Study of Fatigue Behavior and Microstructure of 1.6582 Steel Joint by Resistance Butt Welding

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Abstract

Various fusion welding methods can be used to create a successful jont. However, with the increase in the thickness, fusion welding processes have limitations. Therefore, solid-state welding methods have been developed and in the meantime Resistance Butt Welding method has been chosen as a suitable method. In this study, joining of 1.6582 alloy steel has been investigated and analyzed, and the effect of the electric current parameter has been investigated in this welding method especially on Fatigue parameter. The results have shown this method is suitable for connecting (Joining) parts with symmetrical geometry. Also results shown that increasing the current to an optimum current leads to increasing the strength, As a result, the fatigue properties increase similarly to the strength. The noteworthy point here is that at stresses less than 220 MPa, the mentioned sample has a fatigue limit after welding, and this joint can be useful in various industries, including tool making.

Keywords: Resistance Butt Welding (RBW), 1.6582 Steel, Fatigue behavior, Solid state.

1. Introduction

Nowadays, the relatively new and modern resistance butt welding method as a semi-solid process in various dimension part Joint has drawn attention [1-4] because, in this method melting did not happen and in the case of correct determination of the parameters of the process, to integrate and connect (Joint), a pasty state in the alloy is created, which can be suitable for increasing the quality of welding [5-6]. Fig. 1. shows the resistance butt welding processes schematically [7], in this method, before applying the direct current (DC) the two ends of the piece are closed on the special jaws and the pressure or head-to-head force is applied to them. As a result the passage of current and the increase of electrical resistance, the temperature rises in the connection section and additional pressure is applied, which leads to the creation of a connection [8-9]. This method's most influential independent variables are input current, welding pressure, and heat application time-dependent. As mentioned above, due to the material's inherent electrical resistance, applying the current to the piece increases its temperature. Due to the existence of the interface between the two parts, the temperature increase in the interface area is higher than in other areas [10-11]. The joining operation will be completed by applying appropriate pressure by increasing the temperature up to the pasty state. Moreover, in this method, the use of fillers is not essentially required [12]. Chen et al investigated the resistance butt welding process of nuclear fuel rods. One of the reasons for the selection this process was the high quality of the resulting connection, which can increase the life of the fuel rods [13].

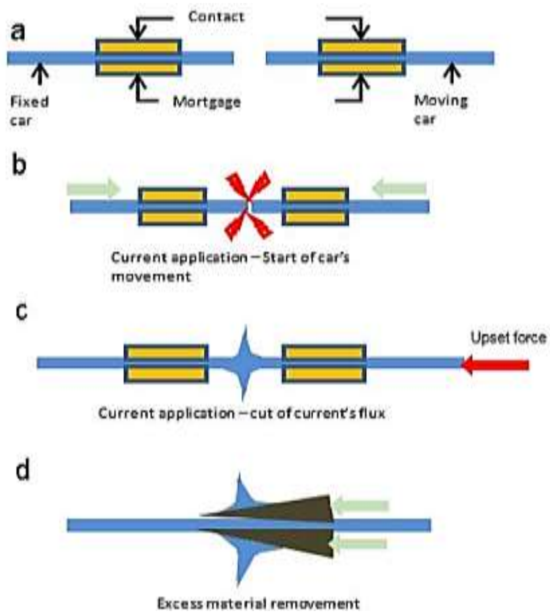

Fig. 1. Schematic of resistance butt welding process [7]. a- Fixing, b- Current Application, c- Upset force, d- finishing.

The results of Elshrief et al.'s research showed that one of the reasons for the growth of fatigue cracks in joints created by butt welding method is the presence of residual stress in the weld [14]. Sharifitabar et al. [15] investigated the effect of two parameters of welding power and pressure in the resistance butt welding process on the microstructure properties, tensile strength, and fatigue strength of austenitic stainless steel 304.

