

EVALUATION OF THE HARDNESS AND MICROSTRUCTURE OF A TUNGSTEN INERT GAS WELD OF A MILD STEEL PIPE JOINT

INNOCENT UDUUEHIABHULIMEN

Department of Materials and Production Engineering, Faculty of Engineering and Technology,
Ambrose Alli University, Ekpoma, Edo State, Nigeria

ABSTRACT

The hardness and microstructure of Tungsten Inert Gas (TIG) weld of a mild steel joint has been investigated. The hardness of the weld joint and the Heat Affected Zone (HAZ) of a mild steel is important when considering its performance during its application in industries. In the use of pipelines for the transportation of gases and fluids over long distances to different destinations, the pipes need to be joined together by mostly welding. Tungsten Inert Gas (TIG) process was used in this research having chosen current, voltage, gas flow rate and electrode diameter as the process parameters. The hardness test was conducted using the Rockwell hardness scale B while the microstructure was evaluated using the metallurgical microscope. The different variation in the hardness values was observed and it was noted that the weld joint has the highest hardness values followed by the HAZ and finally the base metal. With choice of the process parameters, current was also noted to have contributed mostly to the effect of the hardness values.

KEYWORDS: Hardness, Microstructure, Parameters, Rockwell and Scale

INTRODUCTION

The welding of Mild steel pipes can easily be carried out by Tungsten Inert Gas (TIG) because of the easy selection of the input parameters. TIG welding is a process that produces an electric arc maintained between a non-consumable tungsten electrode and the part to be welded (Sathish et al, 2012). The Heat-Affected Zone (HAZ), the molten metal and the tungsten electrode are all shielded from atmospheric contamination by a blanket of inert gas fed through the TIG torch.

Metallurgical characteristics of the weld metal as well as heat affected zone (HAZ) are very important because these directly influence the weld mechanical properties and joint performances. It is well known that the micro structure of the weld metal is different from the microstructure of base metal as well as HAZ (Wang et al. 2002, Kolhe and Datta 2005). The weld microstructures, however, are somewhat different with respect to distributions of pearlite and ferrite, their amounts, grain sizes, etc. depending upon the welding conditions adopted. In a pass of the welding torch, material is rapidly heated to the maximum temperature and allowed to cool more slowly by conduction of heat into the bulk of the parent metal. Phase change can occur depending on the temperature reached. Sufficiently far from the weld pool, the material remains unaffected. The region next to the fusion zone where micro structural changes have occurred but no melting of base metal has effected is known as heat affected zone. Such micro-structural changes may affect the mechanical properties of the weld and need to be controlled. The weld metal microstructure is controlled mainly by the cooling cycle.

The weld metal microstructure is controlled mainly by the cooling cycle (Choi et al 2011). The ultimate tensile strength of the welded joint increases with an increase in the heat input see samples 3 and 25. The average micro hardness of the heat-affected zone and fusion zone decreased sharply with an increase of the heat input and then decreased slowly at a relatively high heat input sample 3. At lower energy input (i.e. with low level of current), the time for solidification is less this makes the cooling rate to slow down and give way to coarse grains. It was also noticed that depending on the number, size and distribution of inclusions, the weld metal microstructure varied.

METHODOLOGY

Welding Process

To achieve the objectives of this study, welding process was carried out for 39 experimental runs using the Tungsten Inert Gas Welding process, and the following procedure was followed, a bead was created using four different steps as follows: 1. Root Run, 2. Hot Pass, 3. filling and 4. Capping.

Mechanical Testing

Mechanical testing measures the strength, hardness and ductility of materials under various temperature, tension, compression or load conditions. Mechanical testing services provide information about the suitability of a material for its intended application.

Metallography

The surfaces of the metallographical specimen which are weld deposits made by applying the different input process parameters, were prepared by various methods such as grinding, polishing, and etching. They were sectioned to the required size from the joint comprising weld metal, Heat Affected Zone (HAZ) and base metal regions and were polished using different grades of emery papers. Final polishing was done using the diamond compound (1 μ m particle size) on the disc polishing machine. The specimen were etched with 5 ml hydrochloric acid, 1 g picric acid and 100 ml methanol applied for 10–15s. Figure 1 shows the polished welded sample. After preparation, the surface was analyzed using a metallurgical microscope.

