Trends in Friction Stir Welding Research in Japan on Microstructural Characterization

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ABSTRACT Researches on microstructural evolution and characteristics during friction stir welding of aluminum, magnesium alloys and stainless steels were introduced reviewing recent studies done by the author's group at Tohoku University in Japan.

1. Introduction

Friction Stir Welding (FSW) is a new solid-state welding process which was invented at The Welding Institute (TWI) in 1991 [1]. The process can achieve butt-welding utilizing frictional heating and intensive plastic deformation as schematically shown in Fig. 1. Many advantages of FSW have been demonstrated on weldability and mechanical properties especially for aluminum (Al) alloys as compared to arc welding. The microstructures of fraction stir (FS) welds have been also investigated relating to the various properties. This paper discusses the microstructural characterization of FS welds for Al, magnesium (Mg) alloys and stainless steels by reviewing our recent studies [2-20].

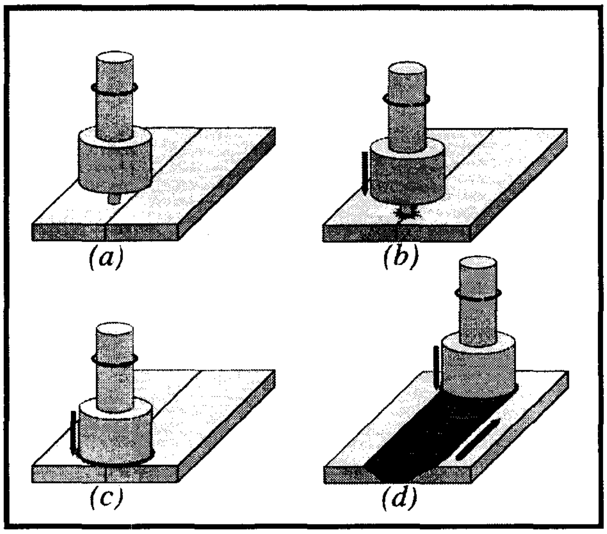

Fig. 1 Schematic illustration of FSW process.

2. Microstructural Characteristics

2.1 Microstructure Distribution

A typical cross-sectional view of Al alloy 2014A-T6 is shown in Fig. 2 [21]. The microstructural regions in the FSW butt joint are generally notated as unaffected (base) material zone (A), thermally (heat) affected zone (HAZ) (B), thermo-mechanically affected zone (TMAZ) (C) and stir zone (SZ) (dynamically recrystallised zone or weld nugget) (D) as indicated in Fig. 2(b). The microstructures in SZ and TMAZ are characterized by recrystallization and recovery, respectively, as shown in Fig. 3 [7].

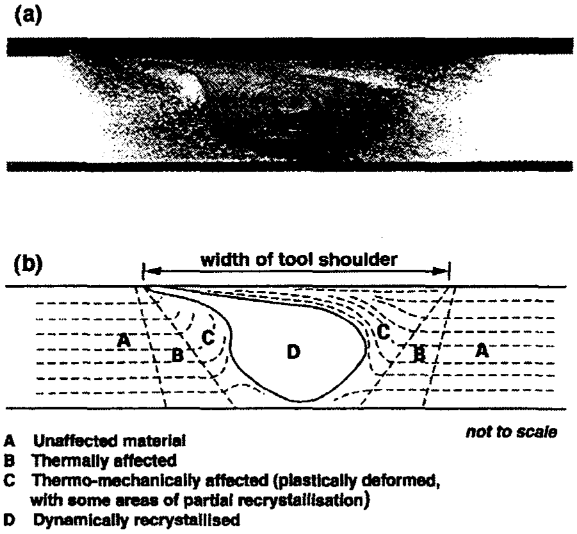

Fig. 2 Microstructural regions in an FS weld [21].

