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Investigation of MIG welding process parameters on welding defects and hardness of low carbon steel weld joints

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Abstract
The process of metal inert gas welding is controlled by various factors. The research intends to investigate the effects of two of these factors (speed, current) on welding flaws by modifying one and altering the other, then conduct (hardness test, optical microscope, the fluid penetration test, and the visual test). With currents between (250-255-260) A and feed speeds between (112, 118, and 123) cm/min, inert gas welding is performed. Because to incompatibilities between feeding speed and current, the findings of the visual examination revealed flaws such as an incomplete welding region, spark, overlap, and a lack of uniformity. Findings that were within 250 A and 118 cm/min had the fewest faults. The liquid penetration was examined, and it revealed some fractures produced on by the temp differential. On the other hand, microscopic analysis revealed how current affected the heat in the welding region and, therefore, the microscopic structure of the specimens.

Keywords: Inert gas metal welding; Low carbon steel welding; Welding defects.

1. Introduction
One of the most crucial methods for combining two distinct or comparable types of materials is welding. Applying the right amount of pressure and heat to the contacting surfaces allows two or more parts to be bonded. Once compared to the plumbing and rivet connection processes, welding is less expensive and quicker. Laser welding, friction welding, oxy-cysteine torch welding, electrical resistance welding, metal arc and inert gas welding, tungsten inert gas arc welding, and electric arc welding are only a few of the various welding procedures available. The most common welding processes are the metal arc welding process, the inert gas process, the inert gas, and the tungsten arc welding process [1, 2]. To facilitate the linking between the parts to be welded in different types of welding, filler material is added. Based on the kind and welding procedure, the filler material offers a variety of advantages. It might be utilized to shield versus oxidizers or to speed up melting and bonding. Although most often employed to join metal components, the welding technique is also utilized to join plastic components [3]. One of the most common fusion welding methods is the inert metal gas (MIG) arc welding method since its ease of application in various ferrous and non-ferrous metals. This method is characterized by the following:
1. Possibility to perform it fully or partially automatically
2. High metal deposition rate in a short period
3. Use the same requirements when welding different metals

4. No need for high experience or skill to carry out the operation [4].

The heat required for smelting is generated from the arc resulting from the contact of the welding electrode with the workpiece, and its quantity depends on the current, voltage, and welding speed. Inert gases such as helium, argon, and carbon dioxide are pumped. The gas isolates the welding area from contact with the outer periphery and gives stability to the arc-generated electricity. In this process, a continuous consumer wire covered with molten material or a metal electrode with a diameter of (0.8-2.4) is coiled into a reel fed at the required speed by the welding gun. It electrically picks up the electric current from the copper contact tube connected to the DC power source. This type of welding is utilized to increase the productivity and the stability of the welding quality [5, 6]. Welding variables are among the best important factors that affect the productivity, quality, and cost of welded pieces [5]. Among the most important variables that affect the welding process in terms of the accuracy and quality of the welding area, the shape and depth of the welding area, and the mechanical properties of the welded area are (current, voltage, speed, and heat) [7]. In a study of welding aluminum alloys by metal arc welding and inert gas, the research showed that the fatigue life would decrease by increasing the heat entering the welding. In contrast, the shock resistance increases in the beginning and then decreases clearly as it was shown that the depth of the welding area increased with the increase of current and voltage. A study conducted by Irfan and Achwal [4] aiming to show the influence of welding variables on the weldability of galvanized steel, showed that increasing welding speed with constant voltage and current leads to an increase in the penetration of area of the welding until the best speed is obtained, after which the penetration decreases. Another study of the influence of welding variables on the depth of the area of welding and the shape coefficient of the welding area showed that the depth of the welding area increases with increasing speed up to the optimum speed, after which the penetration begins to decrease, shape parameter [2]. Although the impact of welding variables has been studied in many kinds of research to obtain the optimum variables, over the past four decades, the manufacturing process worldwide has faced intense competition in the markets for cost-effective production and high-quality products. Because of this, production processes now need to be automated, yet control and quality control issues still need to be fixed. Effective research in control and quality control is required due to these deficiencies in the industry [8].

2. The practical part

2.1 Materials utilized in the study

Low carbon steel sheets with dimensions (100 * 80 * 3 mm) with the chemical composition shown in Table 1 were utilized.