Rockwell Hardness

The Rockwell Hardness test is a hardness measurement based on the net increase in depth of impression on a material as a load is applied. Hardness numbers have no units. The higher the number on the scale, the harder the material. The mild steel specimen of 6.4 mm thickness was placed on the surface of the Rockwell Hardness tester. A minor load is applied and the gauge is set to zero. Then different loads were applied by tripping a lever. After 15 seconds the major load is removed and the specimen was allowed to recover for 15 seconds and then the hardness was read off the dial with the minor load still applied. Numerous aspects of the Rockwell hardness test can influence the measurement result. These include the function and calibration of individual components of the hardness machine, variations in the indenter, the testing cycle that is used, the testing environment, the condition of the test material, and the operator. When considering all of these influences, it seems remarkable that the Rockwell test has provided such a reliable test throughout its long usage.



Figure 1: Polished Welded Sample

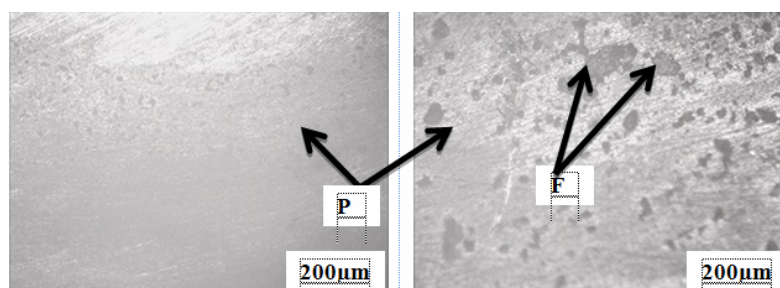
RESULTS AND DISCUSSIONS

Microstructural Analysis

Plates 1 – 30 show the microstructure of weld joints of samples 1 – 30. All samples show the presence of ferrites and pearlite distribution and some fusion materials in the grain structure of the welded mild steel. Samples welded at very high current and moderate voltage (samples 3, 11, 24 and 25) had low volume fraction of ferrite in the pearlite phase with refined grain size leading to improved hardness and tensile strength (samples 3 and 25). Microstructures of samples 28 and 29 show the presence of large clusters of ferrites. Microstructures of samples 1, 9, 14, 15, 20, 25, 27 and 28 also show banding structure on the advancing side of the weldment, this is consistent with the result of Parth and Sachin, 2011. The microstructure that evolved in the weld is heterogeneous due to the temperature and the chemical gradients that evolved during the process. This is supported by the works of Babu and Natarajan, 2008 and Kanjilal, et al 2006.

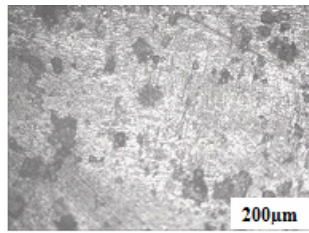
Microstructures of samples 24 and 25 show the effect of direction heat flow on elongation of ferrite grains. These samples with hardness values of (63.15 and 64.35) agree with the ANFIS prediction in the overlay plot of the second solution. The predicted interval shows values between 542.559 MPa and 457.772 MPa. This indicates that tensile strength within this interval can be achieved by considering the factors within the region at a fixed voltage (13.5 V). The yield strength predicted interval lies between 349.450 MPa and 414.164 MPa. Joarder *et al.* (1991) have observed in interstitial free steels that the welded joints are characterized by the presence of very large grains near the fusion line and these grains are oriented along the directions of the large heat flow. This strongly “oriented” structure is in some aspects very similar to certain solidification microstructure, whose morphology depends also on heat flow. On the other hand, it has been found that solidification theory can be applied to welding (Jerzy et al 2005, Kostrivas and Lippold, 2000).

Inclusions were found to decrease in number from top to base of weld metal and because of the prevalence of varying cooling rates in weld metal, a wide range of microstructures, such as pearlite, grain boundary ferrite with pearlite and side plate with cementite along the side plate boundaries were observed in samples 3, 13 and 18.

