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Efficiency of Butt-Welded Joints of Low-Carbon Steel for Different Types of the Cooling Rate and Annealing Time

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Abstract

Effect of cooling rate and annealing time on mechanical properties and microstructure of low-carbon steel butt-welded joints was studied in this paper. Results indicated that the cooling rate will increase the amount of martensite which will reduce the weldability of the dual phase steel. The low-carbon percentage enables water to be as a suitable quenching medium for production of the dual phase steel with better weldability than the quenching medium of a salt solution. The results also indicated that the increased annealing time causes growth of the austenite grain size without touching on its amount. Annealing for a stop of more than 10 minutes produces a structure of polygonized ferrite-martensite, while annealing for 10 minutes or less the structure will be polygonized ferrite-pearlaite with a small amount of martensite. Having in mind that the weldability depends upon the quantity of the martensite phase its distribution inside the ground substance.

Keywords: *Butt welding; Low carbon steel; Microstructure; cooling rate*

Introduction

The weldability of metals and alloys means production of joints free of defects, reflected in their mechanical properties suitable for engineering applications, such as tensile and yield strength for tolerating external loads, hardness for wear resistance and ductility for flexibility and impact loading [1]. All these conditions may lead to the deterioration of the metal or the weld, or transition zone between the weld metal and base metal, In this process the welded connection is formed without melting metal in which joining occurs at a temperature below the melting point of the metal work. Heat is generated by direct conversion of mechanical energy into thermal energy at the interface of the work pieces during the welding process.

Steels containing high percentage of carbon means a high probability of brittle martensite formation in the heat effected zone (HEZ) with high hardness and tensile strength and of low ductility and low toughness, this means an unweldable structure [2,3]. Weldability of metal in fusion welding is their ability to fuse under the effect of the heat, then solidify and produce a giant compared of the similar or dissimilar metals without cracking. The weld zone should be given special consideration; it should be stable for long periods under the complex machining conditions, such as high temperatures, pressure, high alternating stresses, and corrosive conditions.

The main structure of dual phase steel consists of ferrite and martensite. The high hardness is due to the presence of martensite within the ferrite matrix which is responsible of ductility, therefore this type of steel is known for its strength and deformability which enable its use and production of automobile parts of complex design [4,5]. The stability of retained austenite enhances the ductility without affecting the tensile strength. Retained austenite of grain sizes 2-6 mm is relatively unstable and it will transform at small distortions to martensite. Smaller austenite grain sizes will resist transformation to martensite, will increasing transformation of retained austenite to martensite the strength of dual phase steel will increase. The homogeneous elongation will batter when the retained austenite exceeds 10% [6,7]. One of the main property of the dual phase steel in its low yield point and its progressive yielding due to the formation of high number of mobile dislocations by the martensite phase in the ferrite phase. These dislocations do not need high stresses for their movement during plastic deformation, therefore the stress-strain curve will be more progressive and flatter without sharp yield point [8], but with increasing volume fraction of martensite , the dislocation density in the ferrite phase will increase loading to higher strength of the dual phase steel [9,10].

Materials and methods

Material: Low carbon steel of commercial type with the chemical composition shown in Table 1, was used in this research work.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	V	Fe
Content %	0.14	0.13	0.29	0.05	0.049	0.06	0.069	0.49	0.06	0.03	Rem

Table 1: *Chemical composition of the low carbon steel.*

Sample: Samples of dual phase steel were prepared in standard form for tensile testing (ASTM A356/A356M-11). Some of these samples are cut at the middle (see Figure 1) and butt welded by manual are welded using electrode of 3 mm in diameter, 60 Amperes and 230 volt. Vickers hardness samples have a disk shape with 25 mm diameter and 10 mm thickness. Charpy Impact samples were prepared according to (ASTM E23) standard.

Testes: Tensile test was carried out on tensile test machine type instron 1195 with capacity out on of 10 ton and strain rate of 6.67*10/sec. Vickers hardness test was used to measure the hardness of the samples. The readings were taken from weld metal zone (HEZ). Impact strength was also measured after versions heat treatments by using charpy impact instrument.

