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Friction Stir Processing of ODS and FM Steels

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1. Introduction

Application of the latest developments in materials technology may greatly aid in the successful pursuit of next generation reactor and transmutation technologies. Oxide dispersion strengthened (ODS) steels and Ferritic Martensitic Steels (FMS) are expected to be used as a long life cladding in the future advanced fast reactor. Those materials have excellent resistance to creep and swelling as well as superior mechanical strength [1-4]. Applications of FMS and ODS steels grow faster in nuclear engineering society; however, their weldabilities were the barrier to be solved for practical applications. In ODS steels, it is well known that uniform nano-oxide dispersoids act as pinning points to obstruct dislocation and grain boundary motion, however, those advantages will be disappeared while the material is subjected to the high temperature of conventional fusion welding [5-9]. Rotary friction welding, also referred to as friction stir welding (FSW), has shown great promise as a method for welding traditionally difficult to weld materials such as aluminum alloys. This relatively new technology has more recently been applied to higher melting temperature alloys such as steels, nickel-based and titanium alloys [10-12]. Friction stir processing (FSP) is a method of changing the properties of a metal through intense, localized plastic deformation. FSW is the precursor of the FSP technique. When ideally implemented, this process mixes the material without changing the phase and creates a microstructure with fine, equiaxed grains. This homogeneous grain structure, separated by high-angle boundaries, allows some alloys to take on superplastic properties.

In this study, FSW is used as a substitutive welding process between FMS tube and ODS parts. The dimension of tube is 7.0 OD, 0.5 T. During the FSW, dynamic-recrystallized grains are developed; the uniform oxides dispersion is preserved in the metal matrix. The microstructure and microtexture of the material near the stir zone is found to be influenced by the rotational behavior of the tool. The additive effect from FSP on sample surface is considered. Since the mechanical alloying (MA) and FSP commonly apply extreme shear deformation on materials, the dispersion of oxide particle in ODS steels is very active during both processes.

2. Methods and Results

The material used in this study was a FM ODS steel (Fe(bal.)-9Cr-2W-0.2Ti-0.1C-0.35Y_2O_3 in wt.%) and FM steel (Fe(bal.)-9Cr-1Mo-0.1C in wt.%). The FMS was finally drawn to be tubes, the dimension was 7.0 OD, 0.5 T. The tubes were cut into 100 mm long specimens; those tubes are subjected to FSW. Samples are fixed by specially designed zig, the rotating FSW tool is placed in the middle of the attached two tubes while the zig rotates a round. A ring shaped ODS steel is placed outside the attached two FMS tubes. The dimension of ODS ring was 7.5 OD, 0.5 T. This design will be helpful to secure stability of weld by providing enough thickness for FSW. Moreover, partial FSP effect is expected during process, the fine oxide particles will be dispersed in the FMS after FSW. A material of the tool used in this study is a W-12wt.% Co alloy. The ODS steel and FMS are FSWed at tool rotating speed of 1500~5000 rpm. Tempering is carried out at 750℃ for 1h after welding, by considering the characteristic of 9Cr FMS and ODS steels. The welded tubes are tested by conventional hoop stress measurement system, which blow Ar gases inside the tubes until the tubes break apart. The schematic design of current experimental specimen is shown in figure 1. The first design is for the tube welding as described above, and the second design is for the end plug welding. The plug is designed by 7.5 OD , 0.5 T and 16 mm long ODS steel rod, two FMS tubes are inserted through the furrow of the ODS plug. In this case, the thickness of weld part is more than 1 mm, the FSW process becomes more convenient and reliable.

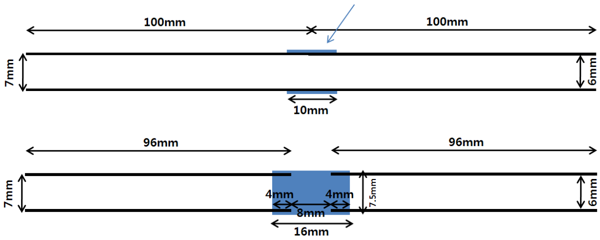

Fig. 1. A schematic design for welding two FMS tubes is shown on top. A schematic design for welding FMS tube and ODS plug is shown on bottom.

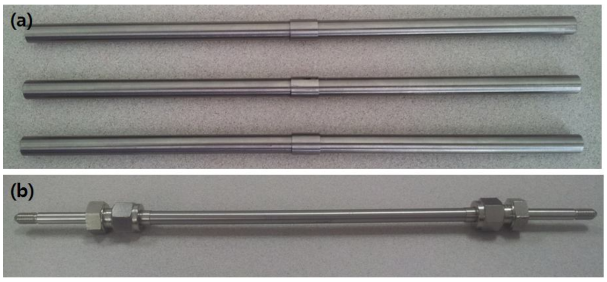

Fig. 2. (a) FMS butt weld tubes (b) Hoop stress test specimen.

FMS tubes and ODS ring assembly is shown in figure 2. Total length of test specimen is 200 mm, this design is adequate for the hoop stress test machine in KAERI. The center part of the tubes expands like balloon with the Ar gas injection, finally the tubes break apart. The internal pressure before the fracture is measured; the whole surface area of the tubes is measured, therefore the hoop stress will be calculated. The real sample of hoop stress measurement is shown in figure 2(b). Both ends of the test tube are sealed with Swagelock. The Ar gas is injected through a small holes in the end of the tube.

For the microstructure characterization of the weld part, the samples were mechanically wet ground and etched in 3% HF + 3% HNO_3 + 94% H_2O solution for 60seconds. The EBSD specimens were electro-polished in 5% $HClO_4$ + 95% methanol solution in vol. % at 20V for 25 seconds at room temperature to remove the work hardened surface induced by mechanical buff-polishing. The thin foil specimens for TEM observation were prepared by jet-polishing using 5% $HClO_4$ + 95% CH_3OH at 25V at -40℃. To investigate mechanical property differences between the base material (BM) and stirred zone (SZ), hardness and tensile tests were carried out. The hardness profile was measured on the transverse cross section, using a Vickers micro-hardness tester with 100gf load for 15 s. Tensile properties were evaluated with SS-J2 type miniaturized tensile specimens as shown in figure 3 at room temperature.

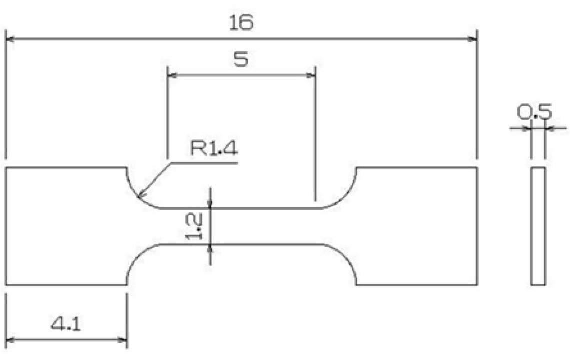

Fig. 3. Schematic illustration of tensile specimen.

3. Conclusions

Friction stir welding appears to be a very promising technique for the welding of FMS and ODS steels in the form of sheet and tube. FSW could successfully produce defect-free welds on FMS tubes and ODS ring assembly. FSW produces a fine grain structure consisting of ferrite and martensite, and the oxide particles are uniformly distributed as the mechanical alloying (MA) process. Tensile strengths and elongations of the SZs are excellent compared to those of the BM. FSW might be an appropriate welding method of ODS steels and FSP might be an appropriate surface modification method of target material.

Acknowledgements

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