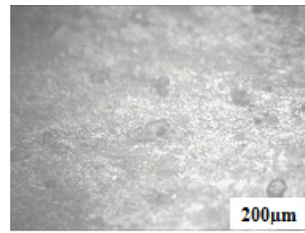


Sample 1

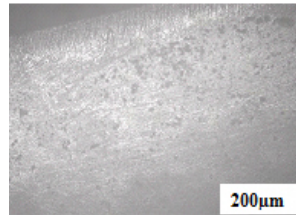
Sample 2



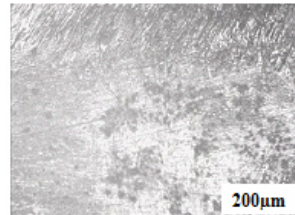
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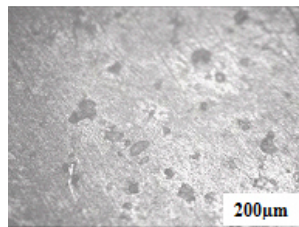
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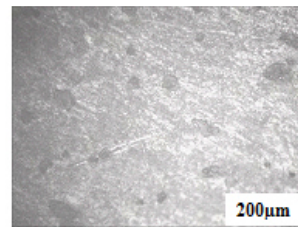
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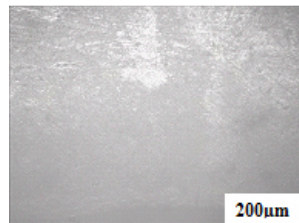
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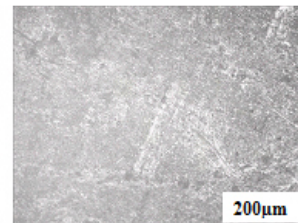
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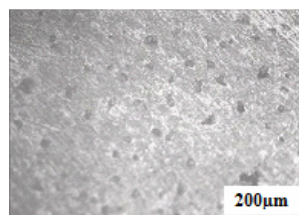
Sample 8



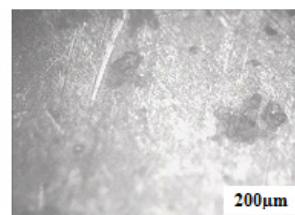
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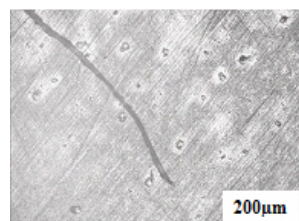
Sample 10



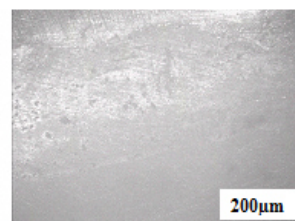
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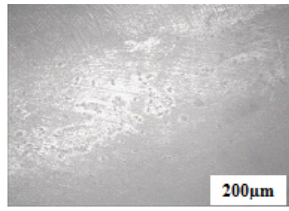
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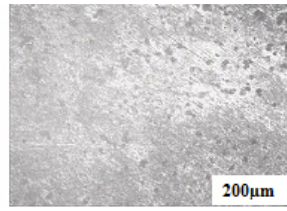
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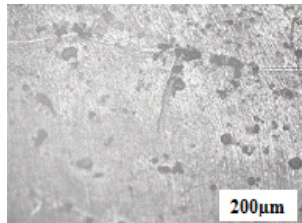
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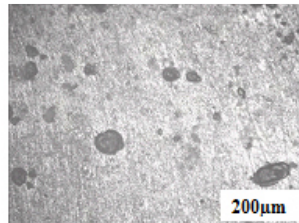
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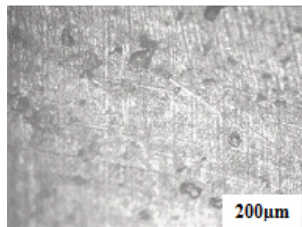
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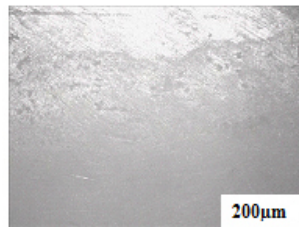
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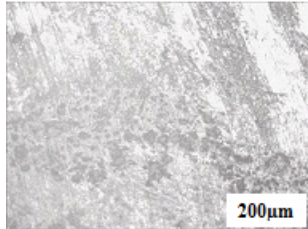
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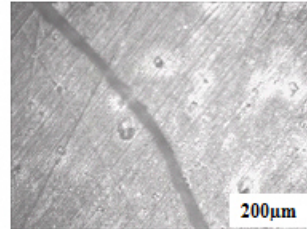
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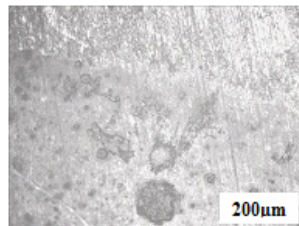
Sample 20