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The results of the mentioned study showed that, by increasing the welding pressure, the tensile strength of the Joint area increases. Correspondingly, by increasing welding power (increase caused by welding current), the tensile strength of the Joint area decreased due to the rise in heat [15]. Moreover, in another research, Sharifitabar and Halvai et al. [16] investigated the effect of welding parameters on mechanical properties and microstructure of non-homogeneous joining by resistance butt welding of martensite stainless steel 420 to austenitic stainless steel 304. The results of this study showed that by increasing the welding power, tensile strength in this type of Joint increases. The highest strength was related to a piece of weld with a current intensity of 1900 amperes at constant pressure and voltage [16]. 1.6582 alloy steels are a group of tool steels that are used in the field of mold making and cutting equipment and these steels are among the most widely used steels in the tool industry [17-19]. This group of steels with the standard name of VCN alloy steel in the types of VCN100-150-200 alloy’s has applications for making tools and machining. The main difference between the two types of 150 and 200 is the weight percentage of Mo and Cr elements [20]. One of the problems in the joining process of these steels is the presence of chromium elements, which can lead to the formation of carbide in the fusion welding process which will reduce the mechanical properties and especially the fatigue properties. Various methods such as pre-heating, post-heating, and using different kinds of electrodes (Fillers) have been proposed to solve this problem, and each of them has its advantages and disadvantages. Among all the mentioned methods, in this research, according to the importance mentioned about the resistance butt method, the joining process of the piece is investigated and also the fatigue properties of the alloy are analyzed.

2. Materials and Methods

1.2. Materials

In this Research, VCN 150 alloy steel (1.6582) was prepared in bars diameter of 12±0.2 mm, it's chemical composition following the standard EN 10027-2 [21] in Table. 1. denoted.

Table. 1. Chemical Composition (wt %) [21].

Material	Al	Ni	Mo	Cr	Mn	Si	C
1.6582	none	1.4	0.3	1.2	0.5	0.3	0.31

Then, the samples were cut to a 100 mm length to be placed in a resistance welding machine, and both surfaces were polished completely by a sanding machine to minimize the possibility of impurity penetration. All sample surfaces were washed with alcohol to remove impurities before welding, and the surfaces were kept in a suitable chamber away from oxygen until welding, so that the quality of the welding surface is at the highest possible level.

2.2. Research Method

To administration present research, the constant pressure parameter (22 MPa) was considered, and variable currents were adjusted according to the device's ability according to Table. 2. Resistance butt welding machine made in Iran by Electro Techno Tech Company with a varying current of 2000 up to 7000 Amps was used for welding and Joining. Fig. 2. Shows the sample after the welding process.

Fig. 2. Sample after Welding

Table. 2. Welding Current Variable in Different Situations.

Code Sample	The current passing through the part (amps)	Voltage (V)	Primary power (watts)
R. 3000	3000	1.2	3600
R. 3500	3500	1.7	5950
R. 3800	3800	2	7600
R. 4000	4000	2	8000
R. 4300	4300	2.2	9460
R. 5210	5210	3	15630
R. 5700	5700	3.5	19950

In order to remove the surplus from welding operations (red circle shown in Fig. 2.) , all samples were under machining operations, 2±0.1 millimeters of sample surface was reduced, and the diameter of the sample was reduced to 10 mm as shown in Fig. 3. Also in Fig. 3.b the fatigue sample shown.

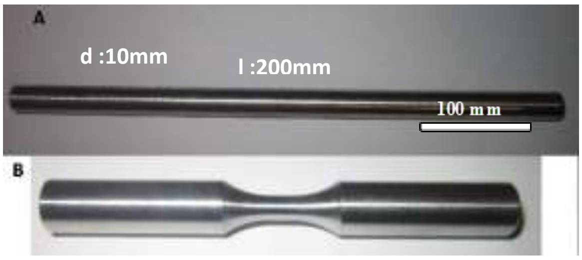

Fig. 3. a) After Machining b) Fatigue Sample.