Table 1. Chemical composition of the low-carbon steel utilized.

Metals	Chemical composition				
	Carbon	Iron	Manganese	Phosphorous	Sulfur
low carbon steel	0.23	Rem	0.25	0.04	0.01

2.2 The utilized devices

Some devices and equipment were utilized to prepare samples and for the welding process and the tests that were conducted to complete the study:

- Welding machine (MIG): The inert gas welding machine welds various ferrous and non-ferrous materials. Machine type (miller) and model (millermatic 252) as shown in Figure 1.
- Smoothing machine
- optical microscope
- Plasma machine.

2.3 Sample preparation and welding

1. Cutting low carbon steel sheets into nine samples with dimensions (100*80*3 mm)
2. Clean the samples to remove dust, oil, fat, and all dirt.
3. Placing the samples to be welded on a regular level (floor) base, butt welding type
4. Fixing one of the welding variables (current or feed speed) and completing the welding process
5. Conducting the welding process after changing the first variable of welding and fixing the second for all samples as in Table 2

6. Completing the welding process by a raw gas welding method utilizing a welding electrode (carbon steel covered with copper) type (ER_70S_6) with a diameter of (0.8 mm).

Figure 1. The inert gas arc welding machine.

Table 2. Welding variables.

Samples	Current A	Feed Speed (cm/min)	Hardness Hv
1	250	112	219
2	250	118	232
3	250	123	246
4	255	112	200
5	255	118	227
6	255	123	232
7	260	112	197
8	260	118	210
9	260	123	226

3. The utilized tests

3.1 Visual testing

In this inspection, magnifying lenses (lances) were utilized to expand the test area, and a light source was utilized to illuminate dark areas on the sample surface. Use this test to detect surface defects that can be observed visually.

3.2 Penetration testing

It is one of the simplest and oldest methods of NDT and is utilized to detect gaps and surface discontinuities, its steps:

- Clean surfaces from dust, oils, fats, and other dirt.
- Putting the permeable substance on the model's surface to penetrate cracks, cavities, gaps, and surface defects.
- After (15) minutes, the sample surface was cleaned, and the excess liquid was removed, leaving the liquid penetrating the cracks and the rest of the surface defects.
- Apply the developer to absorb the remaining permeable liquid and then wipe it from the surface of the model
- After that, the examination is conducted under a suitable light source to detect any existing surface defects (flaws).
- The last step is to clean the model's surface to remove the part's appearance.

3.3 Optical Microscopic Examination

It is a method that uses a visible light source and a lens system to magnify the images of small samples, examining the microstructure of the samples before and after the welding process, the steps:

- Preparation and preparation of samples for microscopic examination (cutting and smoothing (aluminum oxide sandpaper was utilized (1200, 800, 600, 400) and polishing (flax paper and aluminum solution) and the revealing solution was vital).

- Conducting a microscopic examination before and after the welding process utilizing a light microscope.

3.4 Hardness testing

Vickers hardness method was accomplished in accord to ASTM A370-14 standard utilizing Vickers Testing Machine to measure the hardness of weldments at loading of 9.8 N and hold for 15 seconds. The value of hardness has been taken as average of 3 readings in different places along the surface of each sample to get the hardness value. This test is done utilizing Vickers hardness testing machine type (TH714 Tester made in china).

4. Results and discussion

4.1 visual test Results

The findings of the visual inspection showed that the following defects occurred.

4.1.1 Overlap

As shown in Figure 2, as the current is low and the speed is somewhat slow. It is a flaw that develops when the flowing of the weld metal increases on the surface of the base metal without fusing with it (a protrusion outside the weld seam), causing an amount of mechanical stresses in the vicinity of sharp edges (the convergence surface area between the base metal and extrusion). Because of the following factors, such a problem might arise when there is not enough heating: low voltage or current, in addition to the arc length and the speed of the movement being slow.

