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# The effect of microsilica on the microstructure and residual strain of the welded zone in ST35 steel

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**Abstract**

Welding of an alloy can be evaluated as appropriate when the properties of the welded area are most similar to the base metal. In the present study, to perform the welding process, first, ST35 steel plates were prepared and cut to dimensions of 5×10 cm. Then, the welding area was beveled at an angle of 45 degrees and filled with microferro-silica material in weight amounts of 0.5, 1, 1.5, 2 and 2.5 grams. Subsequently, the welding process was used to connect the parts to each other by the hand electrode method and in gravity mode. To evaluate the properties of the welded area, the samples were cut with a band saw machine to dimensions of 1×3 cm along the perpendicular to the weld seam section. The microstructure of the cut section was examined by scanning electron microscope (SEM). The residual strain in the welding sections of different samples was also obtained using X-ray diffraction (XRD) and Williamson-Hall analysis method. The results of the studies showed that with increasing the amount of microsilica, the grain size of the welding zone becomes finer. It was also observed that with increasing the percentage of microsilica up to 2%, the size of ferrite crystals increases, which indicates the growth of crystals under the influence of the presence of microsilica up to 2%.

## Introduction

One of the alloys that has received special attention in various industries is steel. All steels that are currently used can be classified into two categories according to their chemical composition: plain carbon steels and alloy (or special) steels[1-3].

These steels need to be connected to each other during use. Their connection is often made by bolts or welding. According to AWS, welding is the local joining of metals or non-metals to each other by applying heat or applying pressure or both with the help of filler metal or without it. In each welding process, various factors are effective in achieving a weld of desired quality. These factors include a type of energy source to generate heat, a method of protecting the molten pool from the atmosphere, and filler metal (if necessary). In different welding processes, the above factors are achieved differently [4-6]w.

In recent research, attempts have been made to control the grain size of the welded zone and improve its properties by using nucleating or slag-forming materials. Microsilica powder is one of the mineral additives that can be used as a nucleating agent and slag because it is ceramic. Microsilica is a by-product of the glass production process. Microsilica is currently used in three forms: microsilica powder, microsilica slurry, and microsilica gel[7-10].

The presence of a coating on the steel wire of the electrode protects the electric arc and the weld metal from the surrounding air during the welding operation from the melting to solidification stage. The result of this protection is a weld metal that has properties comparable to the base metal. The electrode coating largely regulates the composition of the weld metal, either by maintaining the original composition of the electrode wire or by adding other elements. In this method, alloying elements are added to the weld metal or the previous elements are modified[11-13].

One relatively new method is to add iron powder to the electrode coating. In the intense heat of the electric

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arc, the iron powder is converted to steel and helps to draw the weld on the base metal[14, 15].

By adding some iron powder to the coating material, the welding efficiency is increased and the appearance of the weld is improved. Electrodes containing iron powder are called high-efficiency electrodes. The welding efficiency of such electrodes is high and they are usually used in the flat state[16, 17].

The introduction of low-hydrogen electrodes into the welding industry has led to the modification and improvement of the welding properties of high-carbon steels, alloy steels, high-sulfur steels and phosphorus-containing steels. Some steels tend to have porosity and cracks under the weld bead, and reducing the amount of hydrogen in welding eliminates these harmful properties[18].

In this study, microsilica was used to influence the structural properties of the weld zone and protect it.

## Research Method

In this research, 35 st steel plates with a thickness of one centimeter were selected, which were cut into 1*5*15 cubic centimeters and surface preparation, and then welded in the presence of nucleating agents with weight values of 0.5, 1, 1.5, 2 and 2.5 grams. A current of 145 amperes and an electrode angle of 45 degrees were selected for welding.

In order to examine possible defects in the welding area, radiography tests were performed on all samples, and then samples measuring 3×1 centimeters were cut from the welding area and etched after surface preparation using a Nithal solution. All samples were examined using an optical microscope and a scanning electron microscope. To examine the residual stress in different samples, X-ray diffraction analysis was used, and the crystalline phases were evaluated and analyzed using the Williamson-Hall method.

