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Microstructure and mechanical properties of friction welded joints of a fine-grained hypereutectoid steel with 4% Al

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Abstract

In this study, joining characteristic of a fine-grained hypereutectoid ultra-high-carbon steel (UHCS) with thermo-mechanical cycle was investigated by the friction welding process. The joining performances of UHCS/UHCS friction welded joints were studied, and the influences of welding parameters (friction pressure, forging pressure, friction time, forging time and rotational speed) on the microstructure and mechanical properties of the welded joints were also estimated. The microstructural properties of the heat-affected zone (HAZ) were examined by optical and scanning electron microscopy (SEM). The microhardness across and perpendicular to the interface were measured and the strength of the joints was determined with tensile tests. The results were evaluated considering the microstructures formed during welding. The experimental results indicate that each parameter has a little individual effect on the quality of the joint but the combined effect of the rotation speed, friction pressure and friction time has a significant effect on the mechanical and metallurgical properties. Especially, by choosing rotation speed, friction pressure and friction time properly, it is possible to increase the quality of joint.

Keywords: Solid-state welding; Friction; Friction welding; Hypereutectoid steel

1. Introduction

Superplastic steels have a very fine-grained structure due to the carbides and nitrides of the small amount of the alloying elements added such as Al, V, Nb, Ti, Cr, B and Mo [1]. Superplastic materials are characterized by their high strain-rate sensitivity index (m) and their deformation on resistance to neck growth [2]. Backofen [3] determined that a proper thermo-mechanical treatment led to superplasticity by forming a structure composed of a homogenously distributed carbide network within the fine-grained ferritic matrix in ultra-high-carbon steels (UHCS). These steels, which cannot be readily formed at room temperature due to their high carbon content, became industrial materials after it was learned that they showed superplasticity at some certain temperatures and superplastic forming techniques were developed [3,4]. Joining this kind of steels has gained importance after their industrial applications as structural materials [5]. Though fine-grained hypereutectoid steels can be formed easily at the superplasticity temperature, the superplastic microstructure disappears and high carbon content causes cracking when they are joined with the conventional welding methods [4,6,7]. The main goal should be protecting the superplastic microstructure as much as possible and preventing cracking in the welding of superplastic high carbon steels. Since the structure of HAZ completely changes during fusion welding, friction welding is one of the solid-state bonding methods that seems proper for joining UHC steels [8,9]. There is much research on the diffusion bonding of superplastic steels but no study on the friction welding of UHC steels in the literature. Therefore, in this study, first we manufactured a fine-grained hypereutectoid steel with thermo-mechanical processes. Second, the possibility of joining UHCS, in superplastic state by friction welding was examined. This included examination of the joining characteristics of UHCS/UHCS friction welded joints using different combinations of welding parameters. The microstructural changes in heat-affected

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Table 1
The chemical composition of the hypereutectoid steel by atomic spectrometry

Alloying element	wt.%
C	1.18
Si	0.15
Mn	0.70
P	0.025
S	0.039
Cr	0.029
Ni	0.029
Al	3.95
Mo	0.20
Ti	0.10

zone (HAZ) and the mechanical behavior of the joints were examined.

2. Materials and experimental procedures

2.1. Materials and specimen preparation

The material used in this work was a hypereutectoid steel manufactured by induction melting and casting into the bars of 60 mm in diameter and 400 mm in length. The chemical composition of the materials is listed in Table 1. The cast material was homogenized at 1100 °C for 150 min, then hot forged with a cross-sectional reduction of 94% at 850 °C followed by tempering at 650 °C. Finally, a heat treatment cycle was performed comprising heating up to a temperature 30 °C higher than the A_1 (723 °C) temperature determined by DTA for this steel and quenched in oil at 200 °C. This cycle was repeated 10 times in order to obtain a fine-grained microstructure (less than 10 μm), which is a prerequisite for superplastic behavior.

Table 2
Friction welding parameters used in the present work

Specimen no.	Rotation speed (rpm)	Friction pressure (MPa)	Forging pressure (MPa)	Friction time (s)	Forging time (s)
S_1	1500	25	50	6	2
S_2	1500	30	60	6	2
S_3	1500	25	50	8	4
S_4	2000	25	50	6	2
S_5	2000	30	60	6	2
S_6	2000	25	50	8	4

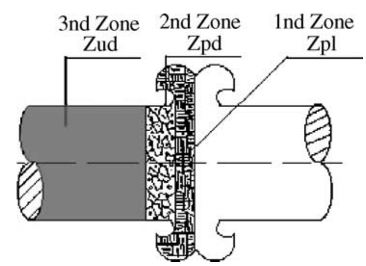

Fig. 2. Schematic of the HAZ showing the fully plasticized (Zpl), partially deformed (Zpd) and undeformed (Zud) regions.

2.2. Friction welding tests

All the friction welding tests were carried out using a direct-drive type friction welding machine, which was designed and manufactured for this purpose (Fig. 1). The surface preparation of each sample before friction welding involved grinding to an 800-grit finish, followed by degreasing with acetone, which ensured grease- and dirt-free surfaces. Friction welds were obtained under different parameter combinations (friction pressure, forging pressure, friction time, forging time end rotational speed). The experimental conditions used are summarized in Table 2.

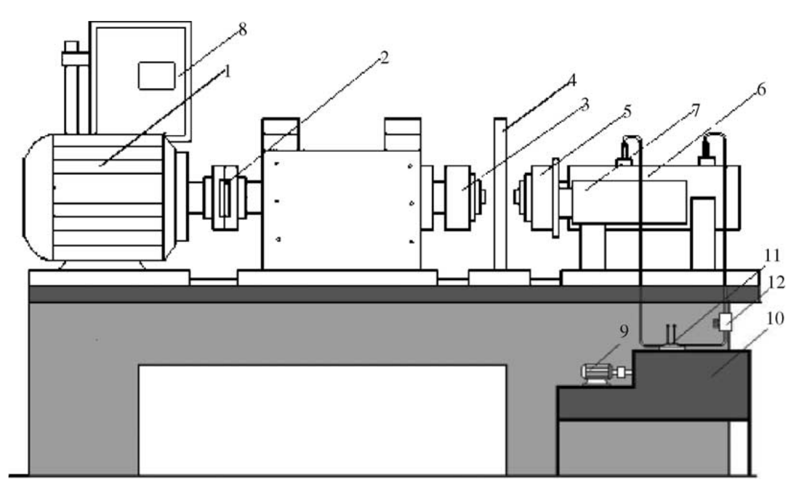

Fig. 1. Experimental set-up: (1) electric motor; (2) clutch; (3) rotary jaw; (4) stabilizer; (5) stationary jaw; (6) hydraulic cylinder; (7) piston bearing; (8) inverter; (9) motor and gear pump; (10) hydraulic tank; (11) direction control valve; (12) speed control valve.