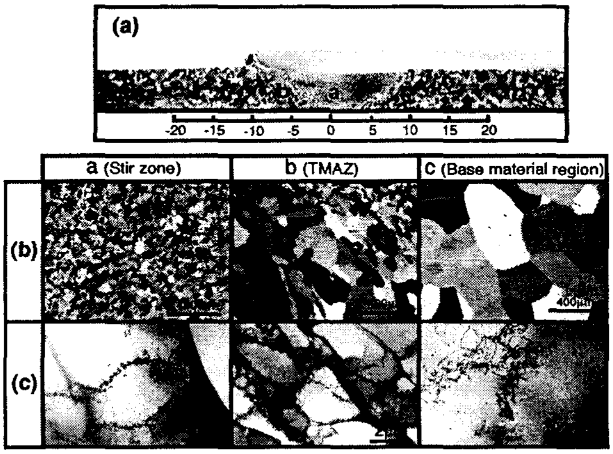

Fig. 3 Microstructures in FSWed 1080 Al [7].

2.2 Fine-Grained Structure in SZ

FSW produces fine-grained structures in the SZ. The hardness and strength are affected by the grain size which can be controlled by the FSW parameters [5-9]. The grain size and hardness of SZ in pure metals and solid-solution-hardened alloys obeys the Hall-Petch relationship [7,13,15] as shown in Fig. 4. The grain-refining by FSW can suppress the softening during welding of ultra-fine grain strengthened materials produced by equal-channel angular pressing (ECAP) [5.9.12,13] and accumulative roll-bonding (ARB) [16], as shown in Fig. 5. The pore-free, homogeneous, fine-grained microstructure in SZ can also improve the post-weld formability [15,18].

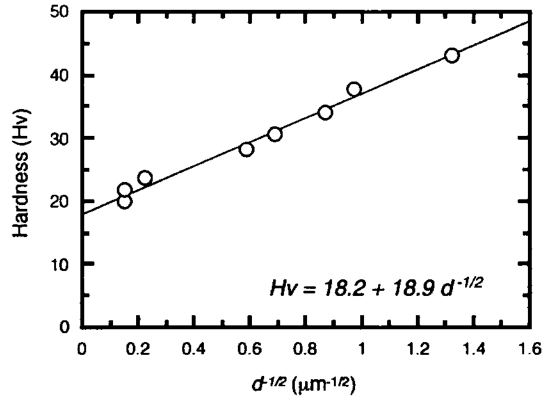

Fig. 4 The relationship between grain size and hardness in the SZ of FSWed 1050 Al [13].

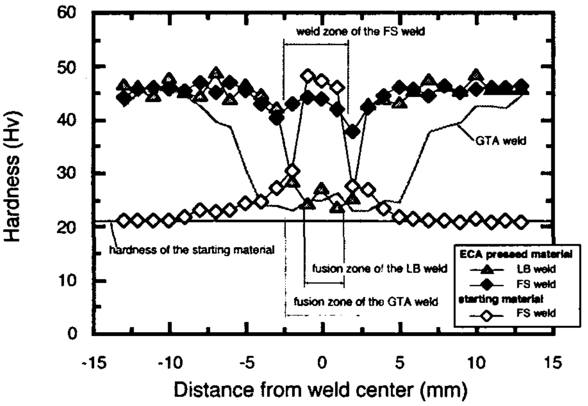

Fig. 5 Hardness distributions in ECAPed 1050 Al after GTAW, LBW and FSW [5].

2.3 Precipitation and Dissolution

Precipitation-hardened Al alloys soften during FSW. Fig. 6 shows the hardness distribution in FSWed 6063 Al alloy [2]. The hardness distribution can be explained by dissolution and coarsening of fine precipitates depending on the local thermal hysteresis, as shown in Fig. 7. Post-weld aging can re-precipitate fine particles and recover the hardness well in the weld because of compositionally homogeneous SZ [3], compared with fusion welds. But we have to note that too fine grain structure in SZ increases the volume fraction of precipitation-free zone along grain boundaries during past-weld aging and prevents the hardness recovery [8]. During FSW of 304 austenitic stainless steel, sigma formation was observed in the SZ as shown in Fig. 8, which suggests that the intense deformation accelerates phase transformation [14,20].