## Results and Discussion

The results of radiography of welded samples are shown in Figure 1.

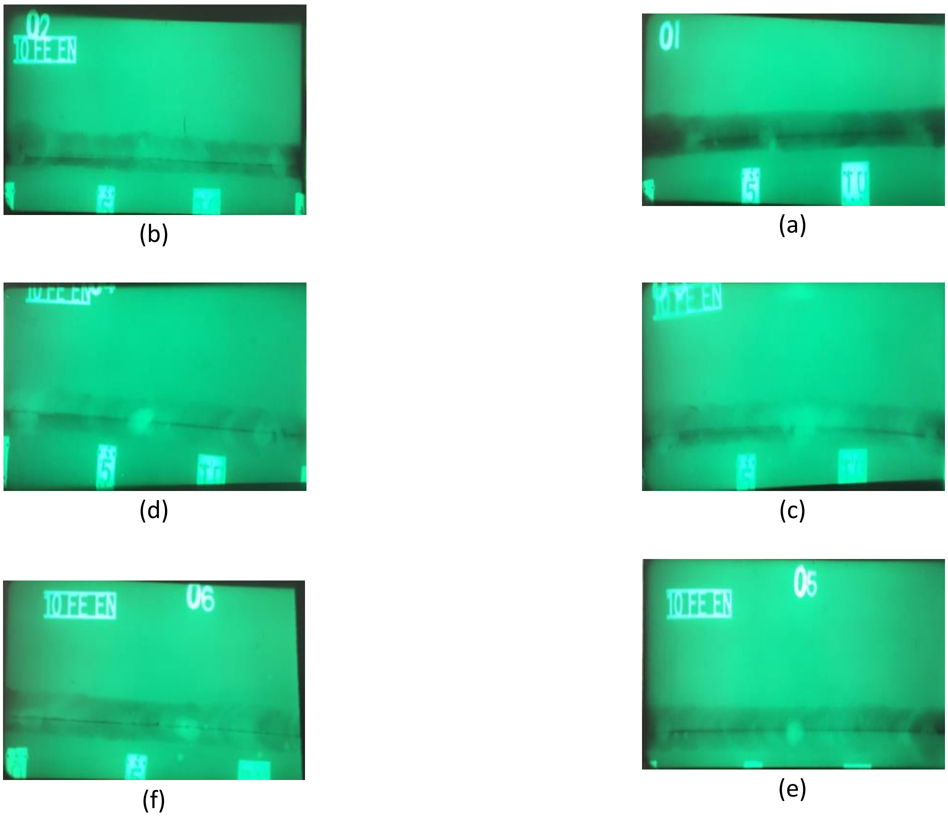


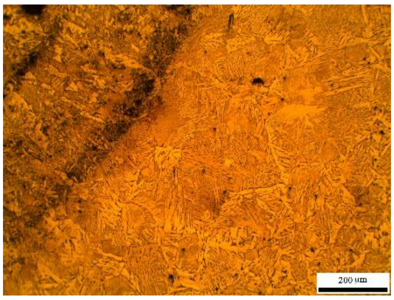

Fig. 1: Radiographic results of the welded area of ST35 steel with different percentages of microsilica, a) 0.5%, b) 1%, c) 1.5%, d) 2%, e) 2.5%, and f) no microsilica.

The images from the radiographic test were analyzed and it was observed that there was a defect called weld loss (Lop) in all the parts. In fact, this defect is caused by the contact of two parts at the root of the weld, which is done to maintain microsilica particles in the weld seam groove of this connection.