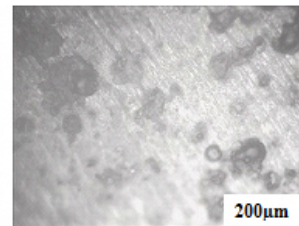
Sample 21



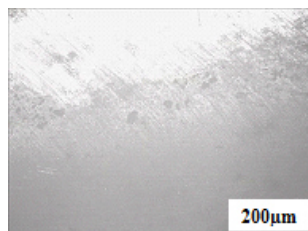
Sample 22



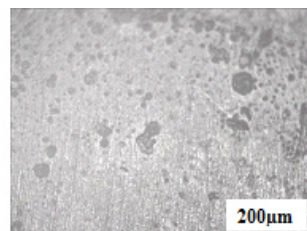
Sample 23



Sample 24



Sample 25



Sample 26

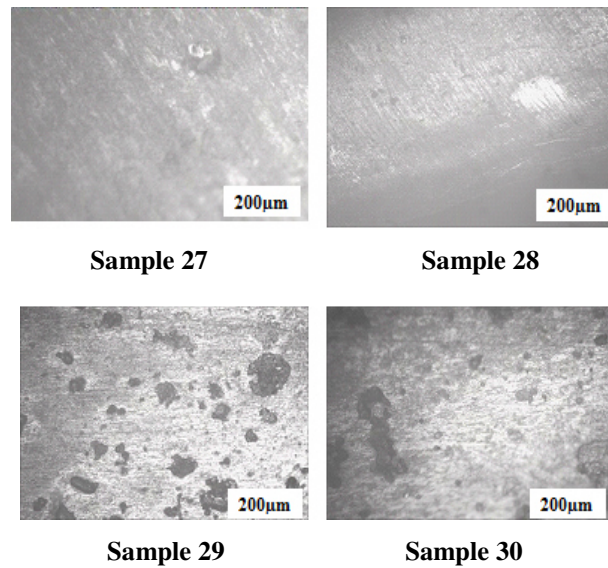


Plate 1: Microstructure of the Heat Affected Zones of the Welded Mild Steel Pipe

Hardness

Hardness test was conducted using the Rockwell scale B hardness tester. The weld material was divided into five zones. The middle zone was the weld while the two adjacent zones are the heat affected zones on each side of the weld. The following zone is assumed not to be affected by the heat of welding and is therefore designated as the base metal. The hardness values for the various segment of the specimen is shown in Table 1

Table 1: Results of Hardness Test

Samples	Base Metal HRB	HAZ HRB	Weld Joint HRB	HAZ HRB	Base Metal HRB
1	48.10	58.00	60.00	53.10	48.40
2	49.40	52.80	62.45	54.40	50.15
3	51.40	48.00	64.40	48.10	50.60
4	49.10	49.10	56.25	48.90	50.55
5	47.40	58.20	59.75	53.10	48.15
6	48.30	55.20	61.85	49.40	54.15
7	48.20	49.70	58.70	49.30	47.70
8	49.30	58.30	53.55	52.20	48.25
9	51.10	57.40	59.25	48.40	50.65
10	52.40	58.60	59.30	59.60	48.65
11	51.20	51.40	55.60	51.80	50.85
12	48.60	49.70	53.15	49.30	48.25
13	49.40	47.90	48.60	48.70	48.75
14	49.30	53.80	53.85	53.20	49.80
15	48.10	52.50	58.40	54.10	50.75
16	51.70	55.20	54.60	53.20	49.35
17	48.30	51.30	55.65	53.30	48.80
18	52.40	48.10	57.05	50.40	50.30
19	50.10	58.60	59.90	54.20	49.25
20	51.10	52.20	52.70	53.10	49.25
21	48.30	52.10	56.55	54.10	49.30
22	49.40	58.40	55.20	53.10	50.20
23	48.20	54.20	58.00	48.10	49.10
24	53.40	58.30	63.15	59.70	49.25

