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Effect of mechanical impact and friction treatment on the microstructure of TIG welding surface

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Abstract

Mechanical impact and friction treatment were applied to improve the TIG weld joints surface performance of Q235 steel. The micromorphology and the size of a crystal grain in the treated weld surface were studied by an optical microscopy, microhardness tester, Scanning Election Microscope (SEM) and X-Ray Diffractometer (XRD). It was shown that a thickness of about 400 μm after 20 treatment times could be reached. Meanwhile, the dense refinement layer was formed on the top of plastic deformation layer with the hardness of 370 HV. After 5 treatment times, refinement layer reached a thickness of about 10 μm, and the grain size was about 27.15 nm. With the increase of the treatment times, the thickness of refinement layer increased and the grain size was further refined. As the treatment times reached 20, the thickness of the refinement layer was about 50–60 μm, the micromorphology became the dense fibrous structure, and the grain size was about 10.6 nm.

K e y w o r d s: mechanical impact, low-carbon steel, weld, grain refinement

1. Introduction

The carbon content of Q235 steel is about 0.2 %, and it belongs to low-carbon steel. It can be welded directly as an ordinary carbon steel, so it has been widely used in industrial production. In the welding procedure, because of existing centralized heating and rapid cooling process, the microstructure and properties of welded joints are uneven. This produces welding deformation, residual stress and weld discontinuity that result in stress concentration in the welded joints and become the weak link and failure zone. Therefore, in most cases, the breakage of welding component originates from the surface of the welded joints, and it is influenced by the weld surface properties. Currently, a variety of methods such as high-energy shot peening [1–4], surface mechanical attrition treatment [5–7], supersonic particle bombarding [8], ultrasonic impact [9–10], laser shock processing [11–13] have been studied to get uniform microstructure and properties. Mechanical impact and friction treatment used a hammer device driving the special punch with high-frequency vibration and rotation to impact the metal surface. The grain refinement layer was formed on the metal surface after strong plastic deformation and improved the properties of the material. The change of grain size, orientation distribution and mechanical properties in the grain refinement layer can produce significant influence for material performance, so the study is of great significance.

In this study, the TIG welded joints of Q235 steel were tested with optical microscopy, X-ray diffraction, SEM, microhardness tester and other microscopic analysis tools. This article studied the effect of mechanical impact and friction treatment on the molecular structure of TIG welding surface.

2. Experimental

2.1. Experimental materials

Q235 low-carbon steel plates were selected as the experimental material, and the size was 200 mm × 50 mm × 6 mm. Q235 is a widely used low-carbon steel; the chemical composition is shown in Table 1, and mechanical properties are shown in Table 2. Q235 steel generally had not hardening tendency, so it had

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Table 1. Chemical compositon of Q235 (wt.%)

Elements	C	Mn	Si	S	P
	0.12–0.20	0.30–0.70	≤ 0.30	≤ 0.045	≤ 0.045

Table 2. Mechanical properties of Q235

Tensile strength σ_b (MPa)	Yield strength σ_s (MPa)	Elongation δ_s (%)	Impact energy A_{kv} (J)
375–460	≥ 235	≥ 26	≥ 27

Table 3. TIG welding parameters

Tungsten diameter φ (mm)	Welding current I (A)	Welding voltage U (V)	Argon gas flow Q (L min^{-1})	Welding speed V (mm min^{-1})	Welding heat input E (J cm^{-1})
3.2	140	20	7–8	60	2860

Table 4. Equipment parameters

Punch diameter (mm)	Impact frequency (min^{-1})	Rotational speed (rpm min^{-1})	Ringle impact energy (J)
16	3900	850	1.5

good welding properties. This kind of steels does not need to take special measures in the welding process and does not require heat treatment after welding.

2.2. Welding experiment

TIG was applied to weld on the surface of the low--carbon steel. Before welding the surface was polished, descaled, degreased, and milled with an angle grinder. Welding parameters are listed in Table 3.

