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FATIGUE LIFE ESTIMATION OF DIFFERENT WELDING ZONES OF OXY ACETYLENE WELDED ALUMINUM ALLOY (AA 5052-H32)

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Fatigue life of aluminum alloys are reviewed mainly on the basis of experimental results. Fatigue strength and failure history of the representative AA5052-H32 are summarized with respect to surface temperature effects during the welding process. In oxy acetylene welding three different zones named as welded zone (WZ), heat affected zone (HAZ) and base metal (BM) are formed having totally varying properties depending on their specific grain structure. Fatigue life and hardness of these different zones are determined in three successive phases of experiments. It is viewed that the grains are shifted from large rough round to elongated oval shaped from WZ to HAZ and relatively small and fine in BM respectively. Depending on grain configuration the fatigue strength increases from WZ to BM due to concentration of grain boundaries, a hindrance in fatigue crack propagation.

Keywords: Fatigue life, Oxy acetylene welding, S-N curve

Nomenclatures

σ= Bending Stress

Q = Sum of the Weights (Pulling Rod + Weights)

M = Bending Moment = Q*(a/2)

I = Moment of inertia=$\pi d^4/64$

A = Central Axial Distance between Two Bearings (Bending Arm) which is 100mm for this machine.

y = Distance of Outer Fiber from Neutral Axis=Half of the Core Diameter of Specimen = d/2

D= Diameter of welded region of specimenR = Coefficient of determination

t = Notch depth

S_t= Sum of squares of the residuals

r = Notch radius

S_r= Sum of the squares of the errors

K_t= Stress concentration factor

S_a = Alternating

1. Introduction

Fatigue of a material is a situation in which rupture is started due to a large number of variations of stresses at a point and the maximum stress is always less than the yield stress. Aluminum alloy 5052-H32 is most widely used aluminum alloy. Now a days it is used in aircraft components and many number of parts and application requiring strength and good formability at reasonable cost [1]. Oxy acetylene gas welding is a fundamental gas welding type. The mixture of gasses is used to form a molten pool of metals to be welded and then fuse them to form a continuous metal piece. Sometimes a filler metal is used to weld the base metal parts. Actually during the gas welding the tempering of the specimen also takes place in other words the artificial aging take place [2]. From the already research literature we can conclude that the aging of the alloys reduced their hardness and other mechanical properties [3, 4]. So the fatigue life of an aluminum alloy after aging is less than the life of specimen before welding. Fatigue life analysis of a structure is performed by calculating the damage due to three factors. (1) Structure cyclic load (2) Structure geometry (3) Materials endurance. If specimen geometry and its loading condition are known then we can define the fatigue life of that specimen by using S-N curve on the basis of fatigue-damage hypothesis [5]. To estimate the reliability of the structures during their use, S-N curves of the applied materials, as well as their scatters, should be accounted for. The S-N curves performed between stresses and the number of cycles also shows the graph of high cycle fatigue region and low cycle fatigue region by a linear function of Coffin-Manson relation. The rupture of the material is started due to tensile stress at macro or microscopic flaw. Once rupture is started, the edge behaves as stress concentrated area and assists in crack propagation until the reduced section bear no imposed load anymore. The research focus on the effects of oxy acetylene welding zones and notches on fatigue life of AA5052-H32 subjected to four point rotating and bending fatigue testing. In the welded zone a dendrite structure of ‘F’ shape is formed and the size of grain is much large as compared to parent metal. During the solidification

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Table 1. Alloy Composition of AA 5052.

Aluminum	Magnesium	Chromium	Manganese	Copper	Silicon	Iron	Zinc
95.5-95.7%	2.2-2.8%	0.15-0.35%	0.1%max	0.1%max	0.25%max	0.4%max	0.1%max

of molten metal pool the alloying elements start to precipitate at grain boundaries which make the boundaries thicker than the other zone. These characteristics make the welded nugget softer than the comparative ones and fatigue crack also propagates easily due to low concentration of grain boundaries.

