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EFFECT OF ULTRASONIC PEENING ON MECHANICAL PROPERTIES OF LOW CARBON STEEL AISI 1020 TIG WELDING JOINTS PROCESS

Ghusoon Ridha MOHAMMED ALI* and Ali Zuhair RIDHA
Middle Technical University, Institute of Technology-Baghdad, IRAQ
E-mail: ghusoon_ridha@yahoo.com

Dina Abbas SADEQ
Middle Technical University, Medical Technical Institution, IRAQ

Ahmed Abdullah EBRAHEEM and Amal Sadeq ATTA
Middle Technical University, Institute of Technology-Baghdad, IRAQ

In this paper, the effect of ultrasonic peening surface treatment on the mechanical properties of TIG butt weld joints of low-carbon steel (AISI 1020) was studied. A single V-angle $\left(45^{\circ}\right)$ was made on sheets of metal used then welded at constant parameters, namely: current, voltage. Wire filler ER70S-3 with argon was used to obtain many butt welding joints. Some of them were subjected to ultrasonic peening at one, two and three passes. The micro-hardness, microstructure, tensile and bending were tested. The results show increases in the tensile strength after the welding process. The test results showed improvements in the tensile strength of the weldments in comparison to the base metal. On the other hand, the tensile strength decreased with the ultrasonic process. Nevertheless, the tensile strength increased at a high number of ultrasonic passes. On the contrary, the ultrasonic process enhanced the bending strength compared to the base metal, whereas the weldments ability to bend deteriorated.

Key words: low carbon steel, gas tungsten arc, ultrasonic peening, mechanical properties.

1. Introduction

The mechanical properties and microstructures of steel weld joint rely on certain parameters such as the carbon percentage and alloying elements welding parameter. Low carbon steels have good welding ability when have carbon percentage less than *0.25*% carbon; it can be commonly welded without specific care procedures using most of the available processes [1-3]. Zakaria *et al.* [4] focused on the effect of arc welding on the mechanical and microstructures characteristics of industrial low-carbon steel (*0.19* wt.% C) used in the production of cylinders for gas storage. Talabi *et al.* [5] discussed the impact of welding parameters using the Shield Metal Arc Welding (SMAW) method. The studied parameters were the welding speed, current and voltage whose impacts were studied on the mechanical characteristics of welded low-carbon steel. The welding parameters were carefully chosen during the study and found to have significant impacts on the studied samples. Ultrasonic peening (UP) has been suggested as a promising way for increasing the fatigue strength of welded metal joints. The procedure includes subjecting the weld junction to post-weld deformation treatment using ultrasonic frequency and denting needles that produce force impulses on the metal surface [6]. The goal is to create useful compressive residual stresses at the treated weld joint and reduce stress concentration on the form of the weld joint [7-10]. The application of the UP successfully improved the fatigue life of welded metals and eliminated the deformations induced by the welding processes. The UP application also improved the residual stress by improving the materials' hardness. The fatigue tests identified the UP as

* To whom correspondence should be addressed

an effective way of enhancing the fatigue life of welded materials in comparison to the existing methods like grinding, shot peening, TIG-dressing and hammer peening. The application of the UP treatment to welded parts can improve or restore the specified stress range up to the fatigue strength of the base metal. The impact of the treatment on the fatigue strength is mainly achieved by reducing the dangerous tensile residual stresses and ushering in compressive residual stresses to the metals' surface layer to reduce the stress concentration of the weld zones and improve the mechanical properties of the materials' surface layer [11].

The UP application is effective in improving the fatigue life of weld joints compared to grinding [12, 13]. The effect of the UP at different passes on mechanical characteristics of low-carbon steel AISI1020 TIG weld joints is studied in this paper.

2. Experimental procedure

2.1. Materials

The chemical composition of AISI-1020 was determined using a spectrometer in the laboratory complex of the General Company for Heavy Engineering Equipment. The chemical composition is shown in Tab.1.

Table 1. Analyses of AISI 1020 elements.