Table 1: Contd.,

25	45.30	49.60	64.35	53.10	50.75
26	51.20	53.40	57.50	54.10	48.80
27	51.10	48.20	55.85	59.20	50.70
28	48.30	58.50	56.90	53.10	49.25
29	49.70	52.30	57.80	54.20	51.15
30	53.10	49.20	56.95	53.10	48.20

Figure 2 shows the relationship between the values of the base metals, the heat affected zone and the weld joint. It is observed that 90% of the weld joint has the highest hardness values followed by the heat affected zone and finally the base metal.

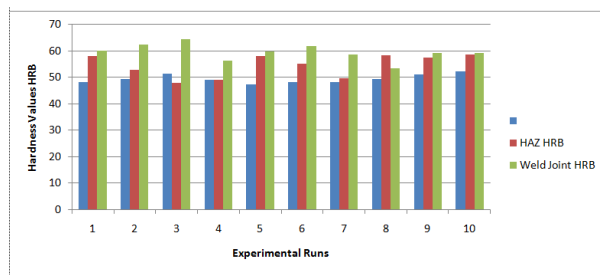


Figure 2: Characteristics of the Hardness Value of Mild Steel

Figure 2 the variation of Rockwell hardness with welding parameters. This plot demonstrates the relationship between all the values on both sides of the welded specimen. It is observed that the values on the left side of the specimen tend to be higher than the values on the right hand side. This is probably due to the handling position of the specimen during the cooling process.

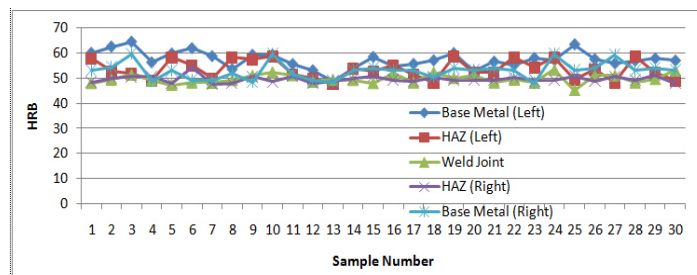


Figure 3: Variation of Rockwell Hardness with Welding Parameters

The hardness distribution in different zones is shown in Figure 2. The hardness values of 45-63 HRB in Figure 4.95 is observed at location within 3 mm from the base metal, through the HAZ across the weld metal to the other base plate. The hardness values obtained for the HAZ appeared higher than those for the base metal. These hardness results are in agreement with literature (Bashenko and Sosin, 1988 and Balasubramanian et al., 2008), because they found that maximum hardness values are measured in the area of weld metal.

The highest hardness value (64.35 HRB) for the weld joint is recorded for sample 25; this may be because of the even distribution of ferrites and pearlites in the microstructure (Plate 1, sample 10). The microstructure of this sample has small grains with almost equal volume fraction of both ferrite and pearlite. Other samples with higher hardness values include samples 24 (63.15 HRB), 2 (62.45 HRB), 19 (59.90 HRB), 3 (64.40 HRB), 1 (60.00 HRB) and 6 (61.85 HRB) which are found to have much ferrite colonies in a non-homogeneous grain structure. Samples with banded structures

(samples 10 and 20) also possess high hardness values compared to all other samples. Sample 20 possess the lowest hardness value (52.70 HRB) probably because of the fully banded structure in the microstructure with few porosity noted along the high heat area.

CONCLUSIONS

The hardness values and microstructure of a Tungsten Inert Gas weld of a mild steel joint has been evaluated and it has been observed that the microstructure of each of the specimen at the Heat Affected Zone, has a direct effect on the hardness of the welded joint with respect to the distributions of the ferrites, pearlites and some inclusions. It is also observed that the input of heat tended to increase the hardness of the joints with increasing intensity.

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