2.3. Mechanical impact and friction treatment

2-20SE hammer impact device with a cylindrical punch was adopted for impact and friction treatment on the weld surface. Equipment parameters are presented in Table 4.

The sample was fixed on the moving table, and the punch was plumb targeted at the weld. The moving speed was 30 mm s^{-1}. Principle diagram is shown in Fig. 1. When multi-time treatments were conducted, the latter impact zone would cover the earlier pass. The treatment times were 5, 10, 15 and 20.

2.4. Sample test

The samples were ground, polished, and uncorroded with 4% nitric acid alcohol. 4XC microscope and JSM-6380LV scanning electron microscope (SEM) studied the section of samples. The hardness of the samples by HV1000 microhardness test was measured. D8 ADVANCE XRD with Cu target was employed to analyze the grain size of the weld. The experimental parameters were as follows: the tube potential was 40 KV, tube current was 120 mA, and scanning step was 0.02°. The grain size and microscopic strain were calculated using Scherrer-Wilson formula [14].

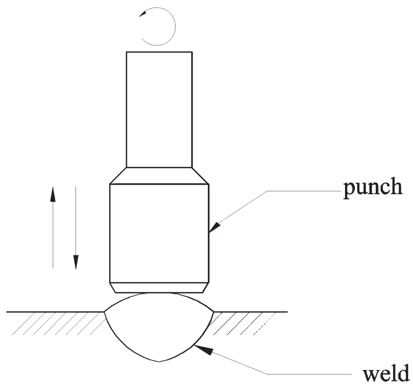

Fig. 1. Principle diagram of the mechanical impact and friction treatment.

3. Results and discussion

3.1. Metallurgical microstructure

Figure 2 shows the photomicrographs of the section

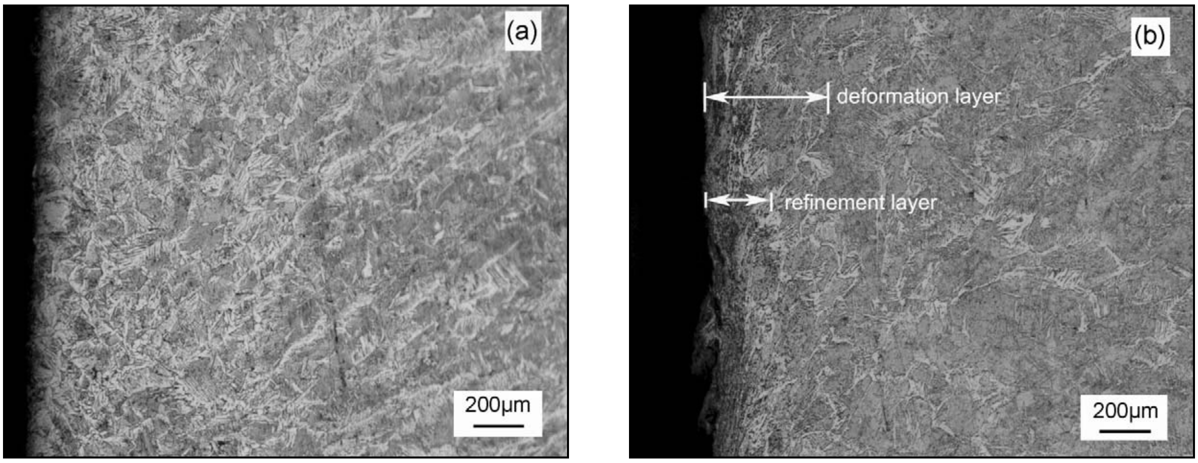

Fig 2. Photomicrographs of original welds (a) and photomicrographs of welds after 20 treatment times (b).