Heat treatment: The steel was heat treated in a medium size electric furnace, type ESFI-PID carbolite wills a maximum temperature of 1200°C. The samples were heated to 800°C and held for 15 minutes for homogenization, then they were quenched, the quenching media were oil, water and salt solution, then the samples were annealed at 800°C for periods of 5, 10, 15 and 20 minutes. Examination of the micro stress here showed that dual phase steel can be obtained by quenching in water or salt solution. The matrix structure was ferrite phase embedded in it islands of hard martensite was more in samples quenched in salt solution when compared with those quenched in water. The volume fraction of martensite was estimated by using point counting method from optical micrographs Figure 1 shown the details of the microstructures after various heat treatment processes. The samples quenched in oil, did not show martensite formation.

Results and Discussion

Microstructure

The microstructure of the low carbon steel was shown in (Figure 2 Figure 3) respectively. The microstructure after heat treatment showed a Matrix structure of ferrite phase included in it small spurs of cementite (Fe3C) addition to small particles of partite at grain boundaries. But the Microstructure of the dual phase steel showed matrix structure of ferrite and the martensite phase distributed within the ferrite phase. These microstructures were observed in the steel samples subjected to quenching in water and salt solution. Quenching in salt solution gave more martensite then quenching in water. While quenching in oil did not produce any martensite due to low cooling rate and low carbon content, Instead it lead to grain growth of ferrite and formation of cementite along the grain boundaries and the pearlite appeared on long islands at the intersection of the grain boundaries of ferrite.

The martensite formed by quenching in salt solution produced acicular martensite distributed more homogeneously within the matrix when compared with the martensite formed by quenching in water. Increasing the annealing period causes austenite grains growth and during quenching a certain percentage. Remains as retained austenite with changing the annealing period, The ferrite grain size varies. It grown with increasing annealing time, and the annealing time has its main affect on the uniform distribution of martensite within the ferrite grains. It was observed that the annealing period of more than 10 minutes produce after quenching in water, polygonized ferrite and martensite, while annealing period of 10 minutes or less produces polygonized ferrite and pearlite with small amount of martensite.

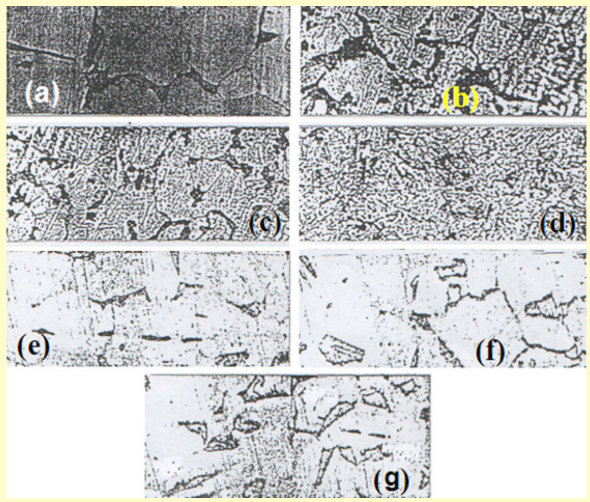

Figure 1: *Microstructures of a) Low carbon steel as received before treatment, b) Annealed steel with 850°C at 15 min with oil quenching, c) Annealed steel with 850°C at 15 min with water quenching, d) Annealed steel with 850°C at 15 min with sail solution quenching, e) Annealed steel with 850°C at 5 min with water quenching, f) Annealed steel with 850°C at 10 min with water quenching, g) Annealed steel with 850°C at 20 min with water quenching.*

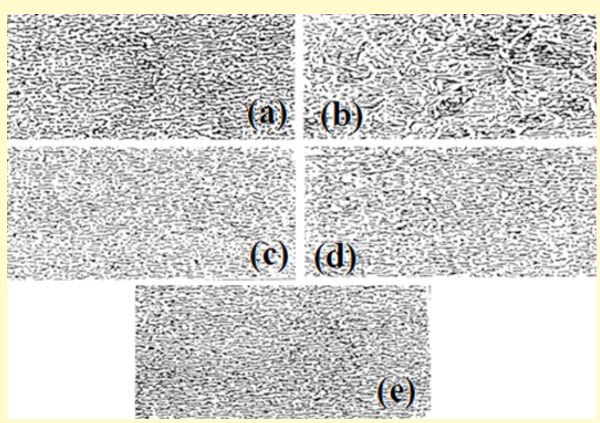

Figure 2: *Macrostructures of a) Welding reign, b) Grain growth, c) Normalizing reign, d) Recrystallization reign, and e) Base metal reign.*

