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THE INFLUENCE OF THE ELECTRIC ARC WELDING REGIME PARAMETERS ON THE FATIGUE RESISTANCE OF WELDED JOINTS

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Abstract: The present paper aims to highlight the effect of mechanical fatigue on weld and its correlation with the parameters of the welding regime. The paper highlights the main welding defects and how they occur in order to better understand the starting point of fractures due to the phenomenon of mechanical fatigue. Most welded joints are made in industry by electric arc welding methods due to the possibility of welding both manually and mechanically so it was reflected in the paper on the characteristics of the electric arc and their influence on the welded seam.
Keywords: welding, tension, fatigue, defects, parameters

1. INTRODUCTION

Mechanical fatigue of materials is one of the main factors responsible for the failure of parts and structures used in industry. A problem of interest in terms of the quality of parts and structures obtained by various welding processes is the resistance over time to variations in the stresses that develop in their operating processes or in other words the resistance of welded seams to mechanical fatigue.

The quality of the welded seams is directly influenced by the welding regime. This is described by a number of parameters that are common to most electric arc welding processes working voltage, electric arc intensity, feed rate, nature of electric current, welding arc length and electrode tilt angle.

The main factors that determine the occurrence of the phenomenon of mechanical fatigue on materials are the nature and magnitude of the loads found in a number of cycles in which they are applied alternately. This phenomenon is manifested by the degradation of the structure of the material of a part when it is exploited at values lower than the yield strength of the material from which it is made. Degradation takes place over time, being achieved by the formation of microcracks, their growth, followed by the last stage representing the rupture of the material. [1]

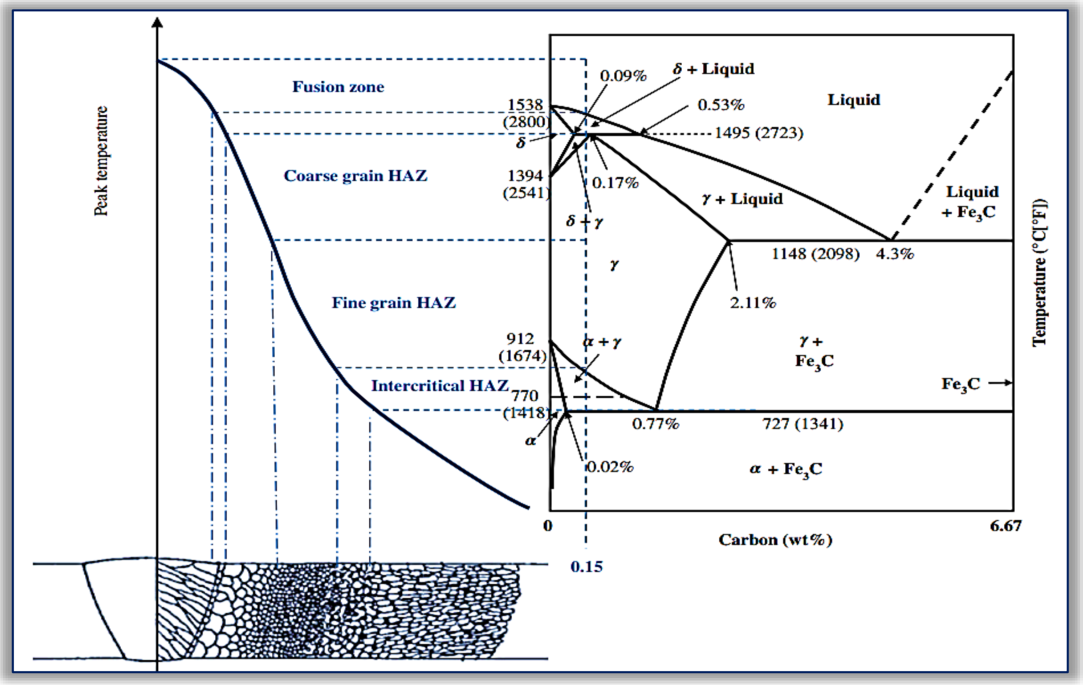

Figure 1. Microstructure of the heat affected zone [3]