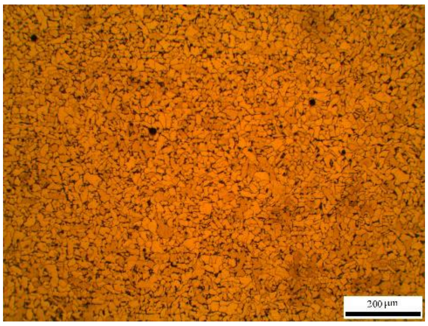
At a distance of 1 cm from the welding piece (slag), an acceptable distribution of microsilica particles is observed.

At a distance of 4 cm from the welding piece, sparks related to the welding process are observed next to the weld seam.

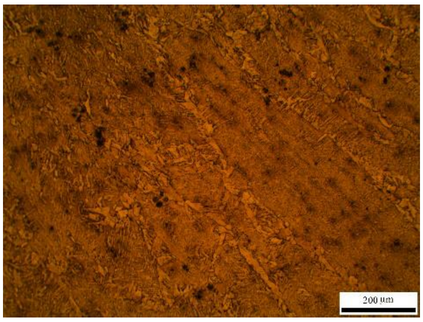
Metallographic images of the welded area of the samples are shown in Figure 2. It is observed that with an increase in the percentage of microsilica in the welding area, although the grains have become finer due to nucleation, the accumulation of residual microsilica particles is visible.




(b)




(a)

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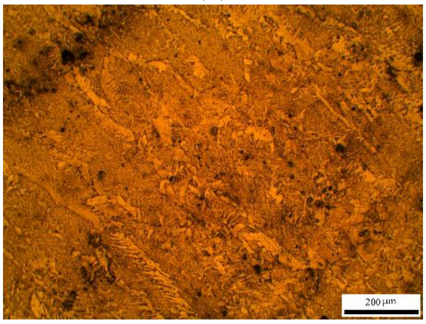


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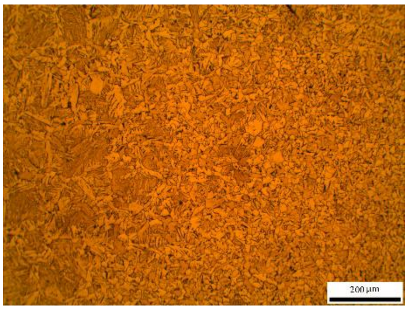
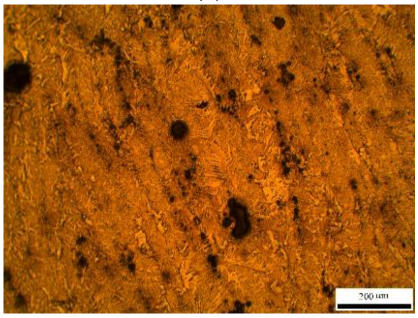



(f)




(e)

Fig. 2: Optical microscope images of the microstructure of the welded area of ST35 steel with different percentages of microsilica, a) 0.5%, b) 1%, c) 1.5%, d) 2%, e) 2.5%, and f) no microsilica.

The results of the scanning electron microscope (SEM) are shown in Figure 3. It is observed that in the welded sample without the presence of microsilica flux, the solidified mass is completely intertwined. In this condition, due to the heat transfer, it was carried out at a faster rate than in the other samples, and solidification occurred faster and an irregular structure was formed in the welded section. By adding the percentage of microsilica, grain growth is limited and the weld is finer.

