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X-RAY RADIOGRAPHY OF AISI 4340-2205 STEELS WELDED BY FRICTION WELDING

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ABSTRACT

In this study, X-ray radiographic tests of friction-welded AISI 4340-AISI 2205 steels were investigated. AISI 4340 tempered steel and AISI 2205 duplex stainless steel, each of 12 mm diameter, were used to fabricate the joints. The friction-welding tests were carried out using a direct-drive-type friction-welding machine for different parameters. After this process, the radiographic tests of the welded joints were examined by X-ray diffraction. The experimental results indicated that the AISI 4340 tempered steel could be joined to the AISI 2205 duplex stainless steel using the friction-welding technique and for achieving a weld with sufficient strength. The result of the radiographic tests indicated that by increasing the rotation speed, the friction pressure and the forging pressure, the amount of flash increased for all the specimens. In contrast, when increasing the friction time the amount of flash decreased. The best properties for steels AISI 4340-2205 were observed for the specimens welded at a rotation speed of 2200 min–1, a friction pressure of 40 MPa, a forging pressure of 80 MPa, a friction time of 6 s and a forging time of 3 s.

1 INTRODUCTION

Duplex stainless steel (DSS) is well known for its excellent strength and corrosion resistance. However, joining DSS plates by fusion welding causes a significant reduction in the mechanical properties, because of microstructure changes during weld solidification. It is essential to maintain the characteristics of the weld zone to use DSS in servicing highly critical environments, such as ocean-mining machinery, oil and gas pipe lines, desalination plants and chemical tankers of ships, etc. DSS has ferrite () and austenite ( ) in approximately equal proportions, which possess body centered cubic (BCC) and face centered cubic structure (FCC), respectively.1 During the controlled alloying process of the DSS, under equilibrium conditions, ferrite-promoting elements (Cr, Mo, Mn, W, Nb, Si, Ti and V) will concentrate by diffusing in the ferrite. At the same time, austenite-promoting elements (Ni, C, N, Co and Cu) will concentrate by diffusing in the austenite phases. This gives the formation of a dual-phase microstructure.2,3 But the welding of DSS forces the microstructure to remain in an excessive ferritic nature, because of the higher amounts of ferrite promoting elements in its chemical composition, and also due to a faster cooling rate. Austenite usually nucleates in the temperature range 1200–900 °C. During cooling, the weld zone remains in this temperature range for a very short period of time, i.e., from 4 s to 15 s. Thus, the arc energy and filler metal composition play a major role in the microstructural stability after welding.4 Tempered types of steel are machinery manufactured steels with and without alloy, whose chemical compositions, especially in terms of carbon content, are suitable for hardening and which show high toughness under a specific tensile strength at the end of the tempering process. Tempered types of steel, due to their superior mechanical properties, acquired at the end of the tempering process, are used in a wide range of areas, including the manufacture of parts such as various machine and engine parts, forging parts, various screws, nuts and stud bolts, crank shafts, shafts, control and drive components, piston rods, various shafts, gears. For this reason, tempered steels are the type of steel used and produced at the highest rate after unalloyed steels and construction steels. These steels constitute the most important part of the machinery-manufacturing steels. Generally, such steels are used for the production of fitting, axle shaft, the shaft and the gear.5–9 Friction welding is a solid-state joining process that can be used to join a number of different metals. The process involves making welds in which one component is moved relative to, and in pressure contact with, the mating component to produce heat at the faying surfaces. Softened material begins to extrude in response to the applied pressure, creating an annular upset. Heat is conducted away from the interfacial area for forging to take place. The weld is completed by the application of a forge force during or after the cessation of the relative motion. The joint undergoes hot working to form a homogenous, full surface, high-integrity weld. Friction welding is the only viable method in this field to overcome the difficulties encountered in the joining of dissimilar materials with a wide variety of physical characteristics. The advantages of this process are, among others, no melting, high reproducibility, short production time and a low energy input.10–19 Welding technology is commonly used in many areas. Because it is aimed to provide high and constant quality in manufacturing sector and in products, the importance of non-destructive is the testing methods in quality-control strategies. Accordingly, the non-destructive testing of welded joints has become a part of the total quality system.20,21 Being one of the most important parts of quality control, non-destructive material testing method is the complementary part of the manufacturing. The non-destructive method is the common name for testing methods through which the static and dynamic information about the materials are obtained by testing the materials without damaging them.

High-energy electromagnetic waves may penetrate into many materials. The radiation penetrating a specific material may affect the radiation-sensitive films that are put on the other side of the material. After the development of the films, the image of the inside of the material is seen. This image occurs because of the spaces in the material or thickness/density changes. This method is called radiographic testing, which is one of the oldest methods of nondestructive testing and has been in use for approximately five decades. Among the advantages of this method, compared to other methods, such as ultrasound tests, is the formation of an internal šphotograph' of the material, which no other method is able to achieve. Various radiation sources may be used in radiographic testing. The radiographic testing of weld bead or casting pieces using X-rays or gamma source is one of the most important uses for this inspection method. The energy gap of the X-ray used in industrial radiography is generally between 50 kV and 350 kV. The beam energy varies according to the type and thickness of the material. In order to get precise results from the testing, it has to be done in accordance with the standards. These standards are determined by considering the type of the material and/or the type of product. There are also application standards together with the standards according to which the acceptance levels are determined. The testing is done by determining the standards suitable for the features of the product. Radiographic testing is generally applied according to the EN 1435 or EN 12517 standards.23–25 The radiography method is applied to ferromagnetic, non-ferromagnetic metals and other all materials. Because X-ray provides the opportunity to analyze the microstructure of the materials without making any damage, it is widely used in non-destructive testing.

2. RESULTS AND DISCUSSION

The flash obtained was symmetric, which indicated plastic deformation on both the rotating and upsetting (reciprocating) side. The integrity of the joints was evaluated for the friction-welded joints. The friction-processed joints were sectioned perpendicular to the bond line and observed through an optical microscope. It is clear that there were no cracks and voids in the weld From the microstructural observations, the microstructures formed in the interface zone during or after FW processes, there are three distinct zones across the specimens identified as unaffected zone (UZ), deformed zone (DZ) and transformed and recrystallized fully plastic deformed zone (FPDZ).39 Typical grain refinement occurred in the DZ region by the combined effect of the thermal and mechanical stresses (Figure 7). A typical micrograph showing the different morphologies of the microstructure at different zones of the friction-processed joint is shown in Figure 7.

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