Factors that play an important role in favoring the deterioration of the parts by breaking due to mechanical fatigue are: stress concentrators, characterized by sudden transitions from one geometry to another of the part (sharp edges, large section variations); the degree of surface processing, surfaces with high roughness is a basis for priming cracks especially if they are required to bend or twist; residual stresses, following mechanical processing or other technical processes. [2]

In the case of welded joints, the critical points of the parts to be exploited are located in the heat affected zone (HAZ) in the immediate vicinity of the welded seam as well as in the weld bead.

Figure 1 shows the micro structure of the welded joint by welding methods based on the melting source of the bath electric arc. It is desirable that in the heat affected zone structural changes take place that favor the formation of a grain structure as fine as possible to provide good mechanical strength. During the welding process, the temperatures developed in this area favor the growth of the grains from the basic material, forming a coarse structure near the heat source, which leads to the decrease of the mechanical properties of the respective area. In order to avoid this situation of grain growth, solutions are adopted such as refining the microstructure in the heat affected zone by dosing the oxygen content and alloying elements in the welding bath (Nb, Ti, V) that can form stable chemical compounds, stopping the growth of grains.

The physical parameters underlying the structural changes of the base material are the welding speed, the heat transfer through thermal conduction and the cooling time.

Defects in material that can occur in the welded bath once it has solidified make this area a critical area subject to the risk of yielding to mechanical fatigue over time. These defects can be of several types with internal volumetric or plane defects and surface defects. The most dangerous being the volumetric ones that require special verification methods such as ultrasound control or radiography, these defects can be:

- Sulphides, which result from the release of gases during the cooling process resulting in the formation of a porous structure inside the weld bead.
- Solid inclusions, which have technological causes, being found in the welding under the flux layer or in the welds made in the slag bath.
- The lack of melting, consists in the non-realization on certain portions of the mixture between the additive material from the welding bath and the base material.
- Poor penetration consists in the incomplete filling of the welding joint forming a cord with a smaller section than the normal one.
- Cracking occurs during the solidification of the welding bath due to the inability of the material to withstand thermal shrinkage, which may be due to too sudden cooling or a high carbon content in the material. [5]

The fatigue strength of a welded joint or other types of parts is very well described graphically by the Wȍhler curve shown in Figure 2.

This curve is drawn in a Cartesian coordinate system having on the ordinate a logarithmic scale on which is represented the number of cycles of the stresses to which the material is subjected and on the abscissa are represented values of the amplitude of the stresses developed in the material. The indicated areas I, II and III represent the 3 stages of rupture and the red line represents the fatigue resistance limit. It can be seen that there is a level of stabilization of the phenomenon where any assessment of the stresses below this limit indicates the impossibility of the material to collapse from fatigue, the number of stress cycles tending to infinity. [6]

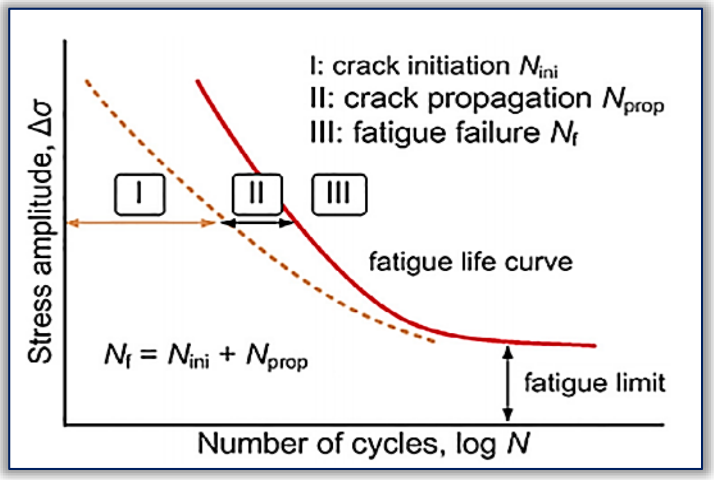

Figure 2. Wȍhler curve [6]

The existence of welding defects has consequence on the Wȍhler curve the narrowing of the area below it resulting in a lower stabilization level in terms of the amplitude of stresses and the elimination of the first stage in which cracks are formed, they already exist in the material.