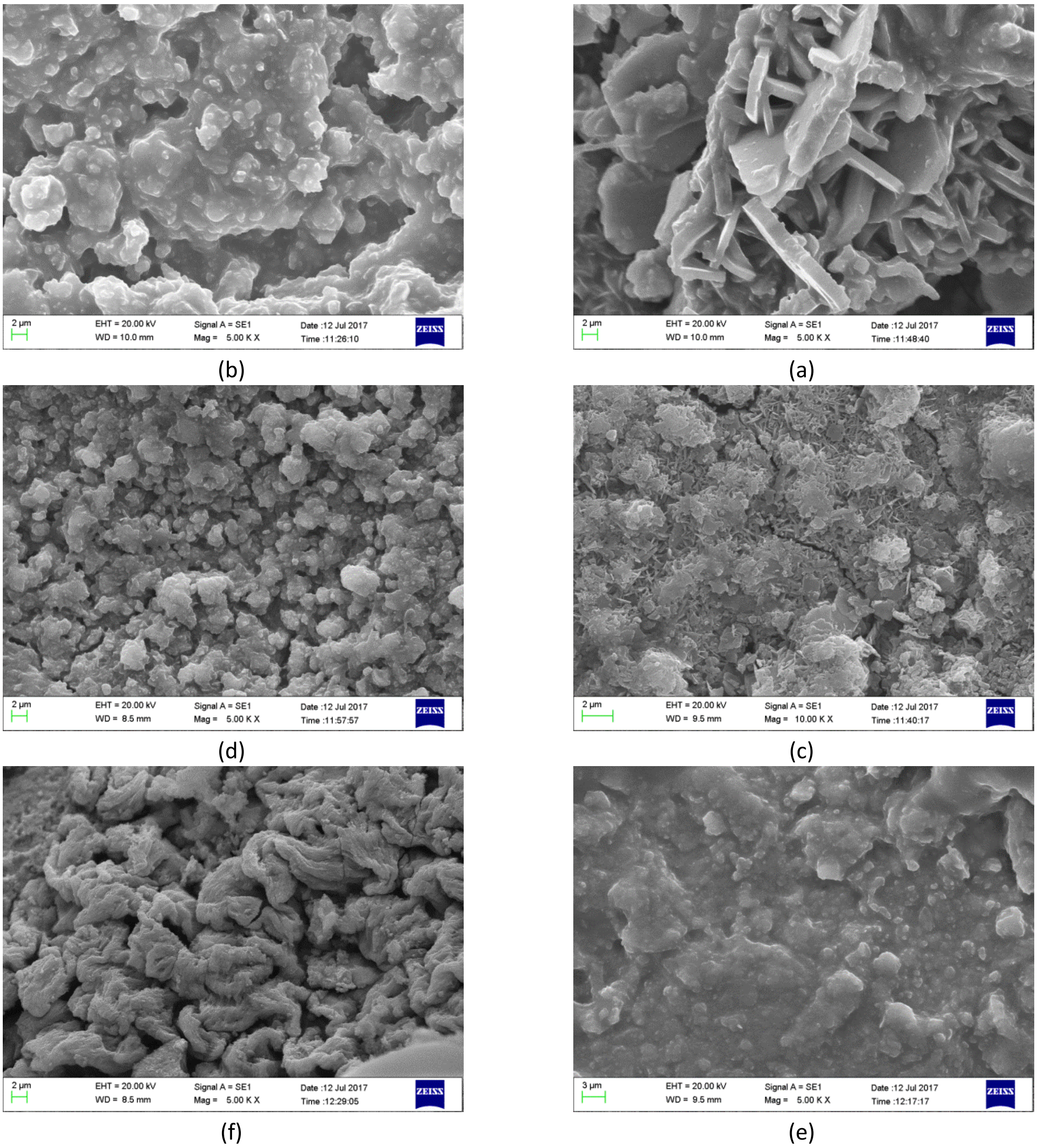



Fig. 3: Electron microscope images of the microstructure of the welded area of ST35 steel with different percentages of microsilica, a) 0.5%, b) 1%, c) 1.5%, d) 2%, e) 2.5%, and f) no microsilica.

The results of X-ray diffraction in welded samples in the presence of 0, 0.5, 1, 1.5, 2 and 2.5 g of microsilica are shown in Figure 4. Peaks related to ferrite are visible in all samples according to PDF2:00-006-0696 standards.