Elements	*C*	*Si*	*Mn*	*Ni*	*Mo*	*Cu*	*Co*	*Al*	*Ti*	*S*	*P*
Wt.%	*0.2*	*0.009*	*0.5*	*0.04*	*0.005*	*0.44*	*0.009*	*0.009*	*0.009*	*0.05*	*0.04*

2.2. Welding process

The plates of AISI1020 with geometry of (length – *150 mm*, width – *120 mm* and *6 mm* thickness) were prepared and V-groove joint design with an angle of (*45*º) was made as shown in Fig.1.

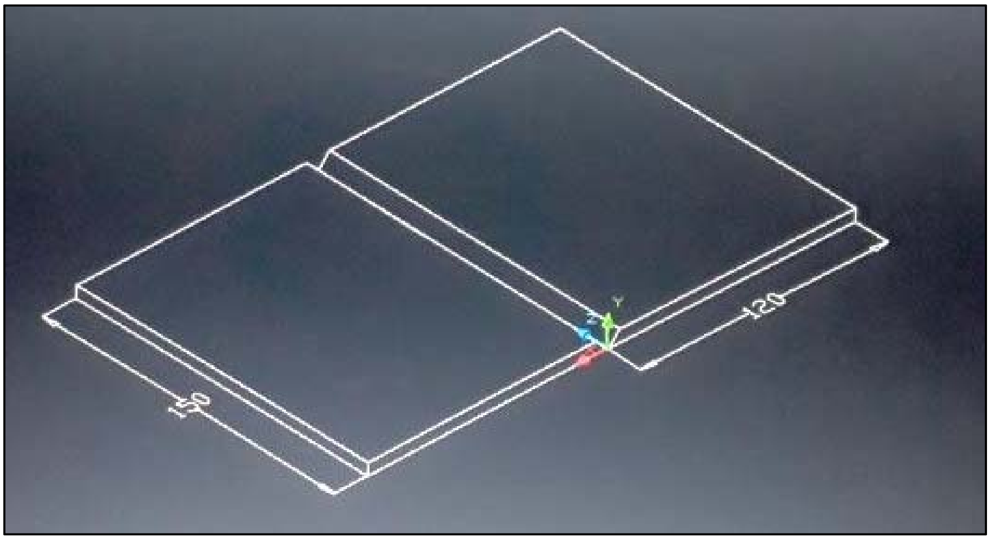

Fig. 1. The V-type butt joint shape.

The welding process was implemented in a horizontal position using a manual welding machine to make many welding joints. The welding parameters were: voltage device *20 V* and welding current at *220 Amperes*. The welding process generated *2.1 kJ* of heat with ER70S-3 wire filler metal which has a diameter of (*3 mm*) chemical composition of the filler metal is shown in Tab.2.

Table 2. Chemical composition of wire filler ER70S-3.

Element	*C*	*Si*	*Mn*	*S*	*Ni*	*Cr*	*Cu*	*P*
wt.%	*0.07*	*0.52*	*1.19*	*0.02*	*0.14*	*0.023*	*0.4*	*0.012*

The calculation of the heat input was done by using the following Eq. [14]:

$$q = V \times I / S \,. \tag{2.1}$$

Welded joints were examined by X-ray radiography; the joints without defect were used for prepared inspection samples as shown in Fig.2.

Fig.2. The weld joint.

2.3. Welding joint classification

The samples classification is listed in Tab.3. Tensile samples were prepared from the base and weld joints according to ASTM 17500 requirements using a water jet machine; the geometry of the samples with dimensions is given in Fig.3A, B. Samples for the bending tests were prepared following ASTM (E 190-92) with dimensions displayed in Fig.4A, B.

Table 3. Classification of welding joint.