Also, the images of the microstructure of the sample were prepared using an optical microscope (Meiji

model). Before welding, the samples were fully annealed (it is kept at a temperature of 680 C Celsius for about 90 up to 135 minutes and we cool it in the air) [17].
At this temperature, the more open crystal structure of austenite can absorb carbon from iron carbide in steel. An incomplete Austenitization process causes some dissolved carbides to precipitate in the structure. For some irons, iron-based alloys, and steels, carbides may appear in the Austenitization stage, which is called two-phase Austenitization [19]. It is presented in Fig. 4.

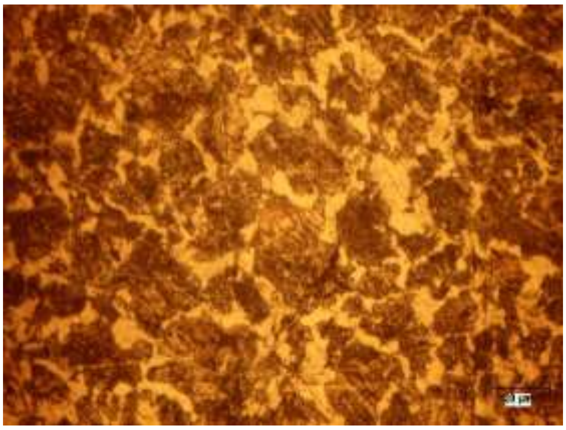

Fig. 4. Microstructure before Joint by 20µm LOM.

2.3. Test Methods

Tensile test was performed at ambient temperature and at a speed of 1 mm/min. The tensile test data was recorded by the device.To perform the tensile test, welded bars were used without special preparation operations. To check the reproducibility of the results obtained from this test, three samples were analyzed and then the average of the reported results was used. Also, In order to perform the fatigue test, prototyping was done according to the standard test method. The sample of the fatigue test is shown in Fig. 3.b. The fabrication of the fatigue sample was done by CNC machine with high precision.
The highest stress applied in the fatigue test was considered equal to 0.67 of the tensile strength of the pure sample before welding. Fatigue life was also measured based on a special machine counter.
In order to check the microstructure of the samples, after cutting, all the samples were sanded with 100 to 2000 sandpaper. Then polishing and washing operations with alchohol were performed. The etching solution used in this research was Nital.

3. Results and Discussion

The results that depend on the type of alloy showed that in some cases the strength decreases with the increase of electric current and in other cases the strength increases [16,24,25].
It should be noted that, by increasing the current to the maximum possible level, the Joint of the sample was not completed and the sample was broken from the inside, in Fig. 5. shows the macrostructure of the fracture surface of the sample during welding.

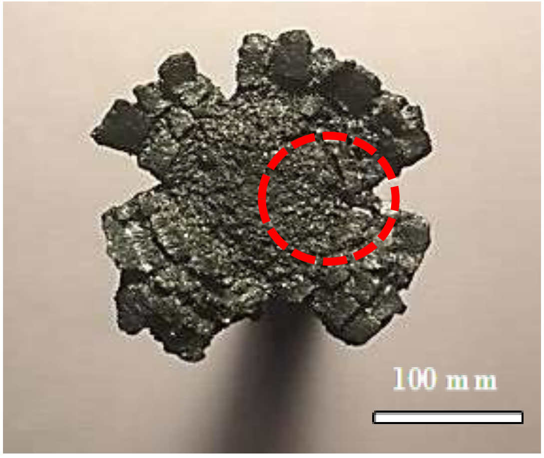

Fig. 5. The shape of failure of the failed sample, the edges of the sample are reported to be extremely brittle and brittle.