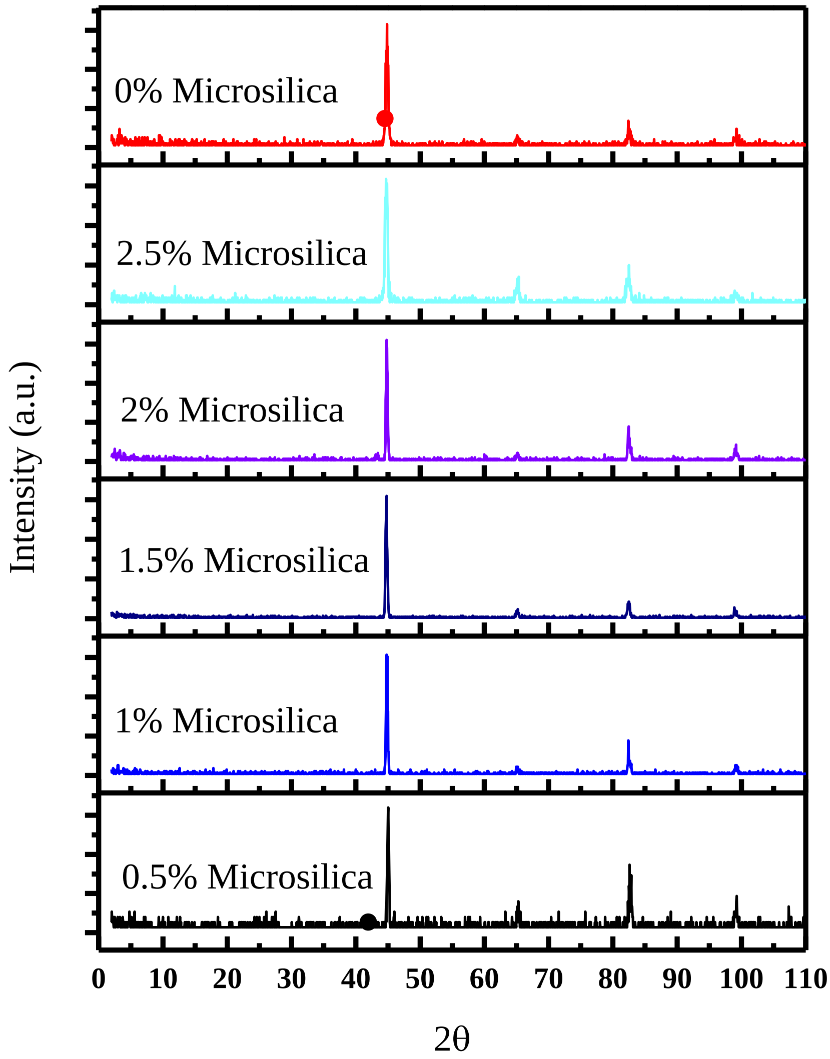
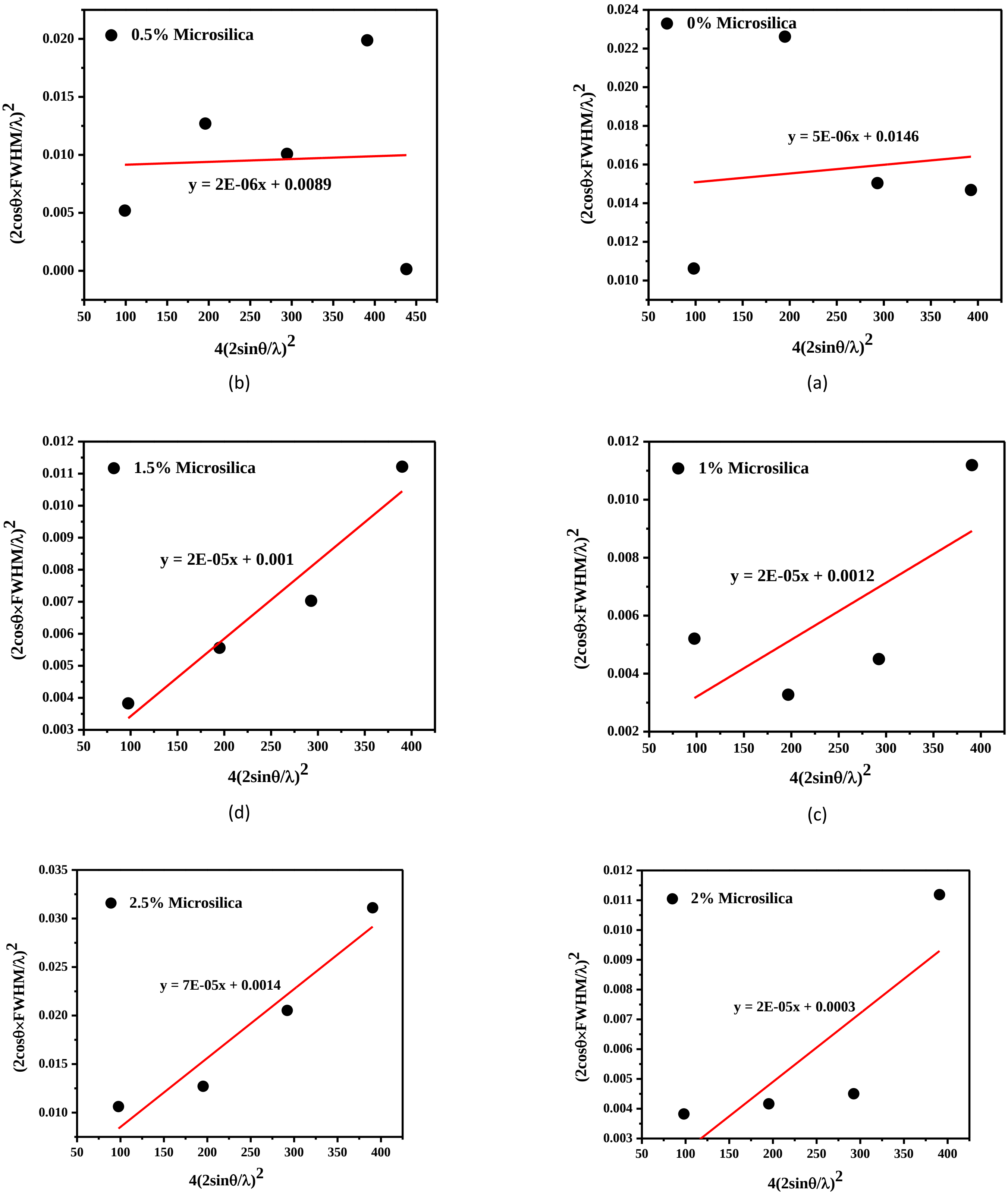



