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Friction Stir Welding of Austenitic Stainless Steel by PCBN Tool and Its Joint Analyses

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Abstract

AISI-316 plates of thickness 4mm are joined by friction stir welding (FSW) with varying welding parameters like tool rotation speed (rpm) and welding speed (mm/min). All welded samples are observed by optical microscopy followed by their tensile tests. Mechanical strength of 104 % of the base material with comparable elongation is achieved in FSW sample of 1100 rpm rotation speed and 8 mm/min welding speed.

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Keywords: Friction stir welding; PCBN Tool; Tensile strength.

1. Introduction

AISI-316 has several structural applications like nuclear-waste-disposal-canister cap closure. Rough usages over the time develop cracks in them which need to be repaired through welding. Traditional welding methods for example fusion welding leads to defects like solidification cracking, formation of brittle intermetallic phases and heavy residual stresses as actual melting of material takes place in it. Friction stir welding (FSW) is a new innovative solid state process in which material is welded below its melting temperature and hence, eliminates fusion welding defects. In FSW, the friction between rotating tool (surface and pin) and plates to be welded generates heat which raises the temperature to make the material semisolid, followed with material flow aided by pin of the tool. Compressive hydrostatic stress and frictional heat together make the surface weld [C. Meran et al. (2010) & R.S. Mishra et al. (2005)].

The main objective of this work is to find suitable welding parameters for joining of 4mm thick Austenitic 316 stainless steel plates through FSW and finding the best welding parameters through mechanical tensile tests and optical microscopy.

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2. Experimental Procedures

2.1. Materials and Experimental set up

Plates of AISI-316 of dimension (120 mm x 80 mm x 4mm) are obtained in as-received form and its nominal chemical composition is checked (Table 1). The sides of these plates are mechanically ground and are butt welded using ETA Welding machine (specifications given in Table 2 with photo in Figure 1) at IISc Banglore. A polycrystalline cubic boron nitride (PCBN) with tungsten rhenium (WRe) composite tool (Megastir commercial name Q70) is used for welding [R. Steel et al. (2011)]. The photo with dimensions of the tool is shown in Figure 2.

Table 1. Nominal Chemical composition of AISI-316.

%C	%Mn	%Si	%Cr	%Ni	%Mo	%S	%P	%Fe
0.03	**0-2**	**0-1**	**16-18**	**10-14**	**2-3**	**0.03**	**0.045**	**balanced**

Table 2. ETA friction stir welding machine specifications: Capacity10 ton vertical bed.

	Minimum	Maximum
Spindle speed	1 RPM	3000 RPM
Welding speed	16 microns/sec	3000 mm/min
Plunge speed	16 microns/sec	2000 mm/min

Fig. 1. ETA FSW Machine at IISc Banglore.

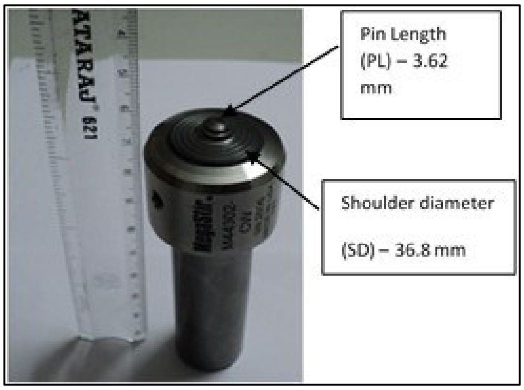

Fig. 2. Megastir Q70 (PCBN /WRe) Tool.

2.2. Optimization of the welding parameters

Process optimization is very difficult in FSW as heat generation due to friction depends on various factors like tool rotation (rpm), welding speed (mm/min), tool plunge depth (mm), axial force (N), and tool design. After finding better tool plunge depth (3.72 mm), experiments are designed with varying rotation speed and welding speed (given in Table 3).

Table 3. Design of Experiments.

Sr No	RPM	Welding Speed
T1	1100	8
T2	1100	12
T3	1100	16
T4	1000	8
T5	1000	12
T6	1000	16
T7	900	8
T8	900	12

T9	900	16

For metallography observations, the transverse section of the welds are mechanically ground up to 1 μ diamond sol and chemically etched with aqua regia for optical microscopy (Leica optical microscope). For tensile tests, ASTM E8M specifications are followed. Flat specimens (as shown in Figure 3) are cut through electric discharge machining and are tensile tested at strain rate of 10^{-3} s^{-1} on a 30 kN Instron machine [V. Balasubramanian et al, (2010)].