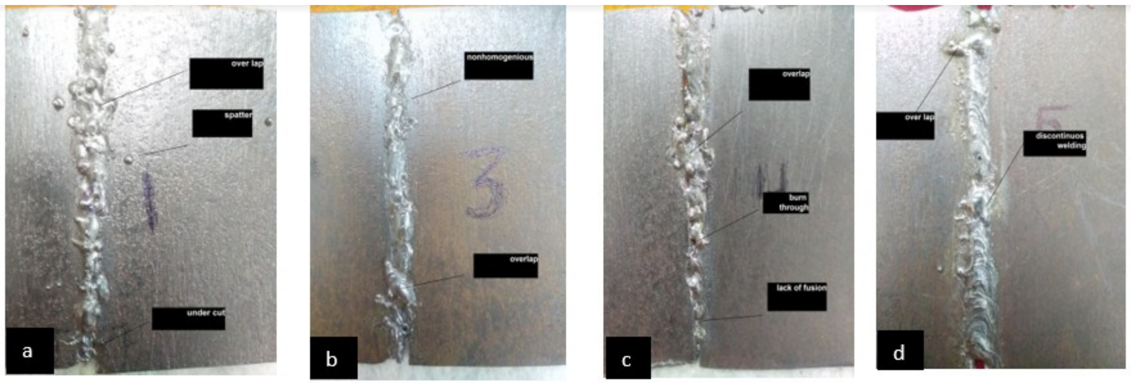

Figure 2. Welding defects at (a) A=250, S=112 (b) A= 250, S=123 (c) A=255, S=118.

4.1.2 The spark or spatter

This defect can be observed in Figure 3. Small granules or drops of a semi-spherical shape are emitted during welding to adhere to the surface of the base metal along the welding line. Such a defect occurs because the current and feeding speed are high, in addition to the length of the electric arc. This defect may have occurred for another reason: the length of the electric arc, so it is possible to observe Low spark in some low-voltage and low-speed samples.

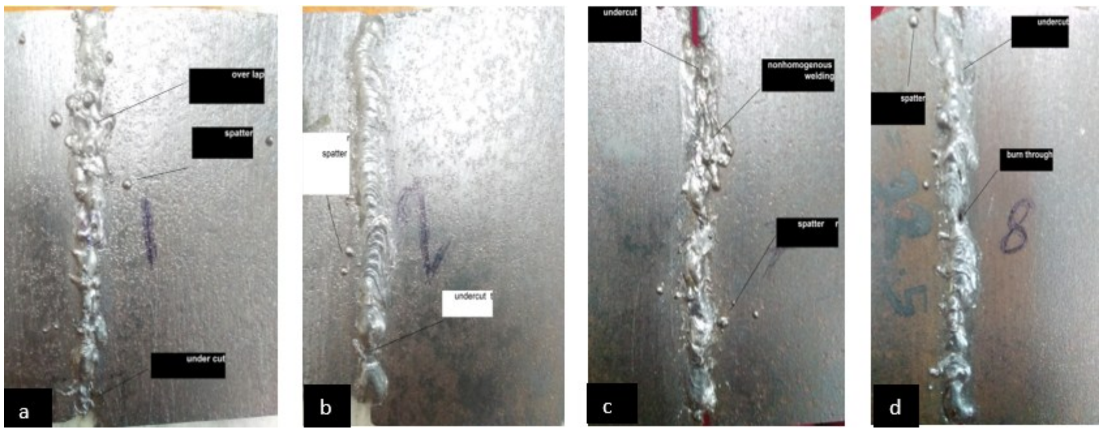

Figure 3. Welding defects at (a) A=250, S=112 (b) A= 250, S=118 (c) A=260, S=112 (d) A=260, S=118.

4.1.3 Incomplete fusion

Figure 4 demonstrates this flaw. When the temperature is insufficient, the melting process and the fusion of the weld metal and the basic metal are incomplete. This is a serious defect, especially when the welding is designed for service in cold conditions or is subject to periodic loading fatigue stress (Fatigue). Such a defect occurs since the lack of heat from the voltage and the low speed of the welding wire or the low current intensity, in addition to the speed of welding transfer exceeding the correct limit.

4.1.4 Undercut

This defect is one of the surface defects in welding and appears in the form of a duct or groove in the base metal directly along the edge of the weld line. This defect is since the use of a high current, as well as the fast movement of the feed (Figure 5).

4.1.5 Discontinuous or non-homogeneous welding

The reason for the appearance of this defect is the high speed of movement and mobility during welding and the instability of the movement of the hand, as shown in Figure 6.

