Effects of strain rate due to SMAW welding on mechanical properties of AISI 1005 low alloy steel

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Abstract. The welding process can affect the mechanical properties of the metal. This study was aimed at examining the effects of welding on the strain rate of AISI 1005 carbon steel. Shield metal arc welding, utilizing an E6013 electrode with a diameter of 2.5 mm, a double V-notch with an angle of 120°, and a welding position of 1G, was used to weld low carbon steel. A tensile test was performed to determine the mechanical properties of the steel at various strain rates to represent the loads that it would be subjected to. The test was performed at strain rates of 3 mm/min, 9 mm/min, 15 mm/min and 20 mm/min. The results showed that as the strain rate of steel increased to 20 mm/min, the maximum tensile strength of 447.67 MPa and highest yield strength of 362.94 MPa were obtained, while the lowest values were obtained at a strain rate of 3 mm/min. An examination of the fractured surfaces using SEM showed that at the strain rates of 3 mm/min, 15 mm/min and 20 mm/min smaller voids were formed.

1. Introduction
Low carbon steel applications are beginning to flourish, and it is estimated this metal is being used in more than 60% of heavy vehicles, platinum-fuel offshore oil vessels, car frames and in building construction [1]. This is because low carbon steel has a high thermal conductivity resistance, high toughness, good machinability and good weldability [2]. There are many methods available for joining different materials, and one such method is the welding process, which is used more often because it results in a high level of toughness and strength. However, the welding process will bring about changes to the crystal structure of the material such that there will be a decrease in the physical and mechanical properties of the welded material [3, 4, 5]. Welding produces a change in the mechanical behaviour of the base metal, the welding metal and in the heat-affected zones (HAZ), thereby causing complications in the weld under local stress and strain conditions.

Therefore, the purpose of this study was to determine the impact of the strain rate on the mechanical properties of AISI 1005 low alloy steel due to the influence of welding.

2. Methodology
2.1. Materials
The specimen used in this study was AISI 1005 low carbon steel. The chemical composition of AISI 1005 is: C (0.06 wt.% Max), Si (0.12 wt.%), Mn (0.35 wt.%), P (0.004 wt.%), S (0.050 wt.%), and Ni
(0.50 wt.%). The filler metal used an E6013 electrode, which is the standard used by AWS, with an electric welding wire with a tensile strength of 60 ksi for all the welding positions [6]. The chemical composition of E6013 is: C (0.12 wt.%), Mn (0.3-0.6 wt.%), Si (0.35 wt.%), S (0.035 wt.%), and P (0.04 wt.%).

### 2.2. Preparation of Specimens

First, a groove was made in the specimen before the welding process. The double V-notch with a seam angle of 120° and a diameter of 10 mm was very suitable for use on AISI 1005, as shown in Fig. 1 [6]. After the welding process, the AISI 1005 material was used as a tensile test specimen with the Standard AWS B4.0, as shown in Fig. 2 [7].

![Double V welding camp.](image1)

**Figure 1.** Double V welding camp.

![Dimensions of circular tensile specimens according to AWS B4.0](image2)

**Figure 2.** Dimensions of circular tensile specimens according to AWS B4.0 [7]

### 2.3. Tensile Test

A universal testing machine with a maximum capacity of up to 10 kN was used to conduct the tensile test at room temperature. Tensile tests are performed to determine the mechanical properties such as the tensile stress and yield stress of materials [8].

### 2.4. Microstructural Test

A microstructural test, using scanning electron microscopy (SEM) in combination with computer software for image analysis, was carried out to determine the shape of the visible fault and the cause of the fracture. The specimens for the SEM test were cut according to the required size of the fracture that occurred in the tensile test. The area of the fracture was scraped with various grades of sandpaper, and then etched with 5 ml HCL, before the SEM test was conducted.

### 3. Results and Discussion

#### 3.1. Tensile Properties

From the tensile test results at various strain rates of the welded AISI 1005 material, it was found that the highest yield strength (0.2% offset) and tensile strength of 362.94 MPa and 447.67 MPa, respectively, occurred at a strain rate of 20 mm/minute, while the lowest yield strength (0.2% offset) and tensile strength of 142.68 MPa and 406.39 MPa, respectively, occurred at a strain rate of 3 mm/min., as shown in Table 1. This showed that the faster strain rate increased the yield strength and tensile strength of AISI 1005. This was a result of strain hardening on the metal that arose as a consequence of
the more difficult formation and movement of dislocations. Hardening occurs when there is increased resistance to dislocation movements. Following the symptoms of melt, there was a continuous increase in stress to maintain deformation. In other words, the flow stress of the deformed metal increased with increasing strain [9]. The curve of the tensile test for each strain rate is shown in Fig. 3.