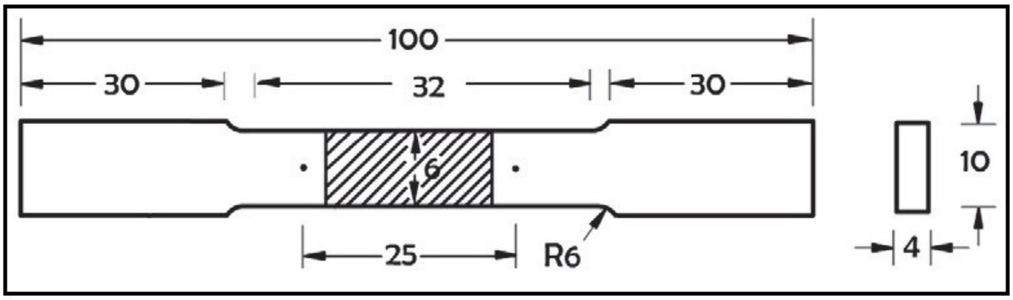

Fig. 3. Schematic diagram of E8M Tensile specimen.

3. Results and Discussions:

The optical micrograph of the base material, the magnified optical image of the nugget zone of a weld and the transverse section few of welded specimens (seven) are shown in Figure 4. The base material consists of equiaxed austenite grains (Figure 4(a)). The weld specimens in the transverse section showed mainly the central nugget zone containing onion rings like microstructure, followed by thermomechanically affected zone (TMAZ), given in Figure 4(b). The grains appeared equiaxed but smaller in the nugget zone than in in the base material. There is a clear contrast, appeared at around 3-4 mm, in the image visible between the nugget zone and TMAZ in the advancing side stating not proper mixing than in the retreating side. Inside the nugget zone, the material flow line (onion rings) show material being swayed from the advancing side and mixed forcibly into the retreating side, creating smooth transition with no contrast. The complete transverse section optical images of seven welds (Figure 4(c)) showed several defects (except in T1) like pores at the bottom of the nugget zone region.

Tensile tests are performed on the base material and all the nine welds and their values are given in Table 4. The base material showed 608 MPa of ultimate tensile strength (UTS) with an elongation of 49% till fracture. Except T1 and T6, all the welds fractured near the plastic yield value of the base material, achieving very little elongation. Except T1, all the welds necked and fractured in between 3-4 mm of the nugget zone-TMAZ interface in the advancing side. This is expected with the fact of sudden change in grain microstructure between the nugget zone and TMAZ, becoming the weak region and therefore, failed first under stress. T1 weld showed a UTS of 630 MPa (104% of the base material) with nearly equal elongation of 37% and necked at the advancing side of the base material region. T6 weld gave 553 MPa UTS with 20% elongation. Containing no defects (pores) and smooth transition of grain structure from the nugget zone to the TMAZ and then to the base material, the weld region of T1 behaves quite similar to the base material and hence, achieved with equal UTS value. The tensile plot of the base material, T1 weld and T6 weld is given in Figure 4 for comparison. Both the welds plastically yielded at similar value as of the base material and also demonstrated similar work hardening in the plastic region as of the base material, suggesting good weld with no change in deformation behaviour.