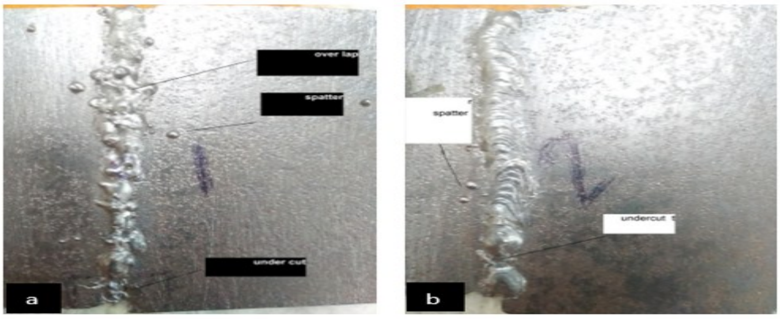

Figure 4. Illustrate welding defects at (a) A=250, S=112 (b) A= 250, S=118.

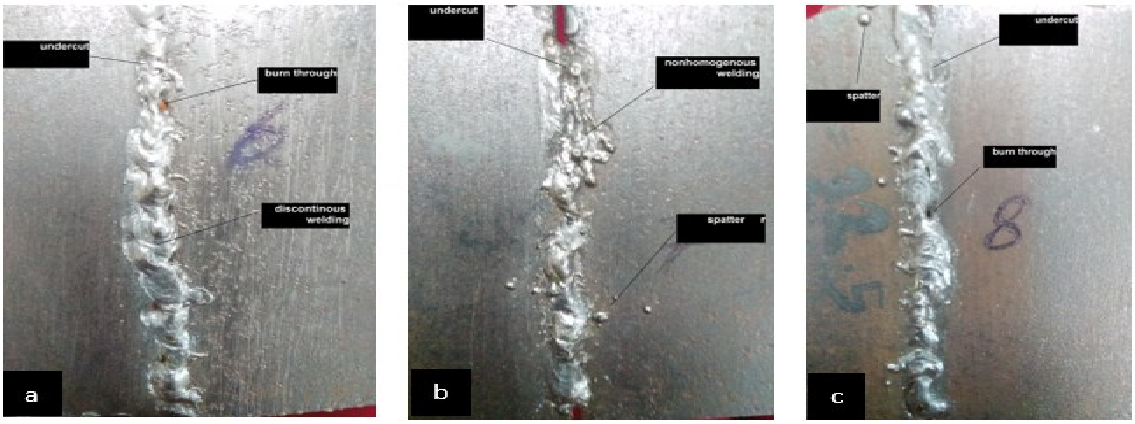

Figure 5. Show welding defects at (a) A=255, S=123 (b) A=260, S=112 (c) A=260, S=118.

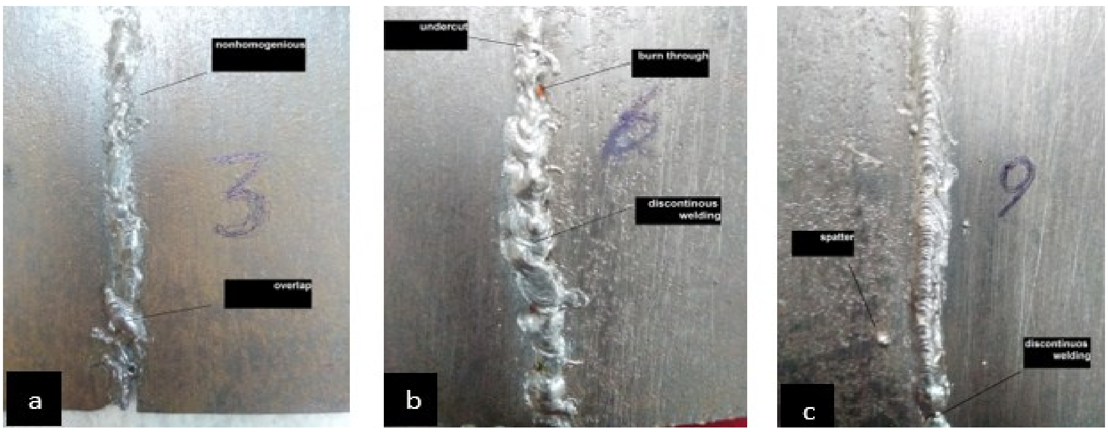

Figure 6. Welding defects at (a) A=250, S=123 (b) A=255, S=123 (c) A=260, S=123.