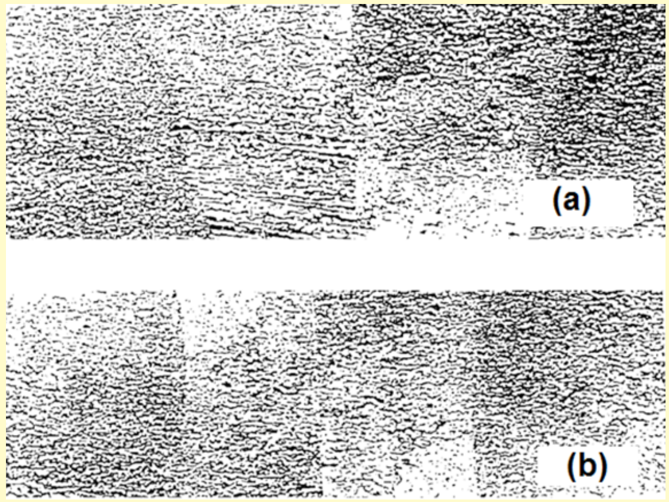

Figure 3: *Microstructure of welding reigns a) With thickness direction, b) With surface direction.*

Weldability

In this process the welded connection is formed without melting metal in which joining occurs at a temperature below the melting point of the work metal. Heat is generated by direct conversion of mechanical energy into thermal energy at the interface of the work pieces during the welding process. Weldability is the ability of the metals and their alloys to melt needs the effect of heat and then solidify for bonding there similar or dissimilar parts. These joint produced showed be stable for long periods under seven working conditions. So the main purpose of weldability of metals and alloys is to produce welding joints free of defects, Particularly cracks besides that the mechanical and chemical requirements showed be satisfied for engineering applications, while include the tensile strength, hardness, elongation to resist external load, were resistance and impact loading. To concentrate the stress within the weld metal, a notch with angle (45), depth, of 3 mm and root radius of 0.1 mm was cut. The results show that the tensile strength increasers with increasing cooling rate due to the formation of longer volume fraction of martensite within the ferrite structure. It is well known that martensite has higher strength than ferrite and pearlite phases. decreasing martensite grains will further increase the strength of structure, because smaller grain size means more obstacles against dislocation movement. Similar results were obtained for hardness, namely, hardness increase with increasing cooling rate, while the impact strength decreased with increasing cooling rate.

Therefore the samples quenched in salt solution gave the least impact value, while these samples quenching in water showed butter toughness results and good strength and hardness. These results are included in Table 2 with the strength of dual phase steel. The best weldability results were obtained after annealing for 15 minutes which produces optimum grain size and butter mechanical properties. Reducing the annealing period resulted in dimension of the martensitic phase that means no steel with dual phase behaviour.

Cooling Rate	Annealing Time (min)	Volume Fraction of Martensite	Tensile Stress Mpa	Hardness Kgf/mm^2	Toughness Joule
Oil	15	-	176	122.6	7
Water	15	14.1	194.6	129.3	8.2
Water	20	15.1	182.3	137	7.6
Salt Solution	15	18.8	200	156.3	7.7

Table 2: *Mechanical Properties of Dual-Phase Steel with Different Cooling Rate and Annealing Time.*

Conclusions

The volume fraction of martensite increase in its size decreases with increases the rate of cooling. Cooling in salt solution causes high hardness and reduced toughness, while cooling in water produced better weldability of dual phase steel concerning strength, hardness and toughness. In annealing for 10 minutes or less, the structure of the steel will be polygonized ferrite-martensite-pearlite, while annealing for a period more than 10 minutes produced a structure composed of polygonized ferrite-martensite. Increasing the period, results growth of austenite grains, which leads to coarse martensite after quenching, causing unbrittlement. The optimize weldability of dual phase steel was at annealing for 15 minutes.

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