 4a. Three plastic strain values (PS1, PS2, and PS3) were obtained between the yield point and the ultimate tensile strength. The three different pre-strain levels obtained from notched 0.28%C low alloy steel are 0.77mm, 3.3mm and 5.5mm as shown in Figure 4b-c.



4a b.

c. d.

Figure 4a. The stress strain curve for the control sample (fractured notched 0.28%C low alloy steel Sample). **b.** The stress strain curve for fractured notched 0.28%C low alloy steel pre-strained to 0.77mm elongation. **c.** The stress strain curve for fractured notched 0.28%C low alloy steel pre-strained at 3.3mm**.** **d.** The stress strain curve for fractured notched 0.28%C low alloy steel pre-strained to 5.5mm.

3.2. Effect of Strain Induced cavities on the Fracture Morphology of 0.28% Line pipe steel

Plates 1 - 3 show the fatigue crack growth morphology. There appears to be multiple origins in the fracture surfaces at all strain levels. According to Asi, [26] and Bhaumik [27], these multiple origins could be as a result of either high stress or high stress concentration sites. Since the cavities in the materials act as stress concentration sites, these could probably result in several origins of the fatigue propagation starting from cavity sites. This also explains why the origins become more with increased cavity sizes. Under the fatigue loading, the most typical feature of fatigue noticed is the fatigue striations. The striations become clearer with increased strain levels. Many secondary cracks between striations were also observed at both strain levels 3.3 and 5.5, with bigger secondary cracks present at the samples strained at 5.5. The origin of the fatigue crack propagation in Plate 3. showed a rather smaller zone where fatigue crack had spread slowly. However, the zone was very short as the fatigue crack spread more quickly due to the cavities in the material.

