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Acceleration of regeneration treatment for nanostructured bainitic steel by rotary impacting trailed welding

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ABSTRACT

The method called rotary impacting trailed welding (RITW) was proposed to accelerate the regeneration treatment of nanostructured bainitic steel welded joint. Stress and strain behaviors of welding metal under this mechanical process were analyzed using finite element software. Rotary and impacting could simultaneously take effect to generate large plastic deformation in the welded joint. Detailed changes of microstructures in the welded joints were characterized by optical microscopy and scanning electron microscopy. Results show that the large deformation of austenite in the welded joint can accelerate the bainite transformation and reduce the regeneration time. Meanwhile, large shear deformation in the austenite generated during welding has a strong effect on the bainite growth, which results in curved bainite plates.

1. Introduction

Bhadeshia (2008) reported that the nanostructured bainitic steels are with an ultimate tensile strength as high as 2.3 GPa and hardness in the range of 600–670 HV. Remarkable properties make the structural material show great potential for application including submarines, armored vehicles and missiles, etc. However, Bhadeshia (2010) pointed out that nanostructured bainitic steels were difficult to be welded because of high carbon concentration. Hong (2010) reported that cold cracks were easily formed in the welded joint. Poor weldability limits their industrial applications. Fang et al. (2013) put forward a method called *regeneration* for welding of nanostructured bainitic steel. After regeneration treatment, fine bainite forms in the fusion zone and the adjacent heat affected zone. As a result, the mechanical properties of welded joint are comparable to that of base metal. The regeneration technique is carried out after welding. As the welded joint cools toward the bainite-start temperature B_S, it is transferred into a furnace which is set at a temperature between B_S and M_S (martensite-start temperature). Afterward, the welded part is isothermally held in furnace to permit the bainite to grow again from austenite that is generated during welding high temperature period.

Avishan et al. (2012) pointed out that during bainite transformation the supersaturated bainitic ferrite plate grew by a displacive mechanism at the first stage of transformation. Then, the transformation was completed with excess carbon in the plate partitioning into the adjacent austenite. Caballero et al. (2002) found that complete bainite transformation from austenite needed a very long time, because low transformation temperature results in very low diffusion coefficient of carbon atoms. As to welding, long regeneration time means high energy consumption and low welding efficiency. The aim of this research is to accelerate the regeneration process during welding of bainitic steel.

Garcia-mateo et al. (2003) presented that both cobalt and aluminum could improve the free energy change accompanied with the austenite (γ) to ferrite (α) transformation, and therefore accelerated the bainite transformation. It is also demonstrated that refined austenite grain size can accelerate the bainite transformation at low temperature. However, these two methods cannot be adopted to accelerate the bainite transformation in heat affected zone. Gong et al. (2010) studied the effect of ausforming on bainite transformation behavior and verified that bainite transformation could be accelerated by ausforming. This method as mentioned is effective but difficult to be utilized on welded joint. This is because ausforming should be completed before that the austenite in the welded joint transformed into other phases. The time is very short due to high cooling rate of welding. Besides, no available methods can make ausforming of the nanostructured bainitic steel with ultra high strength.

The method called rotary impacting trailed welding (RITW) is proposed here to produce deformation in the welded joint by corporate effect of impacting and rotation. Another advantage of this

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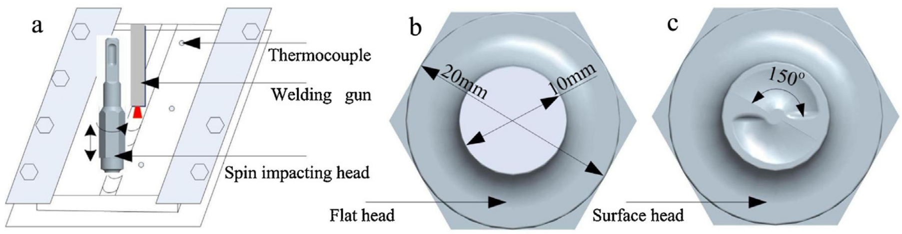

Fig. 1. The schematic configuration of (a) RITW process, (b) the flat surface and (c) the surface head.

method is that the rotary impacting and welding process proceed synchronously, therefore avoiding the time constraint. After RITW, regeneration treatment of the welded joint is performed immediately. The effect of RITW on the kinetics of regeneration process will be investigated.

