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The influence of weld joint integrity on Fatigue properties in carbon steel

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ABSTRACT

Present research is mainly studying the influence of formation weld inclusions on the fatigue life to failure using mild steel compact tension specimen of 6mm thickness with weld position normal to the notch tip where crack is supposed to initiate and propagate toward the weld line which is about 3-to 5 mm away from the notch. The weld was conducted using shield metal arc welding method while the filler weld type used is E6010 Fatigue tests for all the prepared specimens were implemented under a constant load amplitude of 6 KN with loading frequency around 80 HZ, Different numbers of stress ratio were used during tests as explained later on. All tests give a confirmed results that fatigue life improved as stress ratio decreased while the number of fatigue cycle to failure were suddenly decrease when the crack tip hit the spherical weld inclusion which is considered as harmful defect on the weld joint. Scanning electron machine was massively used to investigate the fractur surfaces features and to show the shape and position of the inclusions.

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1. INTRODUCTION

Normally in most metal structures, parts are connected by using a suitable weld method but unfortunately in weld many types of defects may form that could cause a suitable place for stress concentration and eventually resulted of collapses the structure when is applying a dynamic type of loading.

Inclusions of different shapes and morphology are one of these defects which is a solid material forms at the weld zone and line of interface between the weld and base metal. This inclusion might be encountered in weld produced with most arc welding process, such as shield metal arc welding, SMAW, flux cord arc welding, FCAW, submerge arc welding, SAW and MIG weld when the fusion region properties is hardly affected by Welding Velocity and Arc Energy (1). Weld quality is directly related to the integrity of the weld. The mechanical properties of the weld metal are found to be strongly affected by the presence of theses inclusions [1].

Weld defect is the utmost reasons of failures in welded construction and it represent nearly ninety percent of the failure because of dynamic loading.

It is well known that Fatigue fracture is normally in the form of two stages, the first one is called the crack initiation which is normally started from the surfaces and the second stage is known as growth or propagation of the cracks, that resulted always under applying dynamic stresses [2].

From all literatures the famous weld discontinuities are normally internal such as cracks, inclusions, porosity which are found to be influenced the fatigue life of structures [3]. These types of irregular welding defects is the main cause parameters to be considered before selecting any process of the welding [4].

From previous work, it was referred that the numbers of fatigue cycles to failure is influenced by the defect's numbers, shapes and morphologies in particular regarded the weld Mns inclusions [5].

The fatigue fracture always found happened close these discontinuities due their effect as stress concentration and raiser regions [3]. Also, from the past study it is found that Paris and Erdogan were first considered a mathematical representation for the fatigue growth analysis as shown equation (1) which is applicable for plot middle part of the crack growth per cycle and stress concentration factor [6].

$$da/dN=C(\Delta K)m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

When, da/dN is average crack growth rate of the crack for each loading cycles, while (a) represent instantons crack length, N is number of cyclic load, ΔK, is known as a stress intensity factor range and materials constants are represented by C and m. From many previous researches the (m) number was found to be close 3 for the mild steel where m is determined from the plot experimentally [7]-[8].

In these investigations it is concentrated only on the influence Mns type of weld of inclusions formed after using low carbon steel filler in selecting this welding method, that was conducted to study the influence of this type of weld on the fatigue life by using Paris analysis experimentally and all test data were confirmed by SEM images as discussed later on in this article.

2. Materials and Method

The material used in this investigation was a mild steel butt weld plate. The microstructure of the base metal is shown in figure (1) which is mainly of ferrite and pearlite phases. The chemical composition of the base metal consisted mainly from the following elements,0.12%C, 0.8%Mn, 0.28%Si. The mechanical properties of the metal are, Young modulus (135 GN/m²), Yielding around (320 MN/ m²), the maximum tensile Stress (330 MPa), the percentage of elongations is (25).