Specimens	Condition
A	*The metal as received*
B	*Welding joint without ultrasonic peened*
C	*Welding joint +ultrasonic peened at one passes*
D	*Welding joint+ ultrasonic peened at two passes*
E	*Welding joint + ultrasonic peened at three passes*

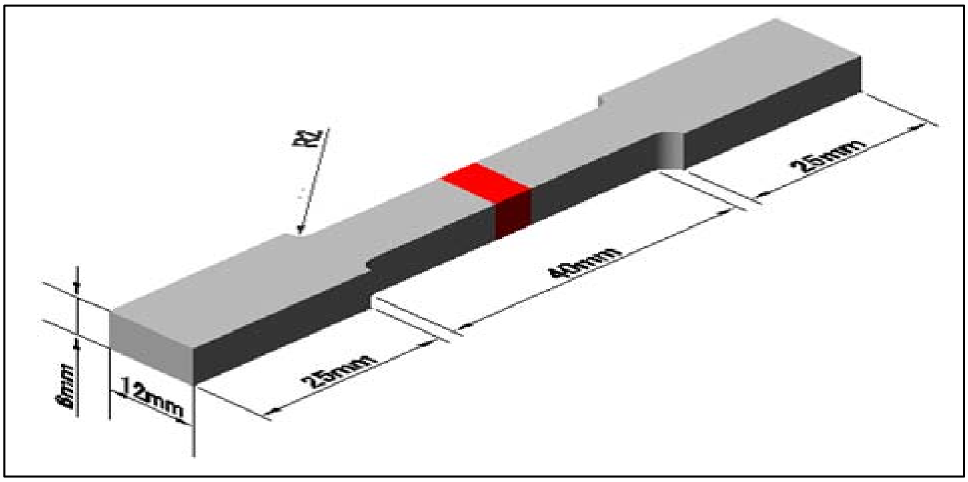

Fig.3A. Tensile sample dimensions.

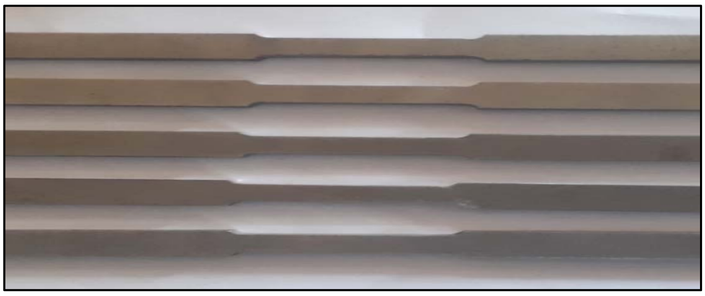

Fig.3B. Tensile specimens before ultrasonic peening process.

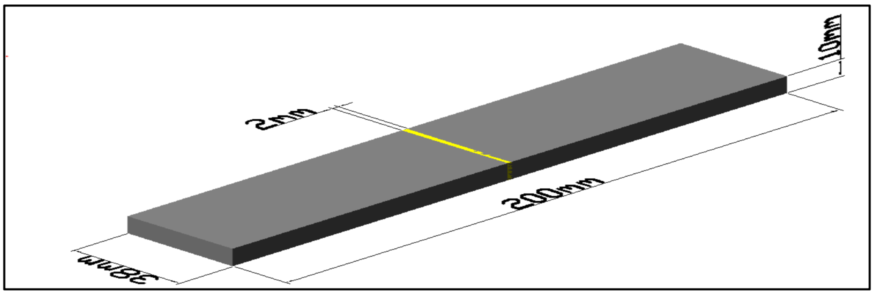

Fig.4A. Dimensions of bending specimen.

Fig.4B. Bending specimen before ultrasonic peening process.

3. Results and discussion

3.1. Ultrasonic process

The surface of the specimens for tensile and bending tests was peened using the ultrasound apparatus shown in Fig.5A. The peening was done using the following technical parameters: frequency = *20 kHz*, power = *500W*, voltage = *220V* and a high-power ultrasonic drive that can produce the required energy on the metal surface during touch. The insertion of this energy into the metal caused harmonic fluctuation on the surface that produced a larger plastic deformation pressure on the metal surface. The original stress field was altered by the ultrasonic wave, thereby generating a certain level of compressive stress that improves the strength of the areas under ultrasonic impact as seen in Fig.5 (B and C).