4.2 Results of penetration testing

Figures (7, 8, 9) show some welding defects are:

Cracks: The temp differential between the base metal and the weld region, in which abrupt cooling happens, is what causes these flaws. The metal should be heated before to base welding in order to minimize the temp differential between it and the welding region and avoid fractures.

Porosity: Trapping of gas produced from welding during freezing and contamination of the base metal before welding and preventing its occurrence by removing any contamination from the surface of the metal to be welded.

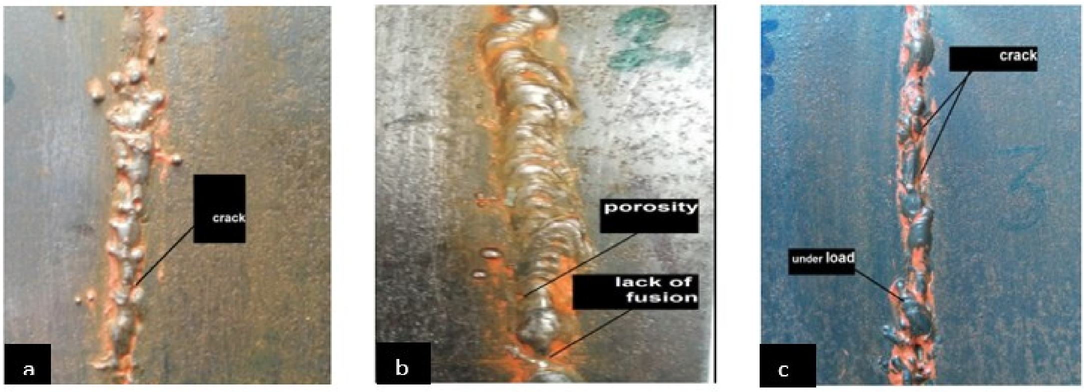

Figure 7. Welding defects at (a) A=250, S=112 (b) A=250, S=118 (c) A=250, S=123.

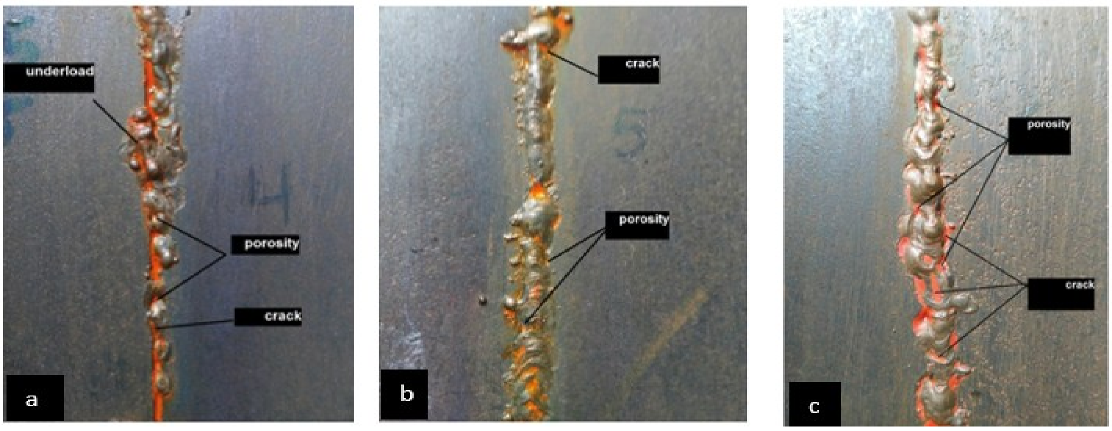

Figure 8. Welding defects at (a) A=255, S=112 (b) A=255, S=118 (c) A=255, S=123.

