Friction Stir Joining of Dissimilar Ferritic ODS Steels

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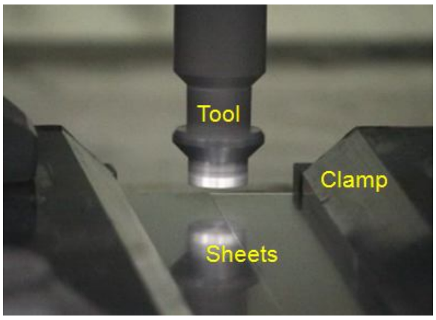
1. Introduction

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) ferritic steels are expected to be used as a long life cladding in the future advanced fast reactor. Comparing to the other steels, ODS steels have excellent resistance to creep and swelling as well as superior mechanical strength [1-4]. Applications of ODS steels grow faster in nuclear engineering society; however, not so many studies have been made for improving weld properties. 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 joining traditionally difficult to join materials such as aluminum alloys. This relatively new technology, first developed in 1991, has more recently been applied to higher melting temperature alloys such as steels, nickel-based and titanium alloys [10-12]. In this study, FSW is used as a substitutive welding process for ferritic ODS steels, solid state microstructure modification is performed. 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 was found to be influenced by the rotational behavior of the tool. The response of material for different process variables have been discussed in terms of plastic deformation amount and heat input.

2. Methods and Results

The 1 mm thick ferritic ODS steel sheets were locally friction stirred at a tool rotation speed of 800 - 1500 rpm. Tools are made of refractory metals and hard crystalline ceramics, polycrystalline cubic boron nitride (PCBN). Surface-modified region exists directly under the trace of the FSW tool movement. Tensile test specimens with a gauge length of 25 mm were prepared for both the surface-modified region and the base material. Tensile direction of the surface-modified

(a)



(b)

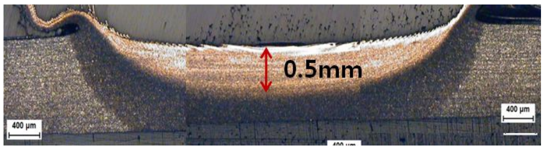


Figure 1. (a) A schematic of the process of joining two plates. (b) Cross section image of FSWed FM steel plates.

region was parallel to the advancing direction of the tool. Crosshead speed was 2.0 mm/min for the tensile test.

A schematic of the process of joining two plates is shown in Figure 1(a). The sheets were fixed by clamps and backing plate. 5mm diameter tool was used to generate frictional heat for joining. The stir zone and surrounding materials consist of four distinct zones. The cross-section image of FSWed plates are shown in Figure 1(b). The first is the base material, which is the area unaffected by the weld. A second zone, called the heat-affected zone (HAZ), exists where plastic deformation does not occur but the microstructure still changes due to heating of the material. The area where plastic deformation has occurred is called the thermo-mechanically affected zone (TMAZ), and if recrystallization has also occurred, it is referred to more specifically as the weld zone (WZ). The specific nature of the microstructure will depend greatly on the welding parameters which need to be optimized to obtain the best joint quality for each type of material being welded. During FSW, it is believed that a large

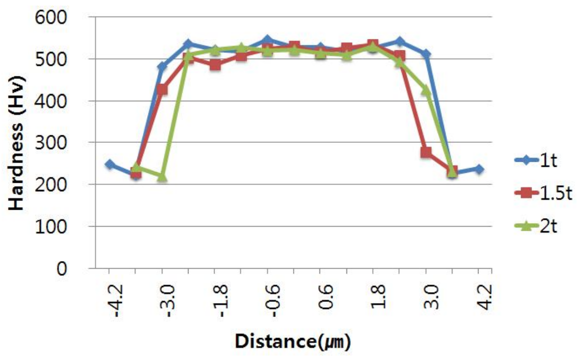


Figure 2. Hardness profile near the WZ (FM steel).

strain was generated in this region during the FSW processing where deformation heterogeneities facilitated the onset of recrystallization. This also suggests that any inhomogeneity of stored energy would affect the nucleation of recrystallization.

It was observed that much finer recrystallized grains were formed along the top of the weld region, this may have been an effect due to the cooling rate or may be a local effect attributable to the shoulder of the FSW tool local to the sample surface, introducing local deformation heterogeneity which provides numerous nucleation sits for recrystallization.

In figure 2, the hardness profile across the heat affected zone and welds is described. Normally, the hardness would be lower in the WZ, because that region is recrystallized. However, it is observed that the hardness of WZ was twice as much as the HAZ regardless of the plate thickness. It suggests that strain hardening effect was stronger than recrystallization effect during FSW. The mechanical properties of WZ is suspected to be enhanced because of those strain hardening and grain size refinement effects. It is observed that fine equiaxed grain structure mainly separated by high angle grain boundaries in WZ. This suggests that the elongated grains can be dynamically recrystallized to a sub-micron primary recrystallised grain size during the FSW process. The stirring action of the rotating welding tool generates a shear deformation texture, which corresponds to rotation of grains in the surrounding materials. (111)<112> and (111)<110> textures predominate in the WZ where the grains rotate in response to the preferred orientation.

3. Conclusions

Friction stir welding appears to be a very promising technique for the joining of ODS materials in the form of sheet and tube. EBSD analysis confirms that low angle grain boundary migration occurs during recovery and high angle grain boundary migration occurs during recrystallization. Alloy microstructures in friction stirred samples, observed by TEM, suggested that the oxide particles were uniformly distributed by friction stirring but that the grain boundaries in the parent metal were pinned by particles. Friction stirring appeared to release these boundaries and allowed secondary recrystallization to occur after further heat treatment.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2012M2A8A1027872).

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