Fig. 4: X-ray diffraction pattern of ST35 steel samples welded in the presence of microsilica flux with percentages of 0, 0.5, 1, 1.5, 2 and 2.5 percent.

The analysis of X-ray diffraction results with the aim of determining grain size and residual strain in welded samples using the Williamson-Hall method is shown in Figure 5. Based on equation 1, it is observed that the slope of the graphs is positive, indicating the presence of tensile residual microstrain in the welded ferrite crystal lattice.

$$(\Delta K)^2 = \left(\frac{0.9\lambda}{d}\right)^2 + 4\varepsilon^2 K^2 \tag{1}$$

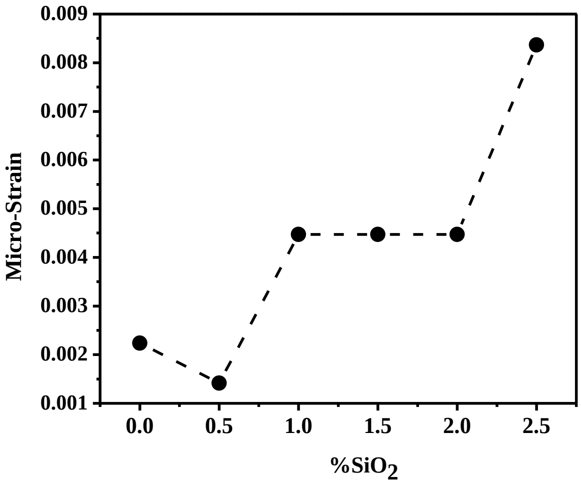
In this relation, ΔK=2cosθ β/λ, β is the peak width at half height, θ is the angle of refraction, λ is the wavelength of the X-rays (copper cathode with Å 5406/1 = λ), K=2sinθ/λ, d is the grain size, and ε is the lattice strain[19].