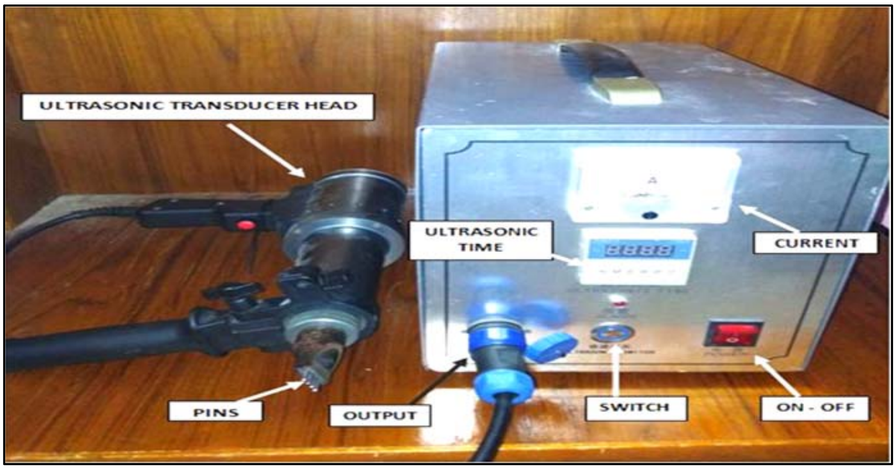

Fig.5A. The ultrasonic peening device.

Fig.5B. Tensile sample after ultrasonic peening.

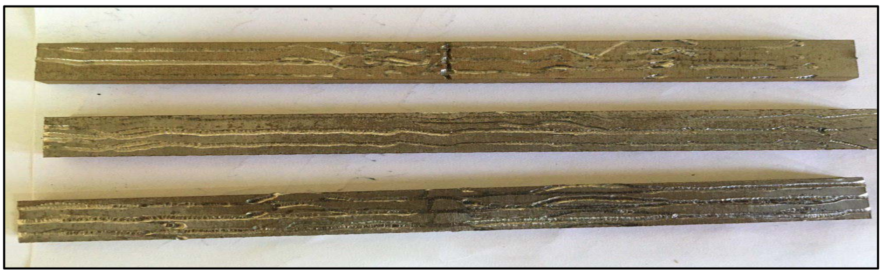

Fig.5C. Bending specimen after ultrasonic peening process

3.2. Compressive residual stresses

A computerized diffraction meter was used to measure the compressive residual stress before determining the strain values; then, the compressive residual stress from the device was determined by substituting the measured strain values in Brag law. The results are listed in Tab.4.

Table 4. Result of compressive residual stresses.

Specimens symbol	*C*	*D*	*E*
Residual stress (*MPa*)	*-287*	*-342*	*-372*

3.3. Micro-hardens test

The hardness was determined by subjecting the samples to *200 gm* load for *15 sec*. The test was done using Vickers micro-hardness tools. The obtained result is shown in Fig.6. The hardness distribution in different zones shown in Fig.6 is observed at places within (*0.25mm*) from the base metal. Through the HAZ (Heat Affected Zone) across the weld metal, the hardness of the weld metal and HAZ was high due to the variation in cooling rates across the weld zone, also in Fig.6 also suggests that sample E exhibited the maximum micro-hardness due to the effect of ultrasonic peening when increasing the number of passes which produce compressive residual stress also. All the samples showed higher micro-hardness in the weld zone compared to the base metal. This observation could be attributed to an increase in heat generation during the process of welding which accounted for the level of plastic deformation as seen in samples C, D and E [15, 16].