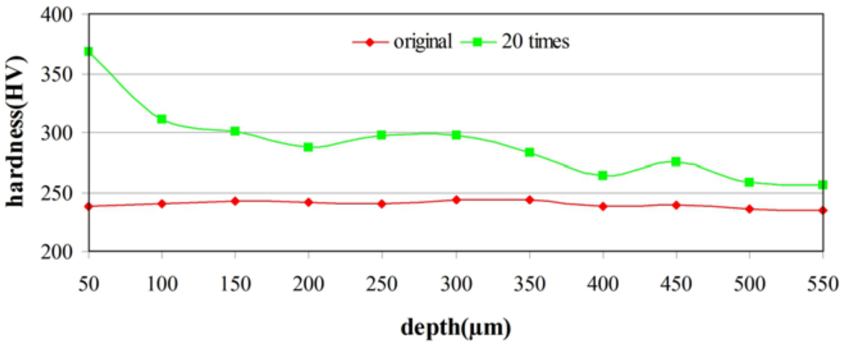

Fig. 3. Microhardness in the vertical direction.

of the sample which are the original weld surface and the weld surface after 20 mechanical impact and friction treatment times. In Fig. 2a, the micromorphology of original weld surface has obviously dendritic structure. As shown in Fig. 2b, the thickness of deformation layer was up to about 500 μm when 20 treatment times were conducted. Meanwhile, the shape of the grains in the deformation layer was significantly changed. The dendritic structure disappeared gradually, and the grain sizes decreased. Then a certain thickness of the dense refinement layer was formed on the weld surface. The thickness of the refinement layer was about 50–60 μm.

3.2. Hardness analysis

The change of hardness in the vertical direction from the weld surface to the inside is shown in Fig. 3. The hardness of the weld surface reached up to 370 HV after 20 mechanical impact and friction treatment times. With the increasing distance from the weld surface, the hardness decreased gradually, and the grain size increased. This phenomenon is consistent with the traditional Hall-Petch formula [15]. Within the 500 μm distance from the weld surface, the hardness after 20 treatment times was higher than the original hardness. So the mechanical impact and friction treatment make the weld surface hardness increase overall.

3.2. SEM morphology

Figure 4 shows the SEM photographs of the weld surface refinement layer. As is shown in Fig. 4a, after 5 mechanical impact and friction treatment times, the dendritic structure of the weld was broken, and grains began to be crumpled. With enhancing of mechanical impact and friction effect, the deformation extent of grains was more obvious, and refinement layer with a thickness of about 10 μm was formed on the weld surface. As shown in Fig. 4b, after 10 treatment times, larger grains were pressed into the strip, and the dendritic structure was pressed to be denser fibrous structure. The thickness of the refinement layer reached 20–30 μm. As shown in Fig. 4c, the grains continued to be compacted in the same direction with the increased impact effects after 15 treatment times. So there were no clear boundaries between the grains. The thickness of refinement layer further increased to about 40 μm. When the treatment times reached 20 as shown in Fig. 4d, the dense fibrous structure was