In this paper the specimens are subjected to constant amplitude loading at ambient temperature in the absence of moisture concentration. To visualize the fatigue failure and to estimate the fatigue life of welded specimens the tests are conducted on four point rotating and bending test system having capacity of 3000 rev/min. The temperature difference of notch upper and lower radius is restricted to increase more than 1^{o}C assuring that there are negligible effects of thermal loadings on fatigue failure of desired welded specimens. The metallic sheets are structured around the mounted specimens on the test system to provide shielding against air currents and major factor of reducing test zone temperature.

2. Specimen Preparation

High carbon steel tool is used to shape the specimen into a dog bone. Firstly cut the dog bone into two parts and then taper the lower radius side of each piece at taper angle of 45°. Then weld the both parts and fill the taper zone by filler metal 5356. According to ASTM standards the metallographic techniques are used to get the chemical free specimen's surface [6]. The specimen's dimensions are not standards these are selected due to the fatigue machine limitations, materials availability and practically interest situation. A v-shaped notch having radius 1mm is machined at the center of welded region as shown in Figure 1.

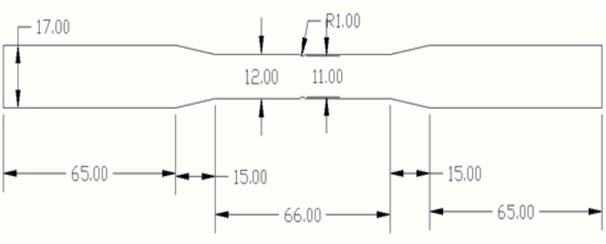

Figure 1. Dogbone Specimen.

3. Experimental Work

Dog bone specimens produced for this research have chemical composition [7] listed in Table 1.

3.1 Metallurgical Analysis and Hardness Test

The basic purpose of metallurgical analysis is to find out the microstructural changes due to oxy acetylene welding. A transition in microstructure is to be seen in welded zone (WZ) heat affected zone (HAZ) and base metal (BM). The material affected by the welding process presents a fine stirred grain structure and the material in HAZ also have recrystallized grain structure with respect to BM having regular grains [7]. During oxy acetylene welding process the filler rod melts and forms molten metal pool which fills the taper zone of the specimen. When this pool is condensed the atoms are oriented randomly and are unable to get a specific geometry. The region near the welded nuggets also tempered somehow due to high temperature welding flame. The difference in microstructure of these three regions affects their hardness. In present research a Brinell hardness test is conducted to get Brinell hardness number (BHN) of each zone. As it is difficult to find out the BHN of a round shaped bar due to stage limitations of Brinell hardness testing devices. So the round slices of each zone are cutoff and prepare the flat surface of slice for hardness test. According to ASTM the hardness test is conducted with a steel ball indenter of (Ø=5.0 mm) and the applied force is 612.9 N. The objective eyepiece is installed having magnification 2.5 x. The hardness behaviors of these three regions are shown in Figure 2.

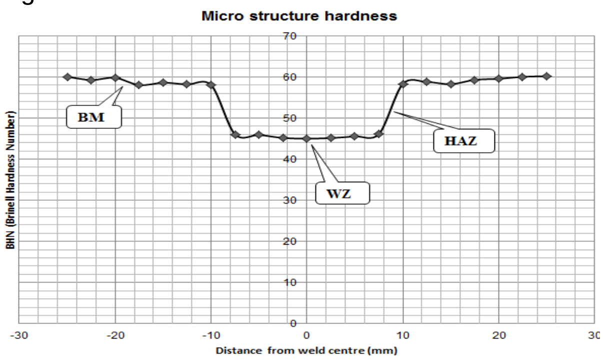

Figure 2. BHN of different welding zones.