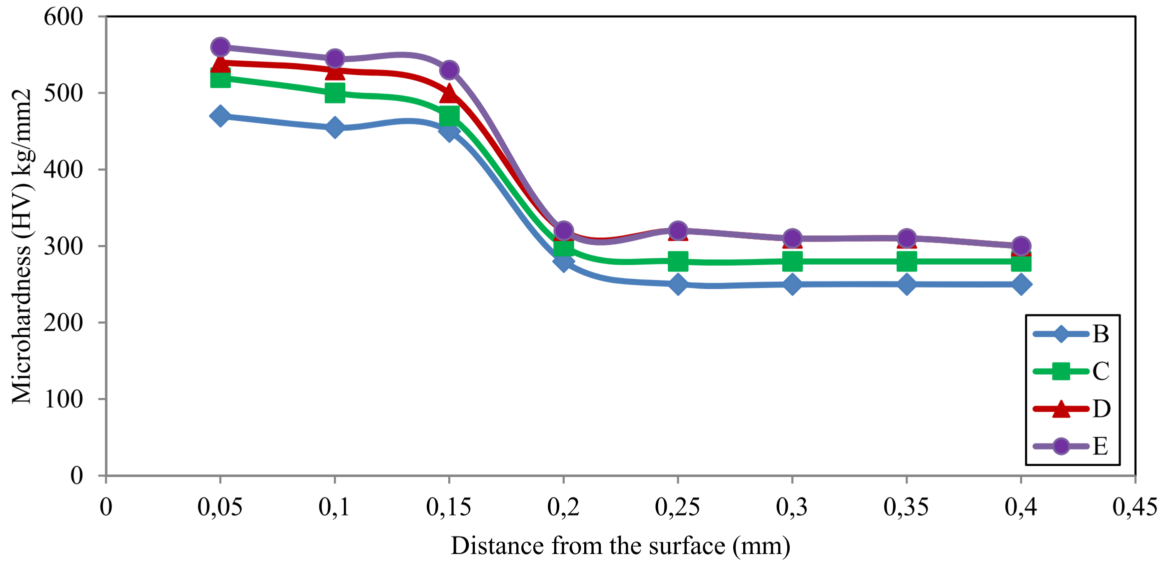

Fig.6. Micro-hardness distribution for all specimens.

3.4. Microstructure test

The specimens were prepared for microstructure test including grinding with the SiC emery paper of grain size (*240*, *320*, *600*, *800* and *1000*) Then the specimens were polished with a polishing cloth and a diamond of size *0.3 μm*. A nital solution containing *98*% alcohol and HNO_3 (*2*%) was used for etching. An optical microscope was used for the optical examination of the specimens. The microscope had a camera and was linked to a computer system. The results are presented in Fig.7.

Figure 7A shows the microstructure of the base metal (AISI 1020) which has ferrite due to low carbon percentage (Tab.1) and some pearlite. All welded joints (B, C, D, E) were affected by the heat transfer which causes elongation of ferrite grains in the (HAZ). The weld fusion zone also contains grains larger than those in the base metal. This region has mostly ferrite and some groups of pearlite due to the use filler metal from low carbon steel as illustrated in Tab.2.