2. STUDY OF THE INFLUENCE OF ELECTRIC ARC WELDING PARAMETERS

The electric arc represents an electric discharge in an ionized atmosphere, the formation of the arc takes place between two electroconductive materials separated by a gap. The direction of travel of the accelerated electrons in the ionized gas column is from the cathode (-) to the anode (+). The cathodic stain is colder by about 400°C than the anodic stain which can reach temperatures of about 4000°C, Figure 3 describes the phenomena and characteristics of the electric arc.

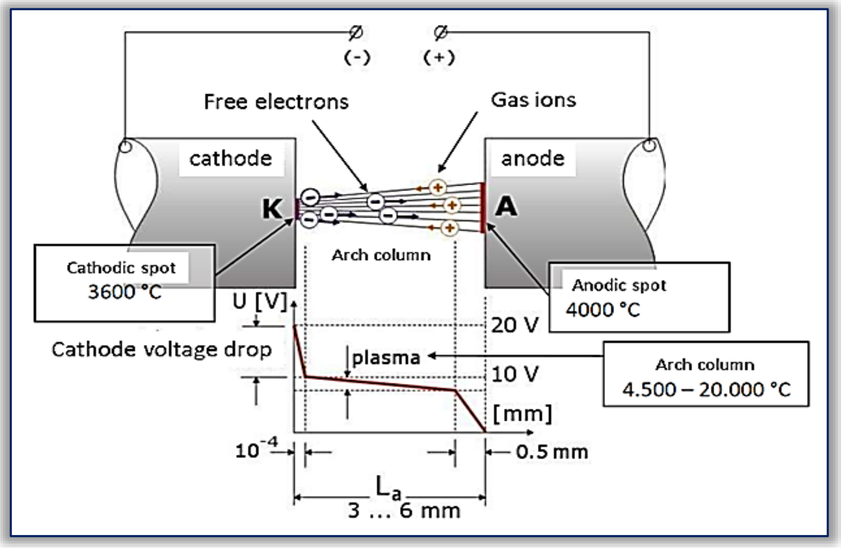

Figure 3. Elements of the electric arc [4]

Alternating or direct current can be used during welding processes. For direct current welding, direct polarization welding is considered when the electrode is connected to the cathode and the base material is connected to the anode the reverse situation is named reverse polarization.

The anodic spot is formed by bombarding the surface of the anode with the conducting electrons in the electric arc, their kinetic energy being transformed into heat. The excitation of the atoms in the ionized environment with the conduction electrons in the electric arc forms light emissions in the visible and ultraviolet spectrum and after the bombardment of the cathode surface by the gas ions, the cathodic spot will form, having a temperature of approximately 3600°C.

The nature of the electric arc directly influences the properties of the welding bath, through the developed temperatures, turbulence, volume and chemical reactions of the welding bath.

As for the electrode, it plays an important role in the formation of welding droplets, behaving like an electrical conductor, around it appears electromagnetic fields concentrated with maximums around the protrusions and edges. They act on the drop of molten filler along with other forces such as gravitational force (*Fg*), force due to surface tension (*Fs*), electromagnetic force (*Fm*) and sheets due to metal vapor pressure, all of which influence the size of the drop as well as the frequency with which it detaches from the electrode. [4]

We can enumerate 4 common parameters of electric arc welding processes, these having a direct influence on the geometry of the weld bead and on the mechanical properties of the seam.