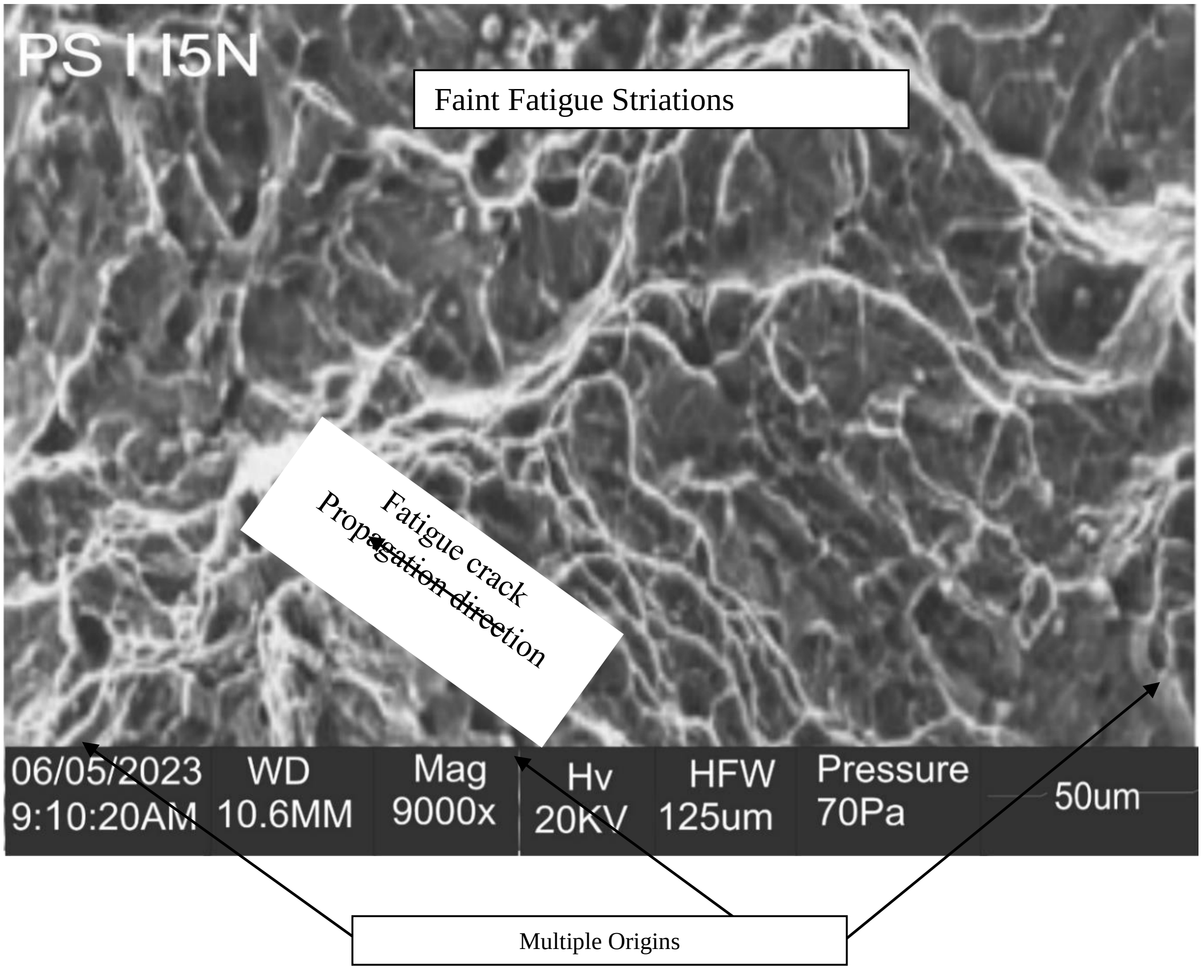


Plate 1. Fatigue fracture surface of samples strained at 0.77.

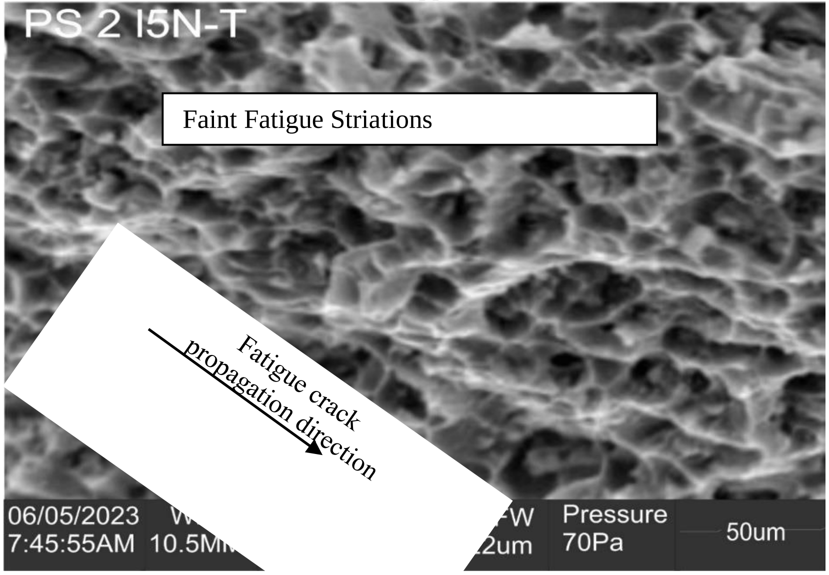


Plate 2. Fatigue fract of samples strained at 3.3.

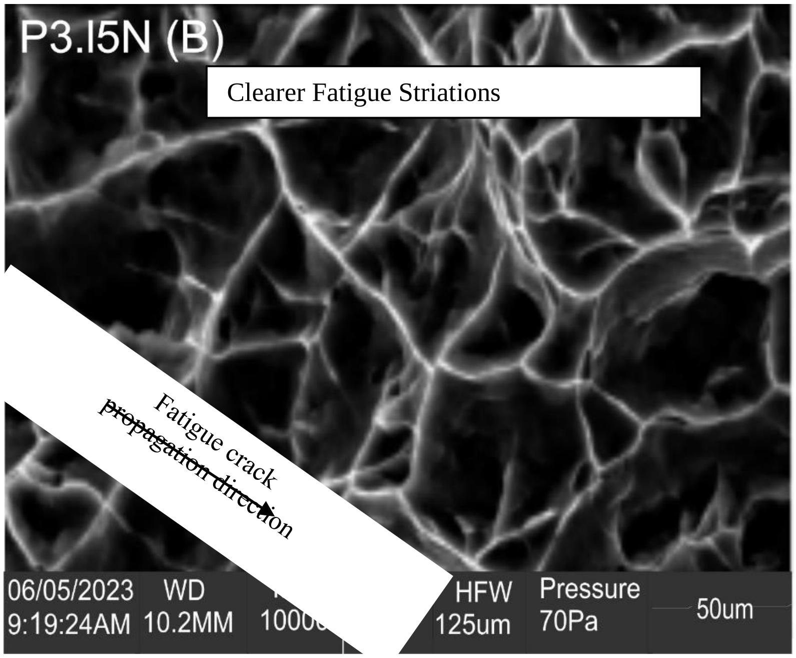


Plate 3. Fatigue fracture surface of samples strained at 5.5.

4. Conclusion

The effect of strain induced cavities on the fatigue morphology of 0.28%C API 5L grade B line pipe steel was studied in this research. Multiple origins of crack growth were observed at all strain levels with an increase in the number of origins as the strain level increased. The cracks and fatigue striations were also observed to become more and clearer.

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