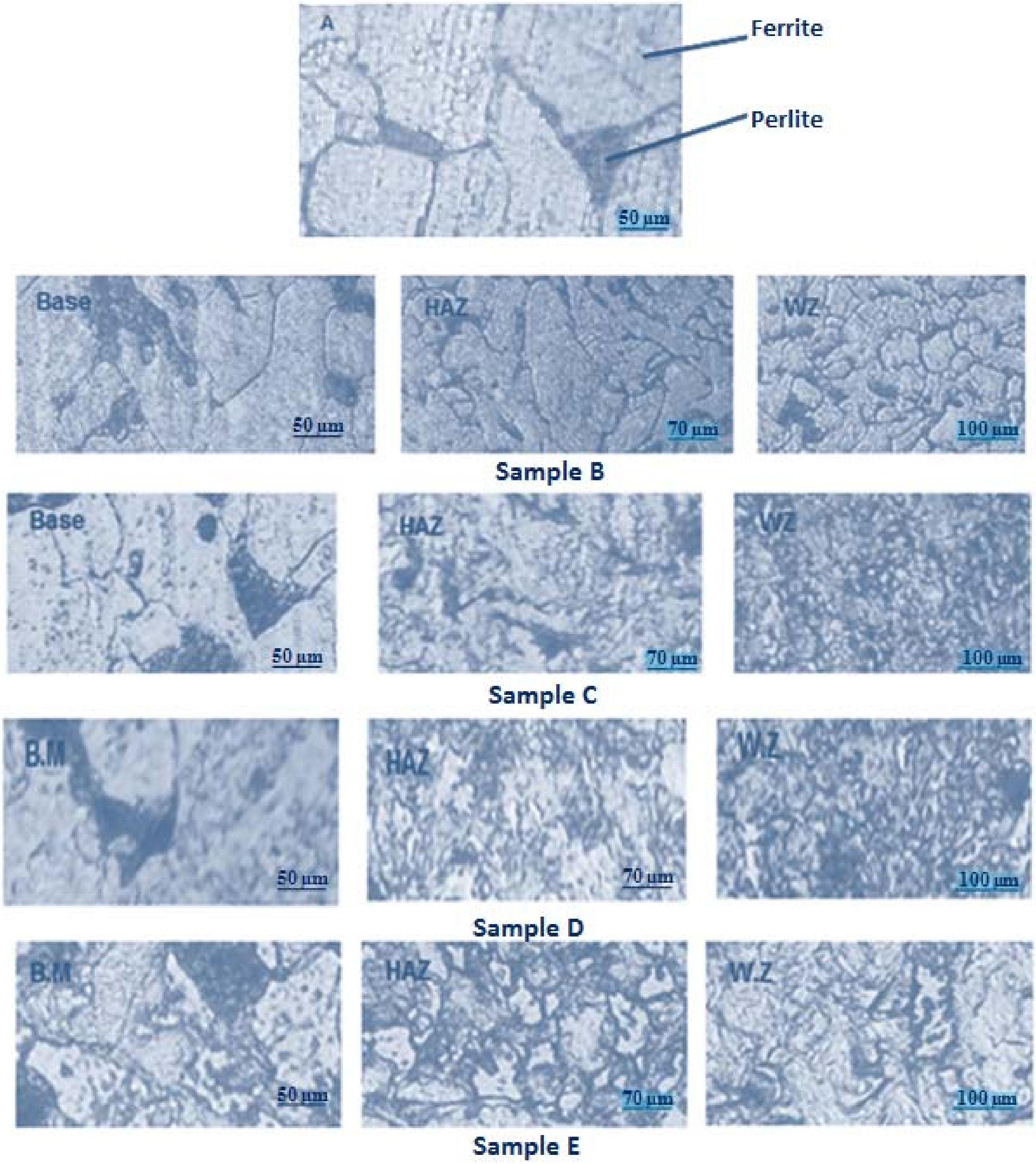

Fig.7. Microstructure of the base metal and peened and unpeened weld joints.

3.5. Tensile Test

A smart machine with a preload value of *50 kg* was used for the tensile tests; the machine had a cross head speed of *2 mm/min*. Table 5 and Fig.8 show the results of the tensile test. Figure 8 and Tab.5 depict the typical stress - strain curve for all the samples. A decline in the tensile strength obviously had a significant impact on the tensile properties of specimens C, D, E in comparison to the base metal (A) and weld without peened specimen (B); this could be due to the plastic deformation by the ultrasonic peen which produced compressive residual stress that increases when increasing the number of passes, thereby contributing to improved tensile properties and heat generation. Specimen (B) shows increases in the tensile strength due to decreases in the fusion zone.

Table 5. Tensile tests results.