3.2. Fatigue Test

The fatigue test is held on “Rotating and Bending Testing Machine” model PQ-6. Tension & Compression stresses vary on upper and lower surfaces while rotation of specimen. Hence fatigue loading is applied on the specimen as the upper surface of the specimen is in compression while the lower side is in tension. Basic fatigue testing involves the preparation of carefully polished test specimens (surface flaws are stress concentrators) which are cycled to failure at various values of constant amplitude alternating stress levels. The data are condensed into an alternating Stress, S, verses number of cycles to failure, N, curve which is generally referred to as a materials S-N curve. As one would expect, the curves clearly show that a low number of cycles are needed to cause fatigue failures at high stress levels while low stress levels can result in sudden, unexpected failures after a large number of cycles.

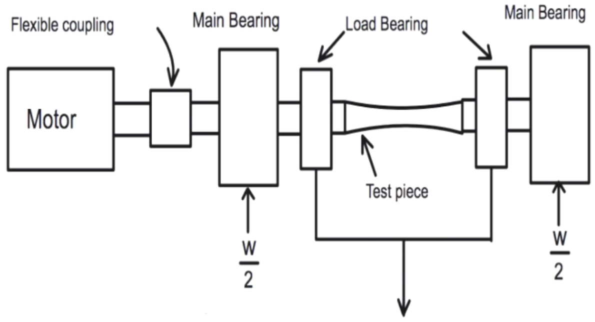

Figure 3. Fatigue test experimental setup.

The "Rotating Bending Testing Machine" is similar to the original railroad axle-type Wohler used where the bending moment is constant along the beam length [8].

Each point on the Surface of the Rotating Bend Specimen is subjected to fully-reversed cycling (σ_m = 0) and the tests are generally Constant Amplitude. In Figures 3 & 4 it is clearly represented how the specimen is in four points bending conditions that are specific characteristics of the present experiment.

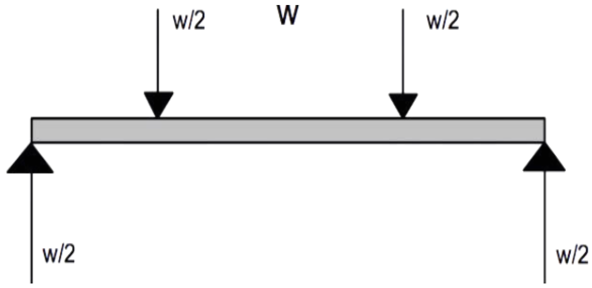

Figure 4. Loading conditions of specimen.

4. Results Discussion

Loading condition shown in Figure 3 produces bending stresses in the specimen. Using the geometric specification of the specimen and the stress formula expressed as:

$$\frac{\sigma}{y} = \frac{M}{I} \tag{1}$$

A relation is determined between the loads which are varying in each experiment and the stresses which are generated due to these loads.

By applying all the required specimen parameters in eq.1 a useful relation can be derived between applying load & stresses.

$$\sigma = 509.3\frac{Q}{d^3} \tag{2}$$

The stresses gains from the equation (2) are applicable only for the plane welded area. The stresses rush at a notch located at the welded zone has been determined earlier [9]. Most of engineering components contain notches, holes or some other stress raiser. To determine the stresses at a notch the plane stresses are multiplied by a new parameter known as stress concentration factor K_t which actually elaborate how many times the stresses increase due to a notch of particular geometry. As this factor is specimen’s notch geometry and loading condition dependent so its value for this experiment is calculated directly. The notch parameters are illustrated the Figure 5.