### Table 1. Value of mechanical properties of four strain rate variations

| Crosshead speed (mm/min.) | Yield strength (0.2% offset) (MPa) | Maximum Tensile Strength (MPa) |
|---------------------------|------------------------------------|-------------------------------|
| 3                         | 142.68                             | 406.39                        |
| 9                         | 328.62                             | 421                           |
| 15                        | 208.68                             | 438.16                        |
| 20                        | 362.94                             | 447.67                        |

![Figure 3. The curve of tensile test results with four strain rate variations.](image-url)
Fig. 4 shows the true stress that resulted in material toughness. The higher the value of the true stress, the higher the decrease in the ductility. The results of the true maximum tensile strength at each strain rate showed that the highest strain rate of 20 mm/min., produced an true maximum tensile strength of 20884.92 MPa, while the lowest strain rate of 3 mm/minute produced an true maximum tensile strength of 5984.31 MPa.

Table 2. The true maximum stress value.

| Crosshead speed (mm/min.) | True maximum tensile strength (MPa) |
|---------------------------|------------------------------------|
| 3                         | 5984.31                            |
| 9                         | 6072.67                            |
| 15                        | 7493.06                            |
| 20                        | 20884.92                           |

3.2. Analysis of Fractured Surface of Specimen.

An observation was made of the macro structure on the fractured surface to determine the type of fracture that was experienced after the tensile test. The fracture surface could be observed microscopically or macroscopically.

The fractured surface of the specimen at each strain rate can be seen in Fig. 5. The results of the macro analysis in Fig. 5(a) and (b) shows that the fault was ductile as it had the distinctive characteristics of a ductile fracture, given that the fracture was fibrous and dark (dull), and that it formed an angle of 45° in the direction of the pull. Fig. 5(c) shows a resilient fracture, which was very evident due to the appearance of the cup and cone [10-12]. Fig. 5(d) shows that the fracture was very resilient as it was fibrous and dull, and formed an angle of 45° in the direction of the tensile force.
An examination of a fractured surface using a scanning electron microscope (SEM) can give important information about the type of fracture that has occurred. The broken surface of each specimen at 4 different strain rates can be seen in Fig. 6-9.

![Figure 5.](image)

**Figure 5.** The fracture surface of the tensile test specimen with strain rate (a) 3 mm/min. (b) 9 mm/min. (c) 15 mm/min. and (d) 20 mm/min.

![Figure 6.](image)

**Figure 6.** (a) Fracture surface of specimens with a strain rate of 3 mm/min. (b) SEM image.

In Fig. 6, the surface fracture was fibrous and dark (dull). The fractured metal surface of the weld was observed using a scanning electron microscope with a magnification of 600x, and it revealed that fracture that was formed had a considerable number of smaller voids.
Fig. 7 shows that the fracture surface of the specimen was fibrous and dull. The fractured metal surface of the weld was observed using SEM with a magnification of 600x, and revealed a crack propagation with large voids compared to the previous fractured surface, specifically at a strain rate of 3 mm/min.

Fig. 8 shows the results of the tensile test at a strain rate of 15 mm/min. on a fractured surface such as glass. The fractured metal of the weld was observed using SEM with a magnification of 600x, and revealed a broken surface with the smallest voids.

Fig. 9 shows the results of the tensile test at a strain rate of 20 mm/min. on a fractured surface such as glass. The fractured metal of the weld was observed using SEM with a magnification of 600x, and revealed a broken surface with the smallest voids.
Fig. 9 shows the tensile test results at a strain rate of 20 mm/min., where the fractured surface was characterized by considerable plastic deformation, before and during the crack propagation process. Faults were observed in the metal weld using SEM with a magnification of 600x, in which several large voids and small voids were seen in the solid metal.

4. Conclusions
Based on the results of the research the following conclusions could be drawn:
1. The strain rate due to welding caused the mechanical properties of the steel to increase. The highest mechanical properties were obtained at a strain rate of 20 mm/min., where the maximum tensile strength was 447.67 MPa and the maximum yield strength was 362.94 MPa.
2. There was an increase in the maximum tensile strength with each increase in the strain rate. The lowest tensile strength of 406.9 MPa and lowest yield strength of 142.68 MPa were attained at a strain rate of 3 mm/min.
3. Voids appeared on the fractured surface of the specimens, with smaller voids being formed at a strain rate of 20 mm/min., while at a strain rate of 9 mm/min., the specimens had large voids on the fractured surface.

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