Materials and Design 33 (2012) 376–383

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

The effect of tool rotational and traverse speed on friction stir weldability of AISI 430 ferritic stainless steels

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ARTICLE INFO

Article history:
Received 16 February 2011
Accepted 9 April 2011
Available online 16 April 2011

Keywords:
A. Ferrous metals and alloys
C. Joining
D. Welding

ABSTRACT

In this study, the effects of tool rotational speed and traverse speed on welding of AISI 430 (X6Cr17, material number 1.4016) ferritic stainless steels by friction stir welding method are examined. Two specimens with dimension of $3 \times 100 \times 200$ mm were joined in butt position. Tool rotational speeds were determined to be 560–1400 min^{-1} and traverse speeds as 80–200 mm/min. During the studies, tool pressure force 3.5 kN and tool angle of 0° was kept constant. Hard metal carbide (WC-Co hard metal identified as K10) with equilateral triangle tip profile was used as the tool material. Determination of the tool advance speeds related to the tool rotation speeds giving the best-looking weld seals with acceptable values of mechanical properties was aimed.

During welding of the specimens joined in butt position, the temperature change due to time and variation of the pressure force applied on welded specimens by the tool shoulder has been recorded. It has been observed that the best mechanical resistance values were obtained at tool rotational speed of 1120 min^{-1} through five tool rotational speeds (560–1400). Also it has been observed that the best mechanical resistance values were obtained at traverse speed of 125 mm/min through five traverse speeds (80–200) with the constant tool pressure force of 3.5 kN and tool angle of 0°.

1. Introduction

Friction stir welding (FSW) is a new solid state joining process. In a typical FSW a rotating cylindrical pin tool is forced to plunge into the plates to be welded and moved along their contact line. During this operation heat is produced by friction between tool and workpiece. The material is stirred by tool and forced to flow to other side. Because of the highest temperature is lower than the melting temperature of the material, FSW yields fine microstructure.

Although austenitic stainless steel has common use, ferritic stainless steel has many advantages. Firstly, ferritic stainless steels are more economic because they do not contain nickel which is an expensive alloy. Ferritic stainless steels have good corrosion resistance with good formability and ductility. They are magnetic and have low thermal expansion. However, there are several problems about welding of ferritic stainless steels with classic methods. One of the problems is about excessive grain growth. It is possible to have the problem of coarse grains in the weld zone and heat-affected zone of fusion welds and consequent low toughness and ductility due to the absence of phase transformation during which grain refinement can occur [1,2]. Excessive grain growth can be avoided, of course, by using lower welding heat inputs. It has also been suggested that nitride and carbide formers such as B, Al, V and Zr can be added to ferritic stainless steels to suppress grain growth during welding [3].

Another problem in welding of ferritic stainless steels is about formation of sigma-phase (σ-phase). Several undesirable intermetallical phases such as σ-phase may occur when stainless steels are exposed to 650–850 °C for a period of time [4]. σ-phase has a great hardness, approximately 700–800 HV, and a tough structure. The σ-phase is the most serious of these secondary phases due to its impact on the mechanical properties, corrosion resistance or weldability of stainless steels among other properties. To prevent the σ-phase, stainless steels must not be preheated over 400 °C. Another solution is after welding stainless steels must be cooled very quick [5]. σ-phase formation and grain growth mentioned above must be avoided because FSW can reach much lower temperatures than traditional methods. However, investigations and results on weldability of FSW and welding parameters of steels and other metals in literature are given below.

Saeid et al. searched the effect of the welding speed on the microstructure and mechanical properties of the stir zone (SZ) in FSW of SAF 2205 duplex stainless steel. They welded 2 mm-thick plates at a constant rotational speed of 600 rpm. They obtained

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doi:10.1016/j.matdes.2011.04.013

successful X-ray radiography for the welding speeds in the range of 50–200 mm/min. They determined that increasing the welding speed caused to decrease the size of the α and γ grains in the SZ, and hence, increased hardness value and the tensile strength of the SZ. They suggested a relationship between the welding speed and the peak temperature in FSW [6].

Meran and Canyurt searched the effect of tool rotational speed and traverse speed on welding of AISI 304 austenitic stainless steels by FSW method. They observed that with rotational speed of 750 rpm, pressure force of 9 kN and tool angle of 1.5° welds with optimal strength are formed with a traverse speed of 47.5 mm/min. Nevertheless, with a traverse speed of 60 mm/min, pressure of 9 kN and tool angle of 1.5° the optimal strength welds are obtained by a rotational speed of 950 rpm [7].

Meran et al. searched the FSW of AISI 304 austenitic stainless steel. They obtained flawless weld of 304 austenitic stainless steel at the rotational speed of 1000 rpm and traverse speed of 40–100 mm/min by use of wolfram carbide tool [8].

Alptekin obtained the best weld seam of 304 austenitic stainless steel at the rotational speed of 1000 rpm and traverse speed of 63 mm/min and tool angle of 1°45″ by use of wolfram carbide tool which has 20 mm diameter [9].