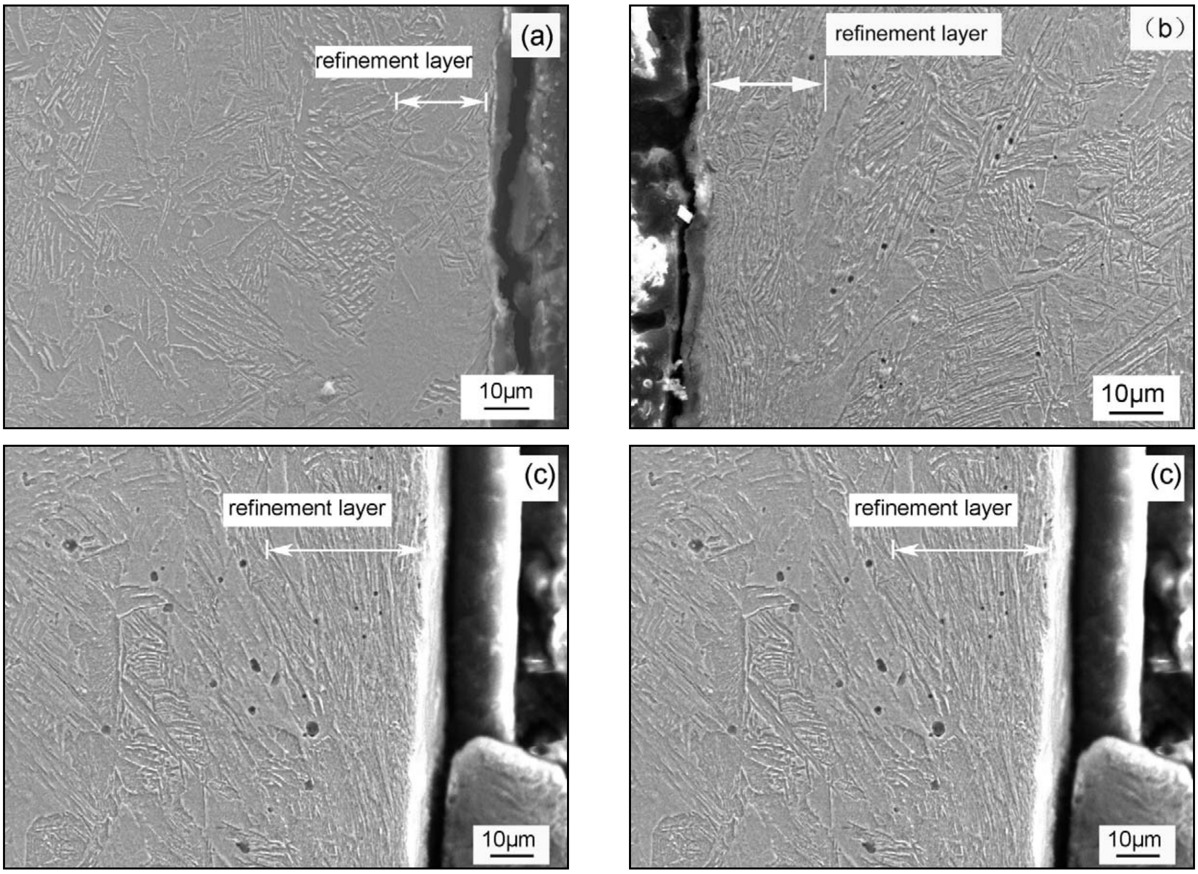

Fig. 4. SEM photographs of welds treated by mechanical impact and friction: 5 treatment times (a), 10 treatment times (b), 15 treatment times (c), and 20 treatment times (d).

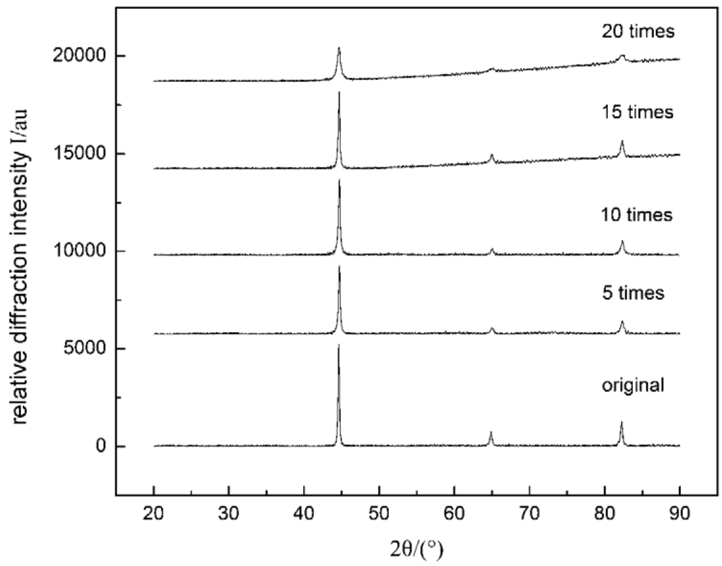

Fig. 5. XRD patterns of the weld surface.

formed in the refinement layer. The original morphology disappeared, and the thickness of refinement layer was about 50–60 μm.