Specimens Symbol	σ_Y *MPa*	σ_u *MPa*	σ_F *MPa*	$\%\varepsilon$
A	*210*	*380*	*280*	*28*
B	*341*	*387*	*305*	*34*
C	*240*	*299*	*140*	*30*
D	*260*	*346*	*210*	*33*
E	*270*	*357*	*230*	*35*

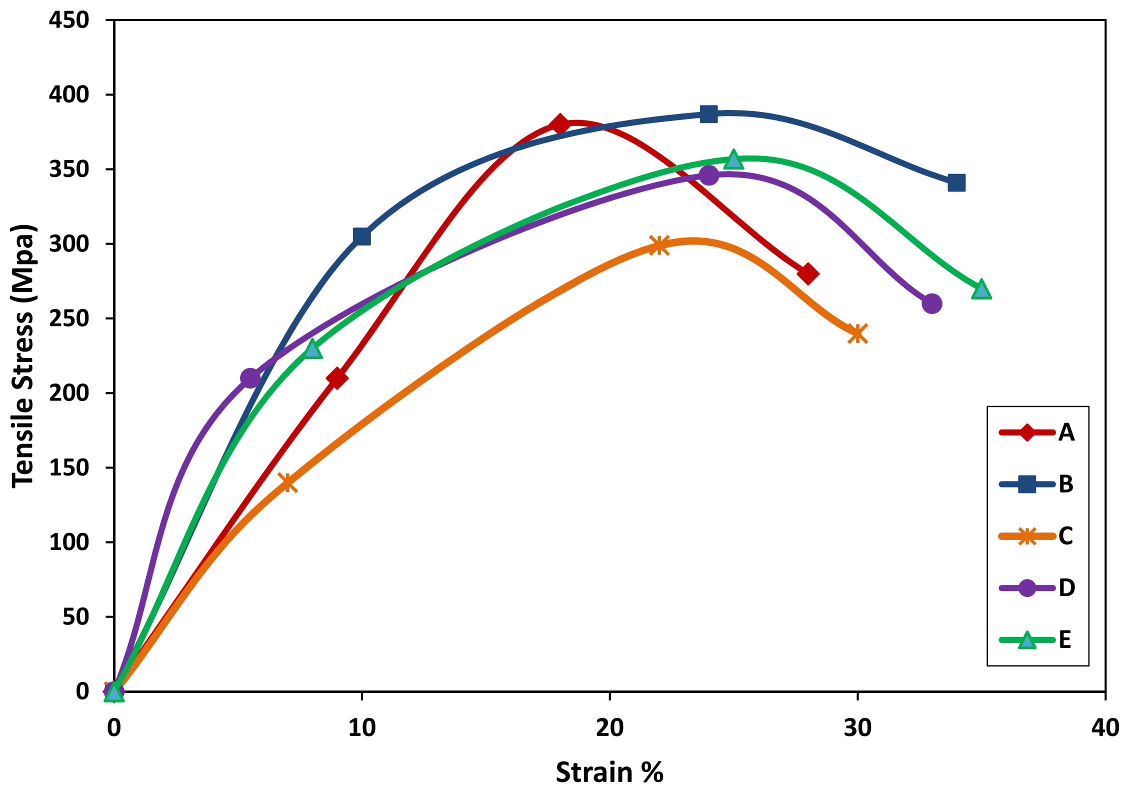

Fig. 8. Tensile strength results.

3.6. Bending Test

The bending test was performed using a universal testing machine of *100 kN* capacity. The test was performed at the speed of *3.5 mm/min*. To perform the test, the three-point method was employed in which the sample was horizontally positioned across two supports before applying force to the top of the welding line to produce U-shaped samples. Table 6 and Fig.9 present the results of the bending test. Table 6 and Fig.9 present the bending curve for all the samples. The TIG method can be considered an efficient way of improving the bending strength of weld metals in the weld zone as clearly seen in specimen B.

Table 6. Outcome of the bending tests.