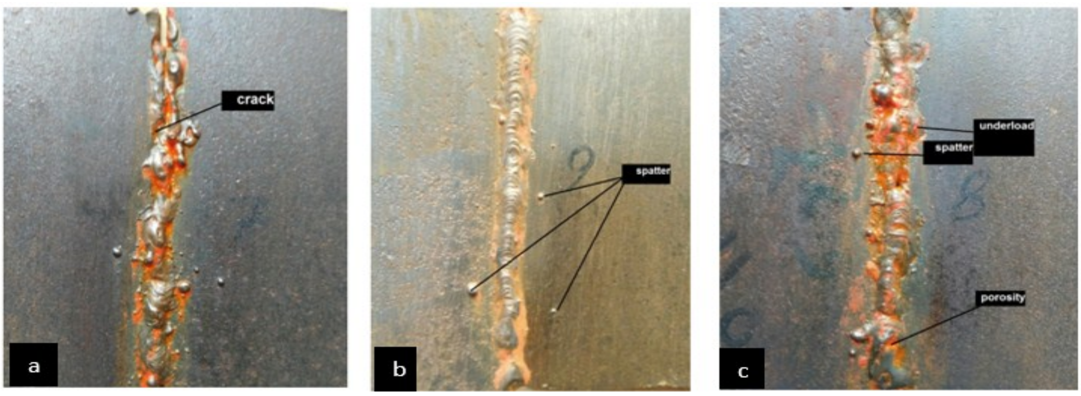

Figure 9. Welding defects at (a) A=260, S=112 (b) A=260, S=118 (c) A=260, S=123.

4.3 Hardness testing results

It was observed that the highest values of hardness were at the fusion zone and then gradually decreased towards the base metal. Increasing the values of welding speed leads to an increase in the hardness, because the input heat is low. And when the welding current values increase, it causes a decrease in the hardness values since the high input heat that leads to coarse of the grains and so a low hardness (Figure 10).

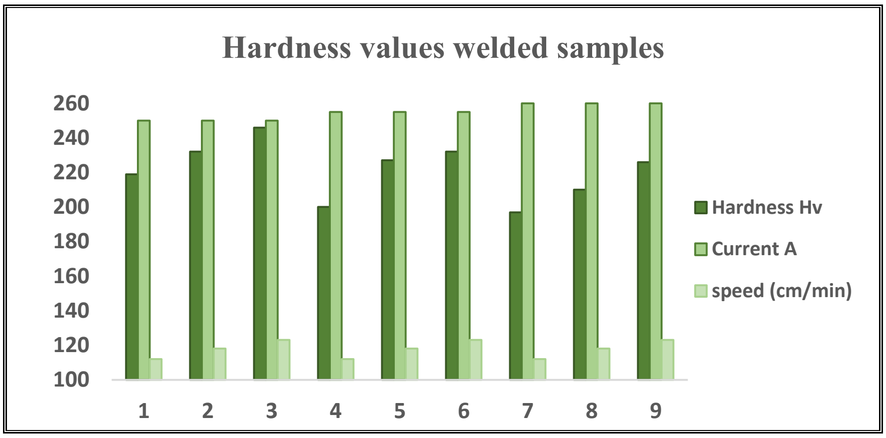

Figure 10. Hardness values of welded samples.

4.4 Optical microscopic results

Examination of the alloy's microstructure before welding (the base metal) consists of large grains of ferrite and small areas of perlite on the edges of the crystal boundaries and corners, as shown in Figure 11. After welding, we observe the effect of welding on the heat-affected zone (HAZ) in the microstructure utilizing optical microscopy through the elongation and shape of ferrite grains. Figure 12 shows the microstructure of the samples (1, 2, 3) that were welded with current (250A) consisting of ferrite and perlite grains since the low current and high-temperature flow. Figure 13 shows the microstructure of the samples (4, 5, 6) welded with current (255A) consisting of ferrite and small grains of perlite, and the velocity did not affect the microstructure. In Figure 14, we note the microstructure of the samples (7, 8, 9) at a current (260A) consisting of perlite and large grains of ferrite since the high temperature.