3.3. XRD analysis

Scherrer-Wilson formula was used to calculate the grain size of the weld [13]. As shown in Fig. 5, com-

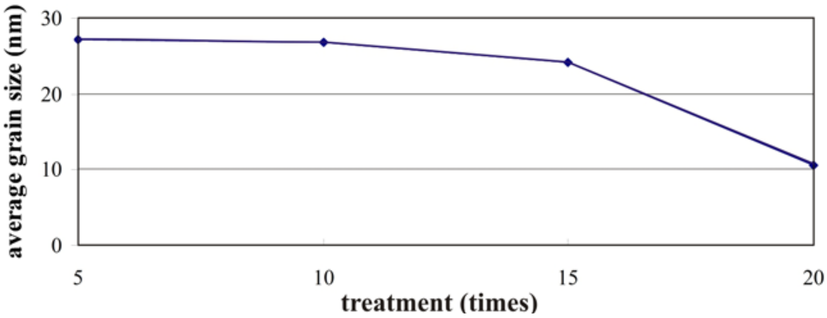

Fig. 6. The changes of grain size with the increased treatment times.

T a b l e 5. The grain size and microstrain in the welds

Treatment	Diffraction planes	Microscopic strain $\varepsilon^{\frac{1}{2}}$ (%)	Grain size (nm)	Average grain size (nm)
5 treatment times	(110)	0.362	38.1	27.2
	(200)	0.641	21.4	
	(112)	0.676	22.0	
10 treatment times	(110)	0.376	34.7	26.9
	(200)	0.604	24.4	
	(112)	0.682	21.6	
15 treatment times	(110)	0.337	46.5	24.1
	(200)	0.814	14.1	
	(112)	1.022	11.7	
20 treatment times	(110)	0.622	15.5	10.6
	(200)	1.170	8.8	
	(112)	1.488	7.5	

pared with the original sample, XRD peak intensity of the sample reduced after 5 mechanical impact and friction treatment times. The diffraction peak broadened apparently. With an increase of the treatment times, the diffraction peak broadened further. When the treatment times reached 20, the intensity of the diffraction peak was minimal, and the width was maximal. The grain size was calculated, and the calculation results are shown in Table 5. After 5 mechanical impact and friction treatment times, the grain of weld surface began to be refined, and the average grain size was 27.17 nm. After 10 and 15 mechanical impact and friction treatment times, the average grain size was 26.9 and 24.1 nm, respectively. After 20 mechanical impact and friction treatment times, the grain size was further decreased, and the average grain size was 10.6 nm. The change of the grain size is shown in Fig. 6. The grain size was refined gradually with the increased treatment times. After 20 treatment times, the refinement degree of grain size was maximal.

The mechanical impact and friction treatment use reciprocating mechanical impact to make strong plastic deformation in the weld surface layer. Low-carbon steel has higher stacking fault energy [16]. Under the applied loads, dislocation slips require less critical force. As a result, the main plastic deformation mechanism is dislocation slip. When the material is treated by the impact and friction, the dislocation density of material surface increased. To reduce the energy of the structure, the newly generated dislocations move along the slip plane. Due to multiple slip systems, the motive dislocations inevitably encounter in different slip plane, and then dislocation cells formed by dislocation multiplication deliver, and tangle. With the accumulation of the impact effect, the amount of the dislocation cells increases, their size reduces and ultimately the cells turn into fine grains.

4. Conclusions

1. With the treatment of mechanical impact and friction on Q235 welded joints, a certain thickness of plastic deformation layer would form in the weld. When the treatment times reached 20, the thickness of plastic deformation layer reached 400 μm. The hardness of welding deformed layer was improved. Meanwhile, the dense refinement layer of about 50–60 μm

in thickness was formed, and the hardness reached 370 HV.

2. By mechanical impact and friction treatment, the microstructure of the weld surface was modified. With the accumulation of the treatment, the grains of weld surface layer was gradually refined, and dendritic structure gradually disappeared. Finally, the dense fibrous tissue was formed. After 5 treatment times, the grain size became nanoscale, about 27.17 nm. After 10, 15 treatment times, the grain size was about 26.9 and 24.1 nm, respectively. When the treatment times reached 20, the grain refinement degree was increased, with the grain size about 10.6 nm.

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