The welding energy *H [J]*, represents the amount of heat necessary to melt the filler material in order to form the welding bath. This quantity in turn has 3 parameters that influence it making up the following relationship (1):

$$H = \frac{I \cdot U}{v} \ [J] \qquad (1)$$

where *I [A]* is the electric arc intensity, *U (V)* the working voltage and *v [mm/s]* the feed rate. These parameters contribute to the definition of the thermal regime of the welding process. [7]

The length of the electric arc *L [mm]*, represents the distance in a straight line between the end of the electrode and the surface on which the welding is performed.

The optimal length of the electric arc is considered in the literature to be equal to the diameter of the electrode used. This parameter has an influence on the rate of deposition of the filler material, the degree of penetration of the filler material into the base material and the surface quality of the weld bead. Welding with a length of electric arc greater than the diameter of the electrode is considered a welding process with long arc and short arc for shorter arc lengths than the diameter of the electrode.

The effects of long arc welding are:

— Favoring the oxidation of the welded seam
— Poor penetration of the base material, as a consequence the mechanical properties of the seam decrease
— The spraying phenomenon occurs which leads to the deterioration of the surfaces adjacent to the seam and at the same time raises the consumption of additive material.

Effects of short arc welding:

— It favors the phenomenon of elevation of the welded seam, resulting in a high and narrow seam section, which leads to a high consumption of filler material.

— Provides good penetration and fusion.
— Reduces the splash phenomenon.
— It favors the formation of a good protective environment, isolating the work area from the ambient atmosphere.[7][8]

The angle of inclination of the electrode *α [degrees]*, represents the deviation from the perpendicularity of the electrode to the welding surface towards the direction of advance of the electrode.

The higher the welding angle, the temperature of the electric arc is concentrated on the additive material deposited in the seam, allowing a better dilution of it, but at the same time the penetration into the depth of the seam decreases. The inclination of the electrode towards the direction of advance allows the achievement of a uniform deposition of the additive material in the welding joint. The geometry of the weld bead is influenced by the angle of inclination of the electrode, as the inclination increases, a seam will be made with an increased width of the bead and a decreasing overhang of it. [8]

The polarity of the electric current, represents the direction of movement of the electrons in direct current regime through the conducting wires that are connected to the electrode holder torch and to the basic material subjected to the welding process. In direct current welding with direct polarization, the base material plays the role of the cathode and the electrode is the anode, the base material heating up harder than the electrode, favoring the achievement of a good penetration. In the case of reverse polarization, the cathode is the base material and the anode the electrode, which favors the melting of the electrode, there being a weaker penetration of the filler material into the base material but increasing the deposition rate.

The main welding defects found in the welded joints by electric arc welding methods are shown in Figure 4.