Specimens Symbol	σ_y *MPa*	σ_u *MPa*	σ_f *MPa*	ε
A	*132*	*162*	*123*	*36*
B	*326*	*447*	*368*	*36*
C	*166*	*233*	*200*	*23*
D	*216*	*291*	*261*	*32*
E	*116*	*300*	*267*	*28*

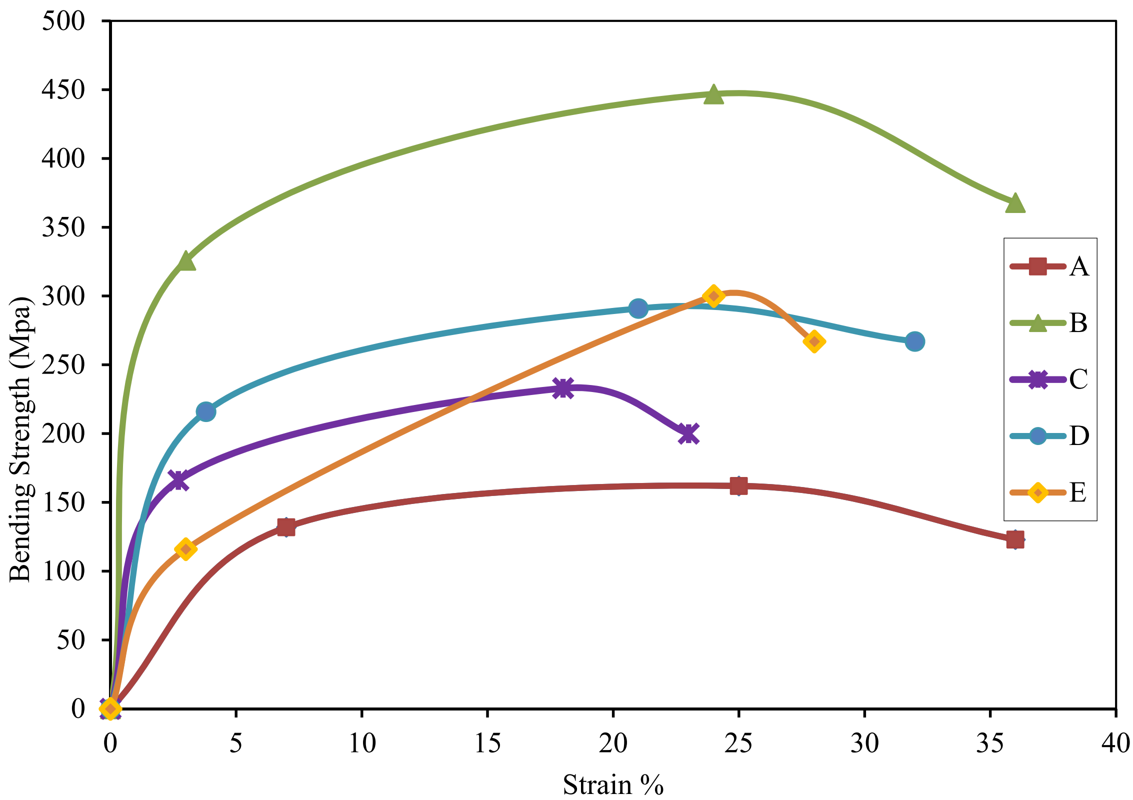

Fig. 9. Bending strength results.

The figure also shows that increases in the passes of the ultrasonic peen slightly increase the bending strength of the metal in the weld zone due to the impact of high plastic deformation as exhibited by all the specimens.

4. Conclusion

- The tensile and bending properties are significantly affected by decreases in grain size as see in specimens C, D and E which were subjected to ultrasonic peening.
- The tensile strength enhances by *17*% in the weld joint without peening as a result of a good choice of the welding parameters.
- The tensile strength decreases by *21*%, *9*% and *6*% for specimens C, D and E, respectively.
- The hardness increases by using the UP to generate fine grain structure in the weld zone.
- The bending property was significantly affected by increases in the number of ultrasonic peening as seen in specimens C, D and E.

Nomenclature

q – heat input, [*J/mm*]
V – welding voltage, [*volt*]
I – welding current, [*Ampers*]
S – welding speed, [*mm/s*]

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