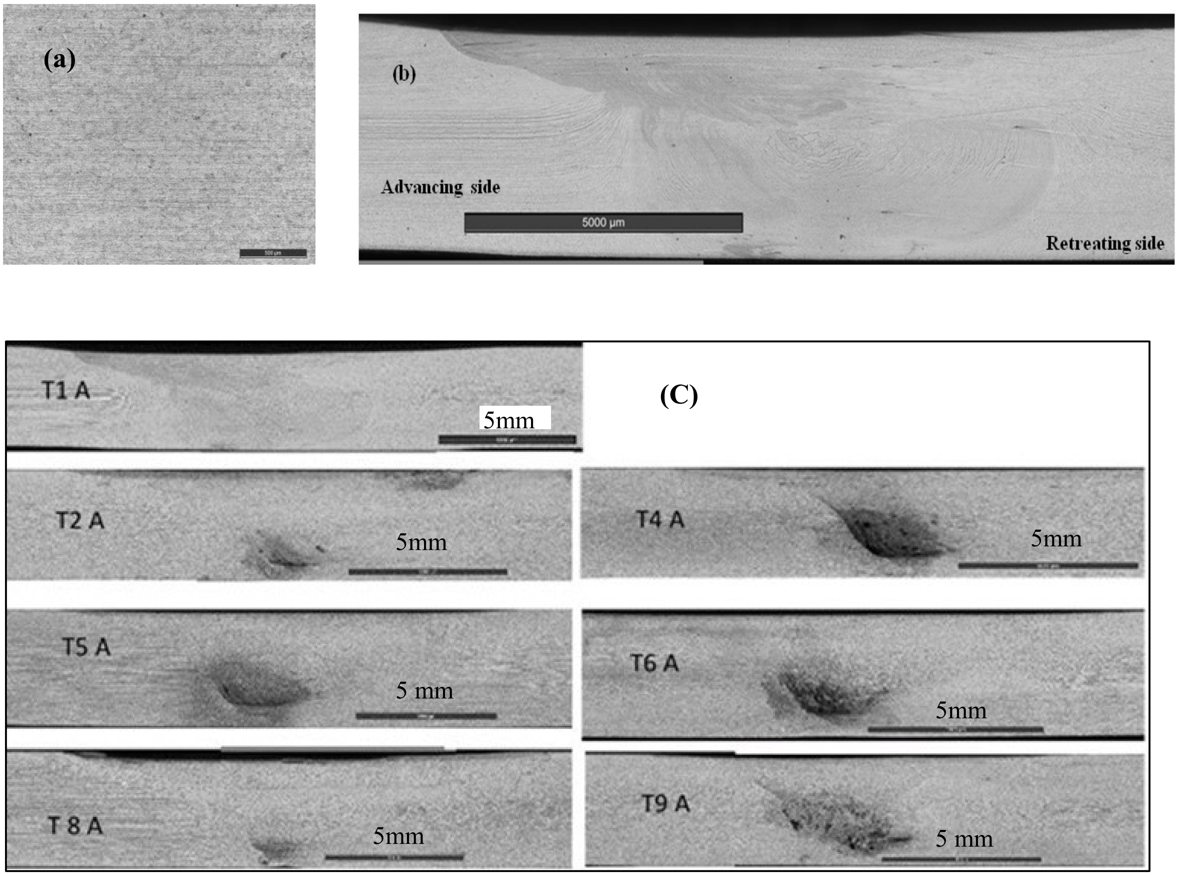

Fig. 4. Optical microscope images at 5X (a) Base Metarial (b) Enlarged image of transverse section of a weld (c) Transeverse section of few welded samples. “A” denotes the advancing side.

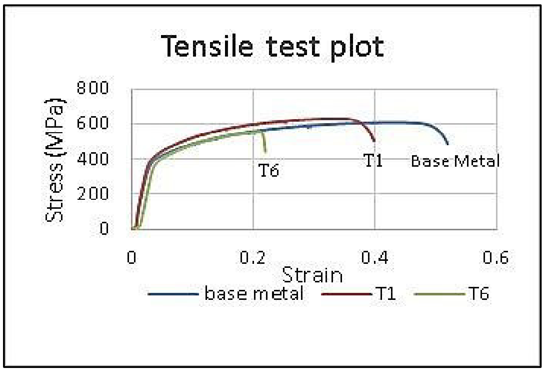

Fig.5. Tensile test plot of welded sample and base metarial.

Table 4. Tensile test result

Sr No	RPM	Welding Speed (mm/min)	UTS (MPa)	% Elongation
T1	1100	8	630	37
T2	1100	12	397	5
T3	1100	16	343	3
T4	1000	8	361	3
T5	1000	12	428	5
T6	1000	16	553	20
T7	900	8	365	3
T8	900	12	399	5
T9	900	16	343	5
		Base Material	608	49

4. Conclusions

Friction stir welding is performed to join 4mm thick plates of AISI 316 austenitic stainless steel with varied parameters (like, tool rotation speed (rpm), welding speed (mm/min)) and the joining conditions are optimized. A defect free weld with parameters of 1100 rpm and traverse speed of 8 mm/min showed similar tensile strength that of the base material with comparable elongation of 37%.

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