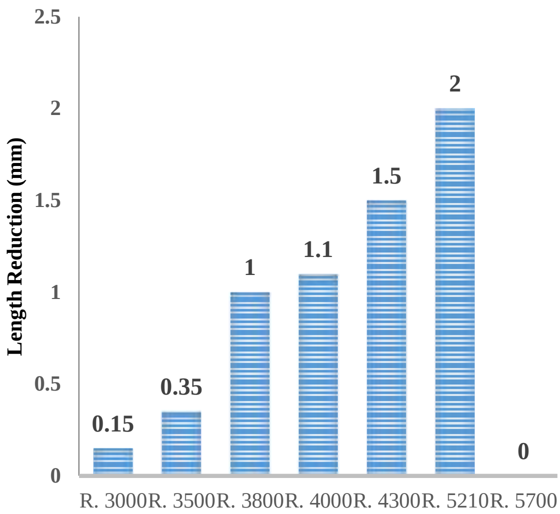

Fig. 6. Length reduction of samples after RBW.

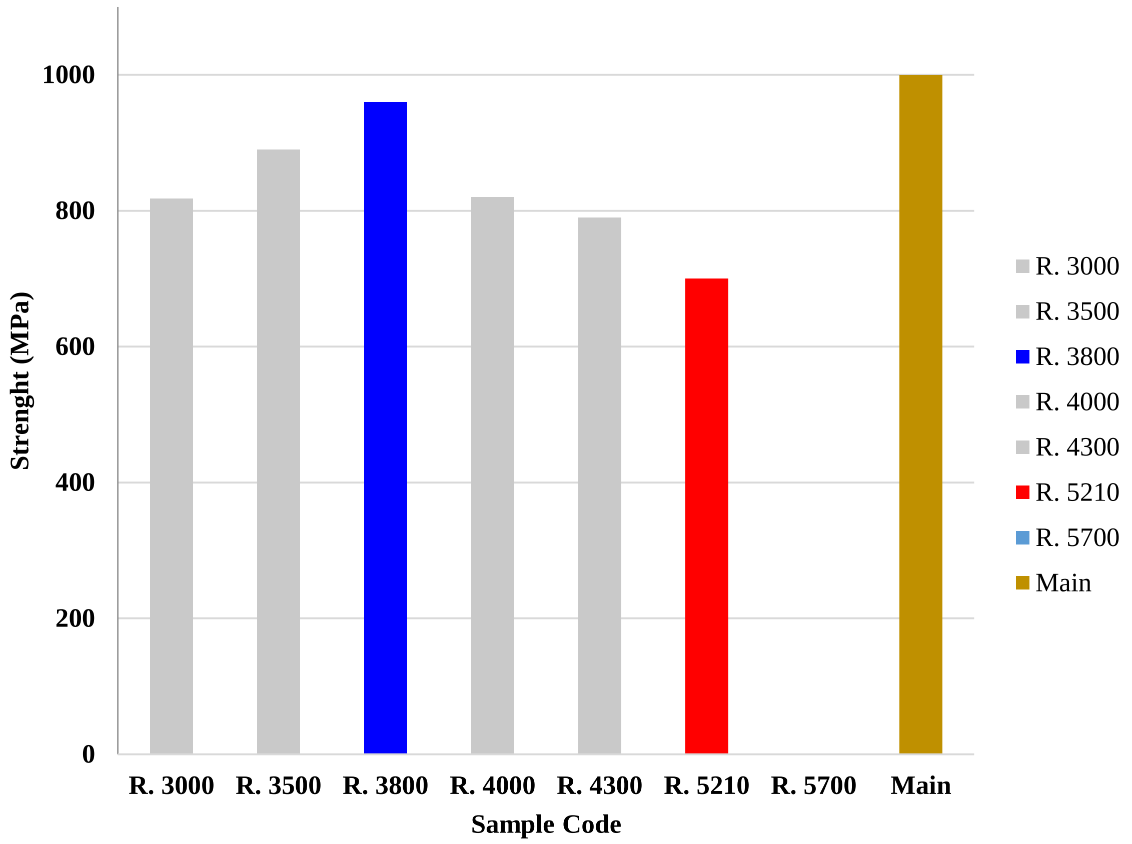

Fig. 7. Changes in the sample Code tensile strength after Joint.