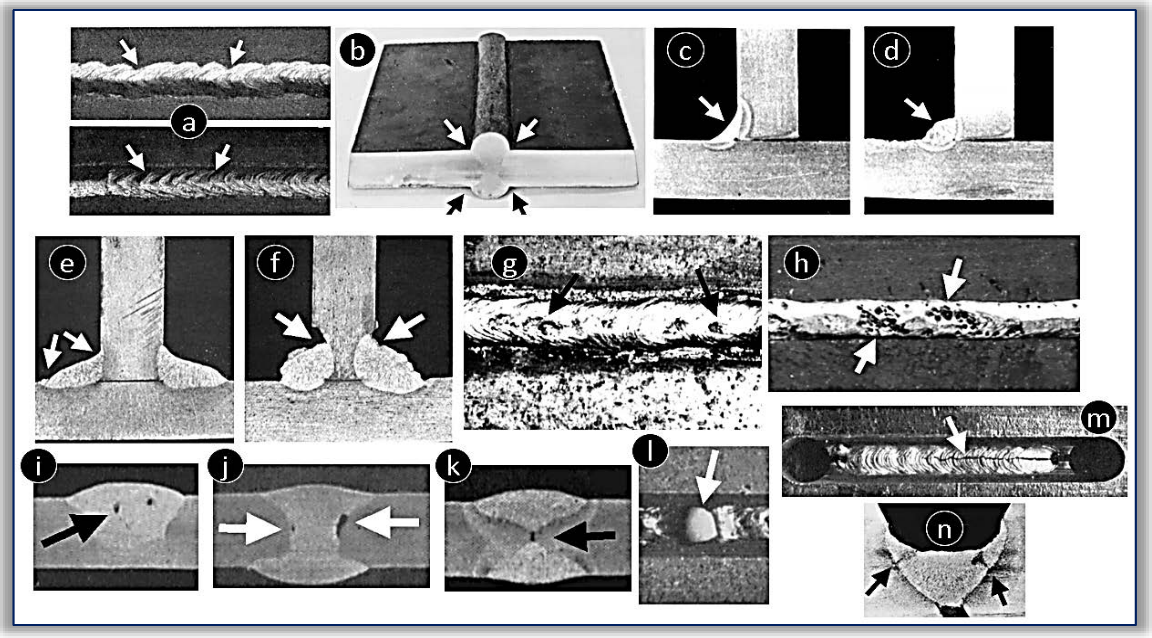

Figure 4. Defects found in electric arc welding processes [9]

— The non-uniformity of the welding bead (Figure 4.a.) is due to the use of too weak a voltage or amperage, improper handling of the electrode in case of manual welding, the presence of moisture in the welding environment.
— The overhanging of the welding bead (Figure 4.b.) occurs when a feed rate is too low, the amperage is too high, short arc welding.
— Excessive concavity (Figure 4.c.), is encountered in welding regimes that have too high a feed rate or use an improper inclination of the electrode.
— Excessive convexity (Figure 4.d.), is found when welding with high amperage, this being optimally correlated with the feed rate and the length of the electric arc. Also an influencing factor being the improper inclination of the electrode.
— Asymmetrical corner welding (Figure 4.e.), represents the uneven distribution of the filler material, the welding bead having a height less than the width or vice versa. This defect is the result of using an inadequate electrode tilt.
— Engraving in the welding bead (Figure 4.f.), appears as a cause of too high welding currents, too fast manipulation of the electrode, long arc welding, at manual welding the electrode does not perform the appropriate movements combined with its inadequate angle.

— Surface spots on the welded cord (Figure 4.g.), are mainly due to unpreparedness of the base material, electrodes or flux before starting the welding process, they may show traces of moisture or rust in the case of the base material.
— Porosities (Figure 4.h, i.), are cavities formed by the non-elimination of gases from the molten bath appeared during the welding process. In this case there may be multiple causes, impurities on the surfaces intended for welding (rust, oils, moisture), high sulfide content in the base material, protective gas medium or insufficient flow, high amperage, long arc welding or high voltage.
— The inclusion of slag (Figure 4.j.) is a phenomenon that manifests itself when there is too low amperage, long welding arc, side wind or too high pressure of the shielding gas, the inclination of the electrode is in the opposite direction to the advance or the remaining slag from the previous cords present in the same welding joint in the case of welding in several successive passes.
— Insufficient penetration of the bead in the welding joint (Figure 4.k.), represents the failure of the welding bead on the entire thickness of the welded joint. Appears as a result of a narrow welding joint, low amperage, long welding arc, low welding voltage, too high feed rate.
— The penetration by cutting the base material (Figure 4.l.) is due to too high an amperage or a welding speed close to friends correlated with an inadequate welding joint geometry.
— The crack (Figure 4.m, n), is the most dangerous defect of the material, they can be of many types, depending on their orientation and are due to the stresses in the base material, too sudden cooling or the existence of chemical compounds unwanted in the melt. [9]

3. CONCLUSIONS

The main cause of fatigue failure of welded joints is due to the existence of welding defects, the most dangerous defect being the crack, followed by porosity, sulfides and lack of penetration of the base material. Responsible for the appearance of these defects are the parameters of the welding regime, the most influential being those that contribute to the thermal regime of the welding arc, the intensity of the welding current, the working voltage and the feed rate. A significant influence also having the length of the welding arc along with the nature of the electric current and the angle of inclination of the electrode.
The failure due to mechanical fatigue of the welded seam material is achieved by creating or developing microcracks that are enlarged over time until the material is fractured.

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