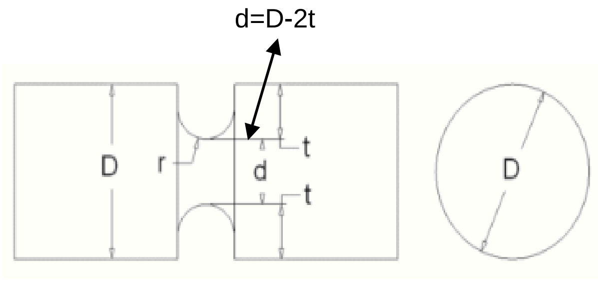

Figure 5. Notch specification of specimen.

$$K_t = \frac{\pi d^3}{32M}\sigma_{max} \tag{3}$$

The K_t valve for this dogbone specimen is calculated nearly 2.62 [10]. During the course of the test, the specimen is tightened; subsequently the specimen is rotating alongwith the main shaft, while the load is applied on both ends of the specimen through the pulling rod. Therefore, a pure bending moment is evenly distributed on the working parts of the specimen. Though the acting direction of the load is unchanged, the specimen is rotating all the time. The bending stress on each point of the specimen is alternative in the same speed alongwith the specimen. After hundreds of times alternative circles, the specimen is broken due to bending fatigue. The stresses change from tension to compression continuously.

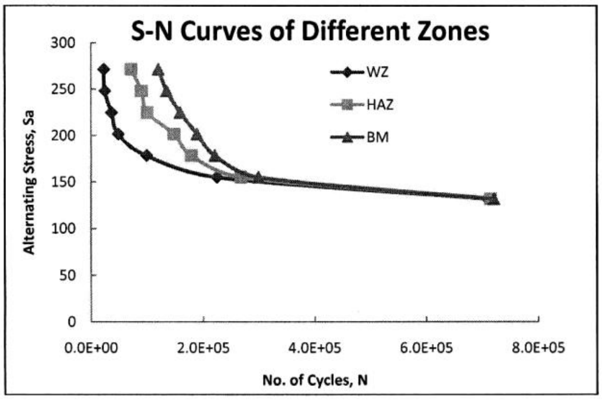

Figure 6. S-N Curves of different welding zones.

Therefore a pure bending moment is evenly distributed on the working part of the specimen as illustrated in Figure 3. From Differential Equation of Flexure the working bending moment is calculated as shown in eq.4 by applying initial condition.

$$EIy = Mx\frac{x}{2} - ML\frac{x}{2} + c \qquad (4)$$

At x=0, y=0, so c=0 then eq. become

$$-EIy = Mx\frac{x}{2} - ML\frac{x}{2} \qquad (5)$$

At x=L/2, y is maximum

$$-EIy = -ML\frac{L}{8} \qquad (6)$$

By using equation (6) the bending moment is calculated nearly 43.38Nm. The fatigue is conducted at constant amplitude, the maximum and minimum stresses remain constant for each cycle of test. The fatigue strength of the material will be determined from S-N curve. Actually it will describe that at which stress how many number of cycles it will bear. The most important part of the curve is often the portion to the right of the bend (or “knee”) in the curve that identifies what is termed the Endurance Limit or the Fatigue Limit [11].

The data obtained for welded zone is analyzed and nonlinear regression was performed and calculated.

$$R^2 = \frac{S_t - S_r}{S_t}$$

Where,

R^2= Coefficient of determination

S_t= Sum of squares of residuals

S_r= Sum of squares of errors

According to equation 7 for a perfect fit S_r=0 and R^2=1, signifying that the curve explains 100 percent of the variability of the welded zone data. So it was found that coefficient of determination was 0.961 and the behavior of material is in power form. For low stress amplitude the S-N curve exhibited a lower limit which implies that fatigue failure did not occur after high numbers of load cycles. The horizontal asymptote of S-N curve represents fatigue limit or endurance limit. Fatigue limit is of practical interest for many structures which are subjected to millions of load cycles in service while fatigue failures are unacceptable. Instead of applying stress amplitude to specimen constant strain amplitude is maintained in the critical section of the specimen. The problem area was designated as ‘low cycle fatigue’ which actually implies that macro plastic deformation occurs in every cycle.