3.1. Reduction of Sample Length

As mentioned above, two bars with a diameter of 10 mm and a length of 100 mm were used to create the Joint. The final length of the piece was recorded as 200 mm, before welding and Joining. it shows that by increasing the welding current at constant pressure, the samples show a more significant decrease in the length. This illustrates an increase in the pasty area and more integration of the two workpieces, which is the consequence of the increase in the inlet temperature caused by the rise in current. The diagram in Fig. 6. shows the results of sample length reduction.

3.2. Tensile Strength

The tensile strength results of the samples were presented in the diagram in Fig. 7. The fracture occurred in all cases without significant plastic deformation. It is clear that by increasing the electric current up to 3800 amperes, at first, the strength increases and then decreases. As can be seen in the diagram of Fig. 7., the tensile strength of all samples is lower than the raw sample before welding.

In the best case, the R3800 sample has the closest strength to the original sample due to the creation of the Heat-Affected Zone (HAZ) caused by the joining process. In the R3000 sample, sufficient heat is not generated to create a pasty state at the welding stage, and therefore the bond strength is lower than that of the R3800 sample. Other reasons for the loss of strength in this welding method can be due to applying pressure and the creation of cracks in the welding section.

Also, Fig. 8. shows the different welding areas for the R3800 sample, which include the base metal (Fig. 8.A), weld metal (Fig. 8.B), and heat-affected zone (Fig. 8.C). As can be seen, the microstructure of the base metal region remains unchanged and consists of a pearlite-ferrite microstructure (Fig. 8.A). On the other hand, according to standard TTT diagrams, due to the increase in the cooling rate in the welding zone, the resulting microstructure is completely martensitic (Fig. 8.B).

In the heat-affected zone (Fig. 8.C), the resulting microstructure is a combination of martensite and pearlite. It should be noted that the presence of the bainite in the heat-affected zone is expectable, which needs much more research and the possibility of the presence of bainite can directly affect the mechanical properties.

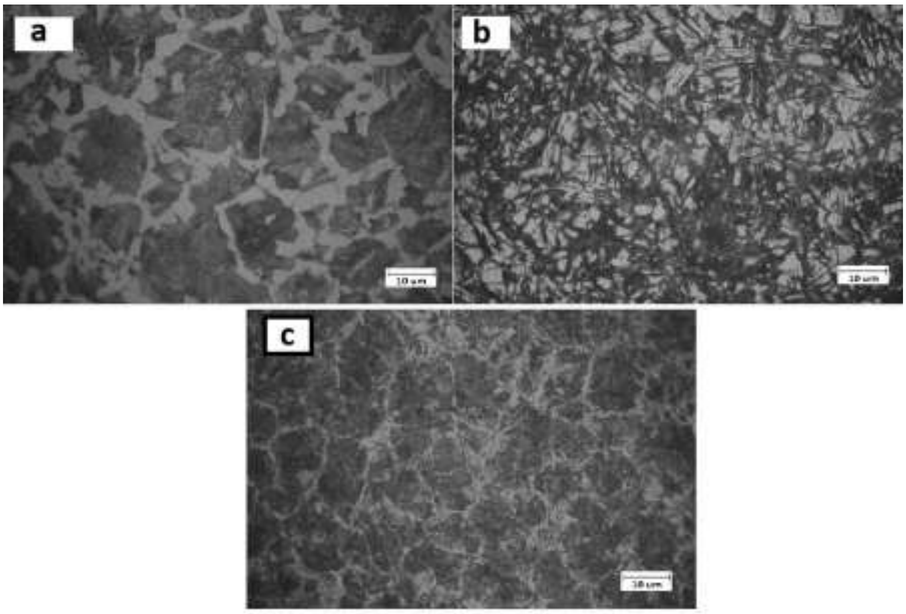

Fig. 8. Microstructure of different areas of sample R3800. a) Base Metal, b) weld zone, c) HAZ.

