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Short communication

The impact toughness of novel keyhole TIG welded duplex stainless steel joints

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ABSTRACT

Keyhole tungsten inert gas (K-TIG) welding is a novel, high-efficiency welding method. In this study, 10.8-mm-thick duplex stainless steel (DSS) plates were welded via K-TIG welding, without groove preparation or filler metals. The microstructure, grain size and grain boundary misorientation angle distribution (GBMAD) of the weld metal (WM) were analyzed to characterize its impact toughness. Charpy impact tests were carried out, and the results proved that the impact absorbed energy (IAE) of the WM increases with the increase in heat input. This finding indicates that the austenite volume fraction and the GBMAD have an influence on the impact property of the WM.

1. Introduction

To reduce manufacturing costs, S32101 duplex stainless steel (DSS), which has a relatively low nickel content, is frequently used. Nickel is an austenite stabilizer. Therefore, the nitrogen content is increased to compensate for the decrease in nickel content, which increases the stability of the austenite phase in S32101 DSS [1, 2]. The austenitic-ferritic (duplex) structure of S32101 DSS is balanced such that there are approximately equal amounts of ferrite and austenite in the solution-annealed condition. Additionally, S32101 is not sensitive to the precipitation of the intermetallic phase. Thus, it is widely used as a structural material in power plants, chemical, marine, nuclear, and offshore petroleum facilities [3–5]. It has been reported that the balance of ferrite and austenite has a remarkable influence on the mechanical properties of S32101 DSS. However, it is challenging to maintain the phase balance of the weld metal (WM) during the welding processes [6]. Mundt and Hoffmeister reported that the microstructure of the WM depends not only on the chemical composition but also on the welding thermal cycle [7].

Currently, traditional welding methods that are applicable to S32101 DSS include tungsten inert gas (TIG) welding, gas metal arc welding (GMAW) and submerged arc welding (SAW). For medium thickness plates, the penetration ability of these welding methods is limited; consequently, a multi-pass welding process is required and expensive filler materials (i.e. ER2209) are used in order to fill the prepared groove and maintain the phase balance of the WM. This makes the process relatively complex and inefficient. Laser beam welding (LBW), electron beam welding (EBW) and plasma arc welding (PAW) are effective techniques for welding mid-thickness DSS plates. However, the equipment for LBW and EBW is costly [8, 9], which means their production costs are high. In addition, PAW entails adjusting a large number of parameters, making the operation relatively complicated.

Keyhole TIG (K-TIG) welding is a novel, recently developed, high-efficiency welding technique. It can generate high-energy and high-stiffness arcs, producing a keyhole through the workpiece during the welding procedure. K-TIG can be used to achieve welds on

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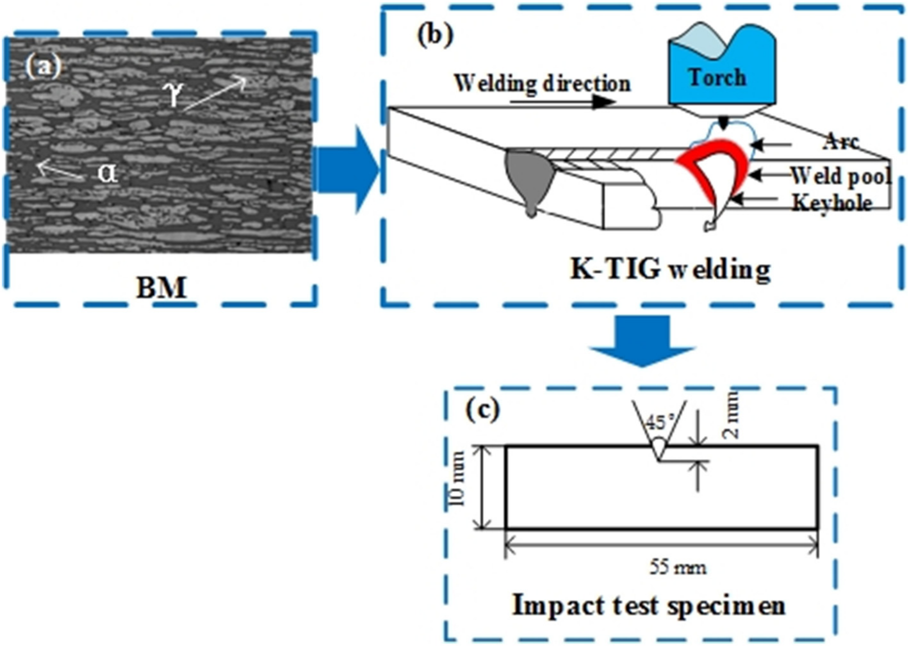