2. Experimental procedures

2.1. Set-up

Fig. 1 shows the schematic configuration of the RITW process, which consists of a rotary impacting head moving with the welding gun, as shown in Fig. 1a. The head is located on an electric percussion drill. When the head impacts on the welded joint, it also rotates tightly on the surface of the weld metal. Using the mechanical movement, compression deformation and shear deformation occur simultaneously. With external power input constant, the shape of impacting head becomes an important part since it directly determines the contacting condition with welding metal. The face of traditional impacting head is flat, as shown in Fig. 1b. As a welding auxiliary tool, it is optimal to promote shear deformation which has a comparatively preferable effect on the weld appearance rather than compression deformation. Therefore, a surface head with two symmetrical grooves is designed, as shown in Fig. 1c. The depth of the groove increases in the clockwise direction and maximum depth is 1 mm. The blade like head can shear the metal more fiercely than the flat one.

2.2. Material and flow curves

The chemical compositions of nanostructured bainitic steels are listed in Table 1. The tensile strength and elongation are 2200 MPa and 7.06%, respectively. During RITW, the austenite phase will be deformed. To analyze this process, the flow curves of austenite phase were tested by Gleeble 1500 thermo-mechanical simulator. Cylindrical samples with diameter of 6 mm and length of 9 mm were heated to 1000 °C at rate of 50 °C/s. After being held for 5 min, they were cooled to deformation temperature at the rate of 10 °C/s and then compressed for 4.5 mm at different strain rates.

Table 1
Chemical compositions of alloys investigated in the present work (wt%).

C	Si	Mn	Mo	Ni	Al
0.87	1.16	1.54	0.28	0.49	1.13

Table 2
Welding parameters.

Welding current (A)	Welding voltage (V)	Welding speed (mm/s)	Shielding gas flow (argon) (L/min)
140	18	1.5	15

2.3. Processing parameters

Welding plate specimens were machined to be in dimensions of 10 mm × 80 mm × 100 mm. Bead-on-plate welding with autogenous gas tungsten arc was performed along the centerline of these specimens. Welding parameters are listed in Table 2. The rotary impacting head was placed 30 mm behind the welding gun and 5 mm away from the welding centerline. Temperature of the impacting area was about 600 °C, which was monitored by infrared temperature measurement device. As the welded joints cooled toward the bainite-start temperature B_S, they were transferred into a furnace set at 250 °C and isothermally held there for 1.5 h and 2.5 h. RITW procedure is shown in Fig. 2. The deformed area is 50 mm in length along the welding direction. Therefore, different areas with different effects can be obtained. The welded joint was

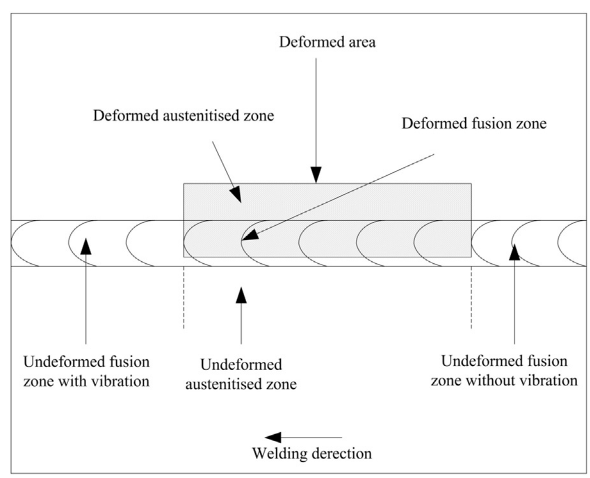

Fig. 2. RITW procedure.

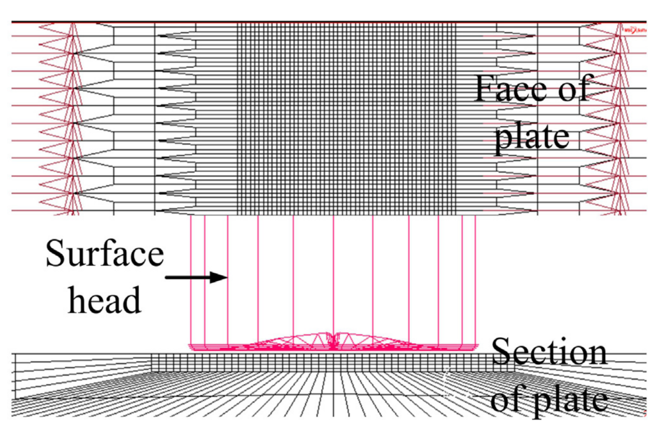

Fig. 3. Finite element analysis model and boundary conditions.