3.3. Fatigue Life

Fig. 9. shows a comparison chart between fatigue cycles between two samples with the lowest and highest strength. As it is clear in the figure, sample R3800 has passed the maximum fatigue cycle at low stresses, which was expected due to the high strength of the sample. The joint stiffness was the controlling factor of the fatigue strength of resistance butt welding [26].
One of the important things in the fatigue properties of welding joints is the residual stresses remaining in the weld, and since in the resistance method, less residual stress is created in the weld, the fatigue resistance of the parts is higher than in the melting methods [27].

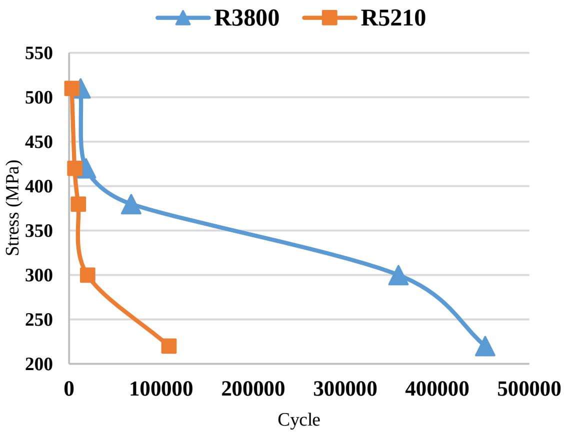

Fig. 9. Fatigue cycles of different samples

Fig. 10. shows the scanning electron microscope image of the fatigue failure surface of different samples. As it is known, fatigue is observed in both samples of beach line area due to the passage of time.

As can be seen in Fig. 10.b, the fatigue crack growth has started in a section of the sample and the fatigue crack has been a factor in reducing the fatigue life of sample 5200.

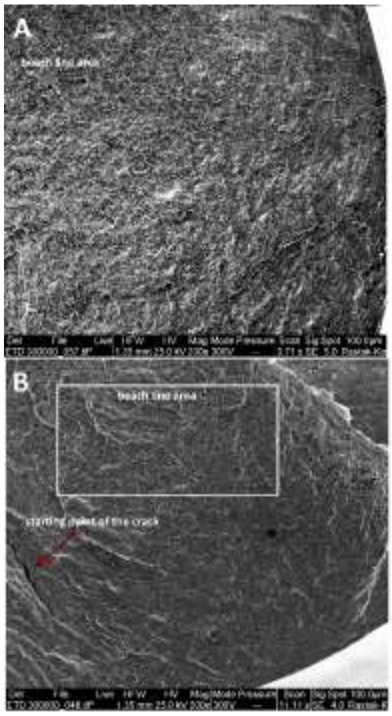

Fig. 10. Scanning electron microscope image of fatigue failure surfaces a) R3800 and b) R5200.

4. Conclusion

Based on the results of this study, the results are categorized as follows:
1. By increasing the welding current, it is possible to occur the fracture in the workpiece during the process as a consequence of pressure.

2. With increasing the welding current, the strength does not increase in all cases and in an optimum current, the strength will be maximum. The optimal current in the present research is recorded to be around 3800 amperes, which decreases with the increase of the current due to the increase of the input heat.
3. The results of the fatigue test showed that the fatigue life of the material decreases with the increase of the welding current.
4. According to microstructural studies, the microstructure resulting from resistance welding operations in this steel is martensitic, which can be improved by post weld heat treatment. (the microstructure resulting from resistance welding in this martensitic steel can be improved by heat treatment after welding.)
5. Resistance butt welding operation is a suitable method for Joining sections with high thickness for related parts.

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