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Original Article

Friction welding of a nickel free high nitrogen steel: influence of forge force on microstructure, mechanical properties and pitting corrosion resistance

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ABSTRACT

In the present work, nickel free high nitrogen austenitic stainless steel specimens were joined by continuous drive friction welding process by varying the amount of forge (upsetting) force and keeping other friction welding parameters such as friction force, burn-off, upset time and speed of rotation as constant at appropriate levels. The joint characterization studies include microstructural examination and evaluation of mechanical (micro-hardness, impact toughness and tensile) and pitting corrosion behaviour. The integrity of the joint, as determined by the optical microscopy was very high and no crack and area of incomplete bonding were observed. Welds exhibited poor Charpy impact toughness than the parent material. Toughness for friction weld specimens decreased with increase in forge force. The tensile properties of all the welds were almost the same (irrespective of the value of the applied forge force) and inferior to those of the parent material. The joints failed in the weld region for all the weld specimens. Weldments exhibited lower pitting corrosion resistance than the parent material and the corrosion resistance of the weld specimens was found to decrease with increase in forge force.

1. Introduction

The Ni saving high nitrogen steels (HNSs) are of four types: martensitic, ferritic, Cr–Mn–(Ni–N)/N austenitic and duplex. It is noteworthy that Cr–Mn–(Ni–N)/N grade of HNS has tremendous potential for substitution for the widely used type 304 ASS for household products, automobile parts and materials for the chemical and food industries, mainly due to their outstanding combination of strength and ductility, excellent work-hardening capability and corrosion resistance [1,2].

Weldability is an important issue for the wider expansion in the use of HNSs for structural purpose. Fusion welding of HNS has several limitations such as N_2 pores and/or precipitation of Cr-nitrides in the heat-affected zone (HAZ), depending on the welding parameters like welding voltage and current, shielding gas composition and level, type of filler metal, type of flux, thermal cycle, etc., employed [3–5]. All those phenomena degrade the local mechanical and corrosion resistance of the weld to a great extent. Desorption of nitrogen has been found to be the governing mechanism for N_2 flux transfer in and out of the base material in case of nitrogen containing ASS

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Table 1 – Chemical composition of the base material.

Elements	C	Mn	Cr	S	P	Si	N	Fe
Wt.%	0.076	19.780	17.960	0.007	0.051	0.340	0.543	Bal.

and thus controlling the final nitrogen content and porosity in the weld, as reported by Toit and Pistorius [6]. Therefore, one may opt for high base material nitrogen content, as suggested by the same researchers. However, it has been reported that the tendency for pore formation during welding goes up with increase in nitrogen content of the base material [7]. Researchers have proposed a solution towards this problem by increasing the solubility of nitrogen with the addition of manganese, especially for high chromium–molybdenum alloys [8]. Again, one potential limitation when welding highly alloyed ASS is hot cracking. As a measure to minimize the hot cracking risk, one needs to choose a filler material with low impurity levels (e.g. S, P) in addition to keeping eye on the least degree of segregation of the major alloying elements and minimization of the level of intermetallic phase in the weld metal [7]. Therefore, fusion welding is a challenging and non-reliable process to apply for the HNS type of material; as, here, extreme careful observation on the influence of welding parameters on joint properties and thus control and optimization of those are required.

Almost all the shortcomings of the fusion weld HNS joint can be wiped out by employing a solid state route. Among the solid state welding processes, friction welding and friction stir welding (FSW) are the two most popular ones. In case of FSW, lots of understanding needs to be there on the selection of proper tool material and only plate shaped materials can be joined together [9,10]. On the other hand, friction welding can be helpful for joining materials with varieties of shapes such as rod to rod, rod to plate etc., wherein, at least one component should be axi-symmetric. Among the friction welding processes, rotary friction welding is by far the most common form which accounts for most of the machines and their accessories in today's industry [11]. This has two principle varieties, based on the availability of energy to weld – (i) direct drive or continuous drive friction welding, sometimes called conventional friction welding uses continuous input supplied by motor driven workpiece, (ii) inertia friction welding, sometimes called flywheel friction welding, uses energy stored in a flywheel. Continuous drive friction welding is a well established solid state joining process which can be used to join a wide range of conventional steels as well as more metallurgically challenging material systems such as superalloys and dissimilar material combinations [11,12].

However, to the best of our knowledge, there are very limited studies on friction welding of HNS [13,14], and that too, on low nitrogen containing HNS. In case of friction welding, upsetting (forge) force has been found to be one of the most important parameters among others such as friction force, friction time (or, burn-off), upsetting time and rotational speed of the moving component [12]. It is also appealing to note that there is very limited report on the corrosion studies of HNS friction welds. In view of the foregoing, in the present study, specimens were joined by varying amount of forge force, while keeping the other friction welding parameters such as burn-off, friction force, upsetting time and rotational speed as constant at appropriate levels and by using a continuous drive friction welding set up. The joint characterization studies include microstructural examination and evaluation of mechanical (micro-hardness, impact toughness and tensile) and pitting corrosion behaviour.

Table 2 – Mechanical properties of the base material.

UTS (MPa)	YS (MPa)	% El	VHN	CVN (J)
982	810	45	325	240

2. Experimental details

2.1. Materials

The base materials employed in this study are high nitrogen steels (rods of 15 mm diameter and 60 mm length) of which chemical composition and mechanical properties are given in Tables 1 and 2 respectively. The materials were available as plates in hot rolled (at 1150 °C) condition. The microstructure of the base material is shown in Fig. 1. It consists of equiaxed austenite grains.

2.2. Welding details

A 150 kN capacity continuous drive friction welding machine was employed for the welding experiments. This is a stepless variable speed machine with rotational speed range of 0–2400 rpm. The main variable parameters are friction force, forge force and burn-off which are generally considered to be the variables controlling the quality in friction welding. Trial runs were conducted by changing one of the process variables and remaining others as constant. The working range of forge

Fig. 1 – Microstructure of base material.