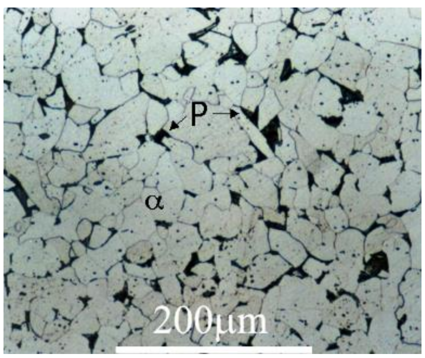

Figure 1. Metal Microstructures

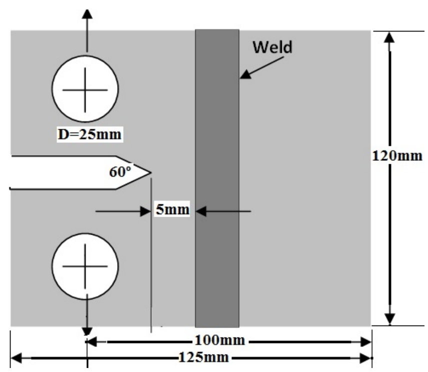

Figure 2. Welded specimen dimension

Specimen Preparation:

The welded CTSs was made by using plate metal of 8mm in thickness provided that the specimen notch must be started in the unwelded part of the specimen with notch tip normal to the weld line at approximately 4 to 5 mm away of the notch as seen in figure (2). mechanical machining was used to manufacture all of the tested specimens.

A. The Welding Procedure:

In the beginning and prior to starting welding it was decided to use V-type weld joint but design of 60 angle with 1.6mm root gap according to ASME standard to produce an efficient weld strength and integrity as shown in figure (3).

weld joints surfaces were hardly cleaned chemically and mechanically by stainless steel brushes remove and the surfaces become cleared from all types of contaminations [10] – [11].

SMAW machine was used for conducting a multi welding layers using weld electrode of 3.2 mm in diameter known as E6010 as named in according to AWS standard.

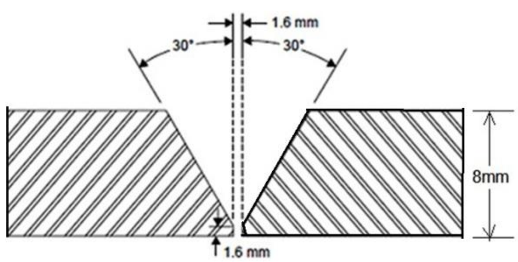

Figure 3. Joint Designation

B. X-Ray Test:

The quality of the weld was examined using an x-ray technique in the, The X-ray analysis of all images was conducted by using software known as Image J to check the weld zone from any internal defects. The result was acceptable; the inspection showed no evidence of any defect in the weld structure; however globular inclusions are detected as shown in figure (4). These inclusions were found to be as MnS compound.

Figure 4. Morphology of inclusions

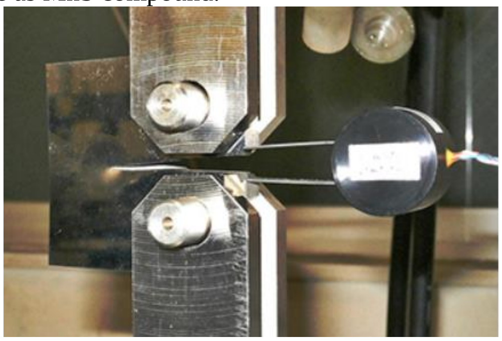

Figure 5. The CTS Setup

C. Fatigue Testing

In order to know the influence of the presence of a weld joint line on the behavior of the crack growth and number of loading cycle to failure. FCP tests were conducted on welded and unwelded welded specimen by using hydraulic test machines as in figure (5), the test frequency was selected according to the machine capacity around of 80 HZ. Tests were carried out at room temperature when a constant load range (ΔP) was selected during the tests and equal to 6KN while the load ratios (R) where R=0.4 and on the other test was 0.5. The change of Crack length was measured during the test by each 0.3 divisions.

SEM, was implemented to identified the results where this equipment is known to show the characteristic and all types of features of any solid materials at an extra-large magnification which is reach about two million times [12].

D. Result and Discussion

Figure (6) represents a plot of the change of fatigue crack length with number of cycles during the tests on the welded and un welded CTS where the weld joint bead was made normal to the notch plane with a weld distance approximately of 5 mm from the notch tip.