The above discussion is supported by the microstructure examination as shown in Figure 7. The grains in the base metal zones are of longitudinal shape having the least concentration of grain boundaries. As the grain size of the BM is largest than any other zone so it shows that the precipitate are arrested and they have no enough time to escape out from grains to come on adjacent grains boundaries [12]. These precipitates are helpful in increasing the hardness of the base metal with respect to HAZ and WZ. In HAZ somehow artificial aging takes place and some of the grains are lucky to cross the boundaries while other accumulate near the boundaries due to which the grain boundaries feels thicker than any other zone as shown in Figure 7. The WZ has a dendritic structure which is characteristic of precipitation. It is the most fragile zone comparable to others [13]. The maximum artificial aging takes place in this zone due to which fatigue life reduces alongwith the decreased hardness. From grain structure it is also visualize that recrystallization of material takes place as multipass of welding takes place as shown in Figure 8. The fine grain structure is obtained after recrystallization producing more concentration of grain boundaries [14]. This structure is helpful in intergranular crack propagations.

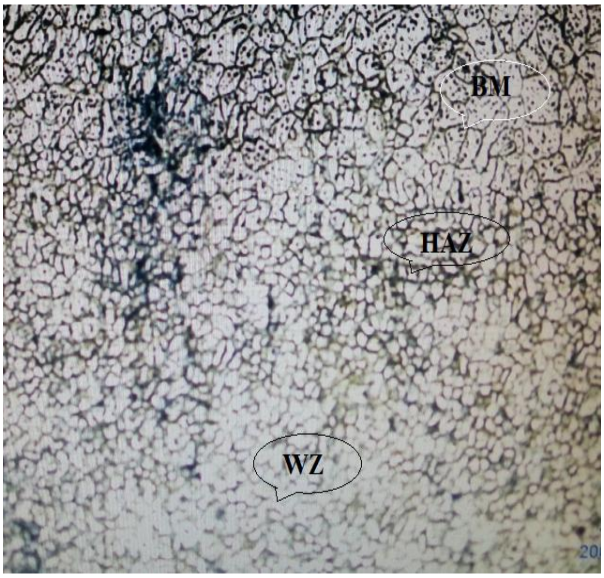

Figure 7. Grain structure of different zones

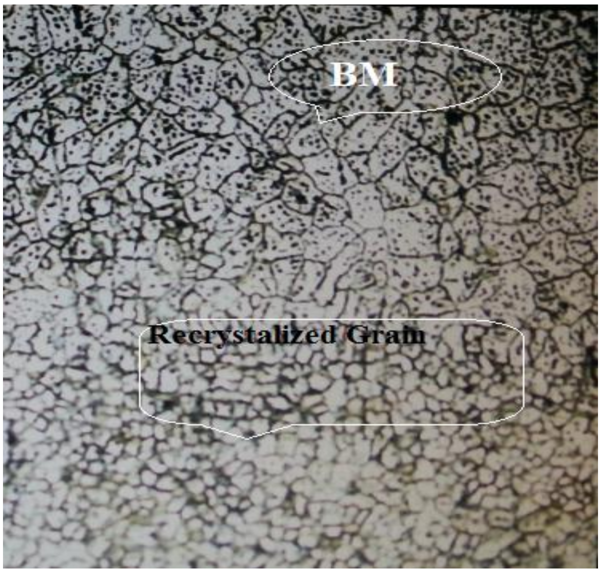

Figure 8. Recrystallization of grains in II pass of welding.

5. Conclusions

This study quantifies the influence of the oxy acetylene welding process on the fatigue life of aluminum alloy 5052-H32 notched specimens. It was verified that in oxy acetylene welded joint hardness drastically decreases as compared to HAZ and BM. The average hardness of the HAZ is significantly lower than the BM. The oxy acetylene welded joints presents lower yield and rupture stress than the parent material specimens. This result is of interest for the design of oxy acetylene welded components, presenting notches in weldment. Aluminum alloy used in research doesn't show the endurance limit in S-N Curves of every zones because failure of all specimens occurs before knee value and the behavior of the curve of welded zone is as $Sa = 1842 \times N^{-0.19}$

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