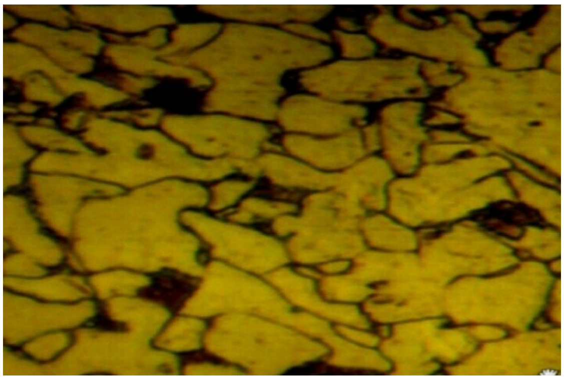

Figure 11. Before welding100x.

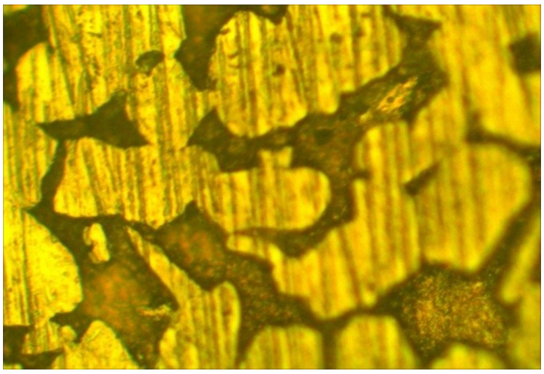

Figure 12. (A= 250)100x.

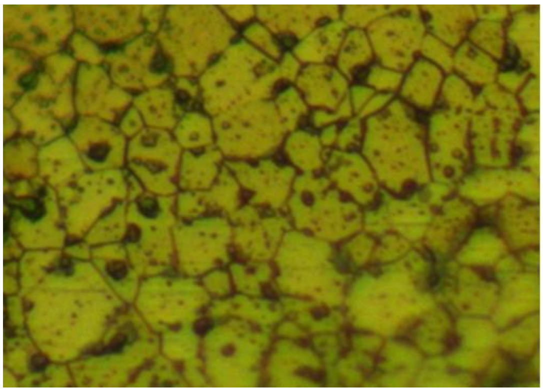

Figure 13. (A=255) 100x.

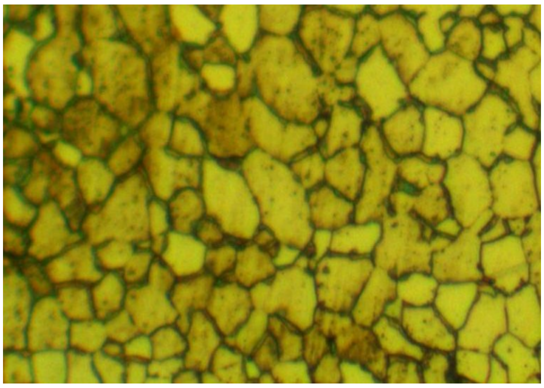

Figure 14. (A=260) 100x.

5. Conclusions

1. The results of the visual examination showed that the laboratory utilized a range of current and feeding speed, which was within the range (of 250-255-260A) and welding (112-118-123) cm/min in the inert gas welding process that choosing a current (250-255) and the speed of (112-118) reveals defects (overlap - incomplete fusion - an interruption in the welding area with the appearance of some sparks and heterogeneity).
2. When changing the feeding speed to 123 cm/min, the defect of incomplete welding disappeared.
3. When choosing a high speed and a high current of 123 cm/min and 260A, the heterogeneity and the cut-off appear.
4. At a high current of 260A and a feeding speed of 112 cm/min, which is the lowest speed of the back of combustion or ignition in the welding area
5. Within the highest current of 260A and medium speed=118 cm/min, the sample was in the least condition, with menstrual defects, the udder with a spark, a slight interruption, and several best readings within the research for inert gas welding.
6. As a result of the thermal variation between the base metal and welding area, which causes a sudden, live cooling and necessitates heating the metal before welding to decrease the temp difference, some cracks and porosity resulting from some contaminants or lack of heat has been revealed during the examination process utilizing the penetrating liquid.
7. Microscopic examination showed that an increase in current, which in turn leads to an increase in temperature, leads to an increase in the size of perlite grains.
8. The results showed that welding current and feed speed are the variables that have the strongest effect on the hardness of welds of MIG welding. The sample 2 welded under current (250 A) and feed speed (118 cm/min) conditions has the highest hardness (246) since the low input heat.

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