Cavaliere et al. investigated the effect of welding parameters on mechanical and microstructural properties of AA6082 joints produced by FSW. They suggested that a strong variation in the nugget mean grain size was observed by increasing the advancing speed from 40 to 165 mm/min up to a plateau corresponding to no further variations by increasing the speed up to 460 mm/min. The yield strength was recorded to increase strongly from the lower speeds to 115 mm/min and after starts to decrease by increasing the advancing speed; the ductility of the material followed the same behavior but restarted to increase after 165 mm/min. The material welded with the advancing speed of 115 mm/min exhibited the best fatigue properties and the higher fatigue limit, while a very narrow similar behavior in the low cycle regime, differing strongly by decreasing the stress amplitude up to the fatigue limit, was observed in all the configurations. The SEM observations of the fatigue specimens, welded at 115 mm/min, showed that at higher stress amplitude levels the cracks initiate at the surface of the welds [10].

Chao and Jahazi investigated the effect of welding speed on the quality of friction stir welded butt joints of a magnesium alloy. They obtained that grain growth appears at an advancing rate (welding speed/tool revolution rate) less than 0.6 mm per revolution. Higher welding speed produces slightly higher hardness in the stir zone. The yield strength increases with increasing welding speed. The tensile strength increases with increasing welding speed up to 15 mm/s but remains constant from 15 to 30 mm/s [11].

Rajakumar et al. searched the influence of FSW process and tool parameters on strength properties of AA7075-T6 aluminum alloy joints. They found that the joint fabricated at a tool rotational speed of 1400 rpm, welding speed of 60 mm/min, axial force of 8 kN, using the tool with 15 mm shoulder diameter, 5 mm pin diameter, 45 HRC tool hardness yielded higher strength properties compared to other joints [12].

Song et al. investigated the effect of welding speed on microstructural and mechanical properties of friction stir welded Inconel 600. They found that the dynamic recrystallization was observed at all conditions, and the grain refinement was achieved in the stir zone, and it was gradually accelerated from 19 lm in average grain size of the base material to 3.4 lm in the stir zone with increasing the welding speed. It also has an effect on the mechanical properties so that friction stir welded zone showed 20% higher microhardness and 10% higher tensile strength than those of base material [13].

Elangovan and Balasubramanian examined the influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminum alloy. They found that the joint fabricated using square pin profiled tool at a rotational speed of 1600 rpm showed superior tensile properties [14].

Zhou et al. searched the effect of rotation speed on microstructure and mechanical properties of Ti–6Al–4V friction stir welded joints. Joints were produced by employing rotation speeds ranging from 400 to 600 rpm at a constant welding speed of 75 mm/min. It was found that rotation speed had a significant impact on microstructure and mechanical properties of the joints. A bimodal microstructure or a full lamellar microstructure could be developed in the weld zone depending on the rotation speeds used, while the microstructure in the heat-affected zone was almost not influenced by rotation speed. The hardness in the weld zone was lower than that in the base material, and decreased with increasing rotation speed. Results of transverse tensile test indicated that all the joints exhibited lower tensile strength than the base material and the tensile strength of the joints decreased with increasing rotation speed [15].

Liu et al. investigated the Effect of welding speed on microstructures and mechanical properties of underwater friction stir welded 2219 aluminum alloy. They found that the precipitate deterioration in the thermal mechanically affected zone and the heat-affected zone is weakened with the increase of welding speed, leading to a narrowing of softening region and an increase in lowest hardness value. Tensile strength firstly increases with the welding speed but dramatically decreases at the welding speed of 200 mm/min owing to the occurrence of groove defect. During tensile test, the joint welded at a lower welding speed is fractured in the heat-affected zone on the retreating side. While at higher welding speed, the defect-free joint is fractured in the thermal mechanically affected zone on the advancing side [16].

Shen et al. investigated the effect of welding speed on microstructure and mechanical properties of friction stir welded copper. They found that as the welding speed increased, the grain size of nugget zone first increased and then decreased, the thermomechanically affected zone became narrow and the boundary between these two zones got distinct, but the heat-affected zone was almost not changed. The ultimate tensile strength and elongation of the joints increased first and decreased finally with increasing welding speed, but the effect was little when the welding speed is in the range of 25–150 mm/min. The defect-free joints were produced at lower welding speeds and the fracture locations were outside the nugget zone on the retreating side. With increasing welding speed, the average hardness of nugget zone decreased first and then increased, but welding speed had little effect on the hardness of the other regions within the joints [17].

Gharacheh et al. searched the influence of the ratio of “rotational speed/traverse speed” (ω/v) on mechanical properties of AZ31 friction stir welds. They found that increasing the ratio leads to a slight decrease in yield and ultimate strength of the stir zone and the transitional zone. They also observed that increasing rotational/traverse speed ratio increases the weld nugget size and decreases the incomplete root penetration [18].

Lakshminarayanan and Balasubramanian investigated on an assessment of microstructure, hardness, tensile and impact strength of friction stir welded ferritic stainless steel joints. They studied on microstructure and mechanical characterization of friction stir welded 409 M ferritic stainless steel with a welding speed of 50 mm/min and rotation speed of 1000 rpm. They suggested that the coarse ferrite grains in the base material were changed to very fine grains consisting duplex structure of ferrite and martensite due to the rapid cooling rate and high strain induced by severe plastic deformation caused by frictional stirring. Tensile testing indicates overmatching of the weld metal relative to the