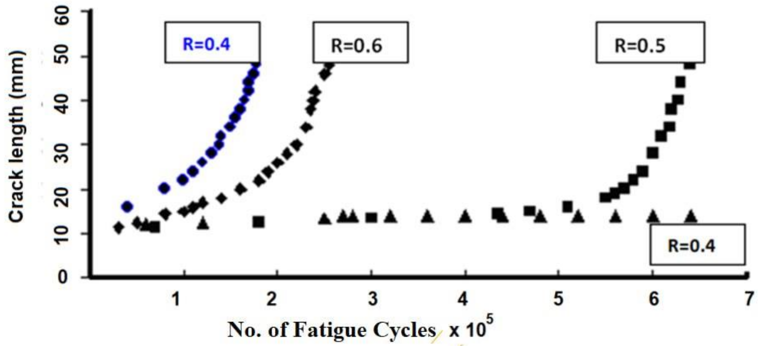

Figure 6. Crack length versus No. of fatigue cycles

It is shown in above figure that, decreasing of load ratio, R, from 0.6 to 0.5 resulted in highly improving of fatigue life for using welded specimens. Same observation was mentioned by another researcher [12]. In this work it was observed that stable crack propagation continues up to around 25 mm long then fast increasing in length is easy to notice, that give an indication about the effect of microstructure characteristic like the presence of global MnS inclusions and also create an increasing level of stress intensity.

The applying of deferent levels of stress ratio (R values) was produced a significant influence on the fatigue life to failure, this give a clear idea that, improving fatigue life ca be obtained by applying less R values as in this work when R is reduced from 0.6 to 0.5 when this reduction caused an increasing of number of fatigue cycles to failure as sketched in figure (6).

Also, other researcher [13] proves experimentally that the formation of residual stresses at the head of crack tip as the crack continue increasing in length is also considered this effect for crack delay and this phenomenon is known as crack closure

Figure 7. Spherical MnS inclusions

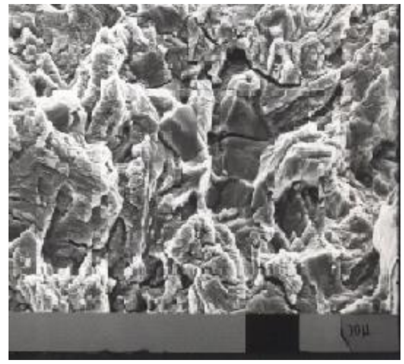

Figure 8. secondary cracking and intergranular Fracture

The SEM effort done in the present work was necessary to perform, that because to show appearance of the specimen fracture surface and to identify the behaviour of the crack through different region of base and welded metals and related that feature with FCP plot.
From figure (7,8) it is clear that the fracture surface of the welded specimen exhibits a presentation of a massive number of spherical MnS inclusions which are associated with cracks and voids,
Inclusions were known as type MnS after analysed by special instrument and confirmed as MnS as in figure (7). The influence of all these types of discontinuities can be considered as the main reasons large crack propagation [16].
Also, the shape and the distribution of all these types of defects can also affect the number of fatigue cycle to failure, the other workers also confirmed this idea in particular when MnS inclusion is considered as a main reason for pitting corrosion then to failure [9]-[17].

3- Conclusions

1.The effect of reducing R value 0.6 to 0.5 caused a significant improvement in fatigue life to failure for all welded specimens and eventually a significant improvement is noticed in fatigue life. By using R=0.4, under range of load around 6 KN, a huge resistant to crack growth is observe with high resistance to weld failure.
2.From SEM analysis, it was observed that the concentration of a lot of MnS inclusions is a main reason for fast crack propagation when the crack hit interface with base metal also the observation during the presence of secondary cracking.
3.The SEM look of the fracture surface show a lot of striations which give confirmation fatigue life to failure is occurred in ductile metal while the smooth regions show the intergranular type of fractures.

4. Suggestion for future work

It is important to suggest a future study related to the effect of other types weld inclusions, defects and discontinuities on fatigue life in addition to run different tests to find the influence of environments on fatigue life.

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