Fig. 1. (a) The microstructure of the BM; (b) Schematic diagram of K-TIG welding; (c) Impact test specimen.

square butt joints with single-pass welding without filler metals for stainless steel plates up to 12 mm thick [10]. Westin proved that the impact toughness of the WM in DSS by traditional TIG joints was generally lower than that of the base metal (BM) but that this varies significantly based on filler composition and the final microstructure [11]. Without filler metals, the weld is formed by the melting and solidification of the neighboring BM during K-TIG welding. Therefore, the chemical composition does not change, and the microstructure of the WM is mainly affected by the welding thermal cycle alone. The challenge of utilizing K-TIG welding on S32101 DSS is that the welding heat input can affect the microstructure and impact toughness of the WM. To date, there have been few studies on the welding of S32101 DSS using K-TIG and the mechanism by which welding heat input affects the impact property of the WM, with the exception of a few limited studies on tensile testing and impact testing of K-TIG welded joints. In this work, a K-TIG welding system was utilized to weld DSS plates with a thickness of 10.8 mm. The K-TIG welding procedure does not require any groove preparation or filling metals. After welding, the microstructure, grain size and grain boundary misorientation angle distribution (GBMAD) of the WM in the K-TIG welded joints were systematically studied to analyze the impact toughness of the WM. After performing a Charpy impact test, the impact absorbed energy (IAE) of the WMs was measured.

2. Materials and methods

S32101 DSS workpieces (300 mm × 100 mm × 10.8 mm) were used as the BM. Fig. 1a displays the microstructure of the BM. Fig. 1b shows a schematic diagram of K-TIG welding. According to several preliminary tests conducted by the authors, the K-TIG welding parameters were set as follows: welding speed = 3.5 mm/s, electrode gap = 2.5 mm, pure argon (99.9%), flow rate = 20 L/min, welding current = 470, 490, 510, 530 A, arc efficiency = 0.9 (corresponding to heat inputs = 1.99, 2.14, 2.30, 2.46 kJ/mm, respectively). Although welding currents for K-TIG welding are higher than those of conventional TIG/MIG welding, the high speed of the process results in modest heat inputs. Furthermore, K-TIG welding is a keyhole mode welding method, and the arc plasma can escape from the bottom of the keyhole, which leads to a decrease in actual heat input on the workpiece. Therefore, the heat inputs for K-TIG welding process are well within normal ranges.

After welding, an optical microscope (OM) was used to study the microstructure of the WMs, which were polished and etched before testing. The GBMAD of the WMs was characterized by electron backscatter diffraction (EBSD). Charpy impact test samples were conducted per the instructions in the ASTM A370 standard [12]. The specimen dimensions are illustrated in Fig. 1c.

3. Results and discussion

3.1. Microstructure and content of austenite in the WM

Fig. 2 displays the microstructure of the WM with different heat inputs. It can be observed that the microstructure of the austenite in the WM includes grain boundary austenite (GBA), Widmanstätten austenite (WA) and intragranular austenite (IGA). The volume fractions of austenite in the WM, which were measured by the EBSD technique, were 36.5%, 38.9%, 39.4% and 41.8%, as shown in Fig. 3. The volume fraction of austenite in the WM gradually increases with the increase in heat input. Higher heat input results in a