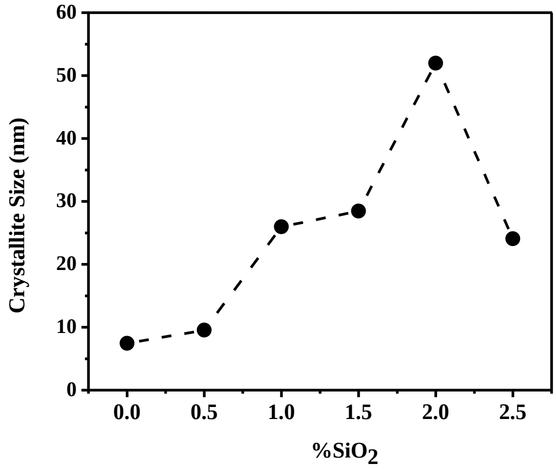

(b) (a) (d) (c) (f) (e)

Figure 5 - Results from Williamson Hall analysis of ST35 steel samples welded in the presence of microsilica flux with percentages of 0, 0.5, 1, 1.5, 2 and 2.5 percent.

The results of Williamson-Hall analysis to determine the crystal size and residual microstrain of ST35 samples welded in the presence of microsilica flux are shown in Figure 6. It is observed that with increasing the percentage of microsilica up to 2%, the size of ferrite crystals has increased, which indicates the growth of crystals. In fact, because at higher percentages of microsilica and its accumulation on the metal surface, the heat transfer rate decreases, so there will be enough time for crystal formation and growth. However, at 2.5% of microsilica, the behavior of crystal size decreases. This decrease is probably due to the dominance and preference of the nucleation phenomenon during the process over the phenomenon of heat transfer reduction. In fact, at this amount of microsilica, the ferrite nucleation sites become so numerous that the formed and growing grains meet and do not have enough space for growth. As can be seen in the microstrain diagram, at 2.5% microsilica, the crystal strain has increased significantly, which can confirm the collision of grains with each other.




(b)




(a)

Figure 6 - a) Diagram of crystal size behavior and b) residual strain of ST35 steel samples welded in the presence of microsilica flux with percentages of 0, 0.5, 1, 1.5, 2 and 2.5 percent.

## Conclusion

In this study, various samples of ST35 steel were welded in the presence and absence of microsilica using the manual electrode method and the following results were obtained:

1- Due to the presence of microsilica at the end (root) of the welding zone, proper penetration of the melt at the end of the weld does not occur well, so it is necessary to perform welding operations from the lower zone as well.

2- At microsilica percentages greater than 2.5%, due to severe fineness of the microstructure, intergranular tension increased and cracks were observed in the welding zone.

3- By adding microsilica up to 2%, the crystal structure of the welding zone of ST35 steel becomes coarser. In other words, the conditions for crystallinity become more favorable.

4- At microsilica percentages greater than 2.5%, the crystals become finer due to the increase in nuclei.

3- Microsilica percentages greater than 2.5% show a strong growth of residual strain, which is caused by the collision of many growing buds with each other.

5- Due to the presence of microsilica at the end (root) of the welding zone, proper penetration of the melt at the end of the weld is not well done, which requires welding from the lower zone as well.

6- The welding zone without the presence of microsilica has an interlocking behavior.

7- By adding microsilica, the morphology (structure) of the welding zone was finer due to the inhibition of grain growth.

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