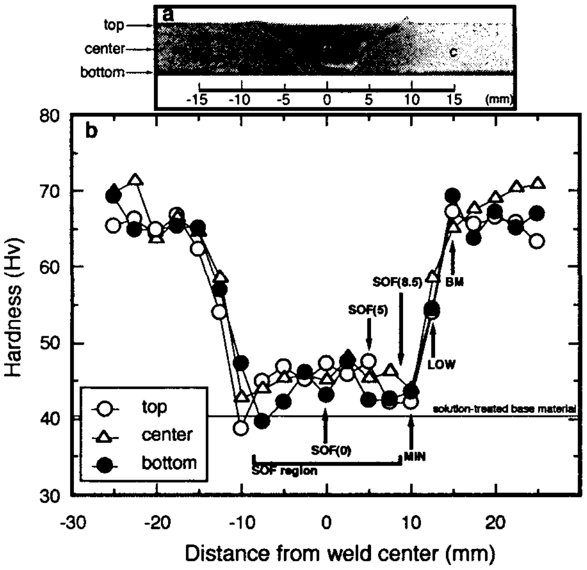

Fig. 6 Hardness distributions in FSWed 6063 Al [2].

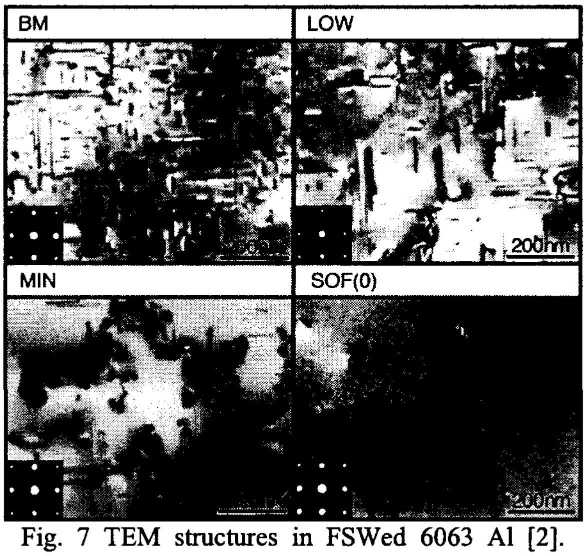

Fig. 7 TEM structures in FSWed 6063 Al [2].

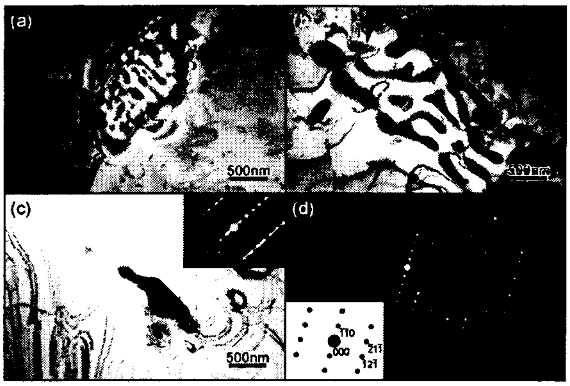

Fig. 8 Sigma in FSWed 304 stainless steel [14].

2.4 Microtexture Distribution

Orientation imaging microscopy (OIM) studies of FS welds has suggested that shear texture components were induced by the shear plastic flow along the rotating tool pin surface during FSW [4]. The microtextures are characterized as slip planes rotating around the tool pin, especially the microtexture of basal slip planes distributes ellipsoidally in the SZ of FSWed Mg alloy, corresponding to "onion ring" as schematically illustrated in Fig. 9 [10]. The microtexture can affect mechanical properties of FS welds [11].

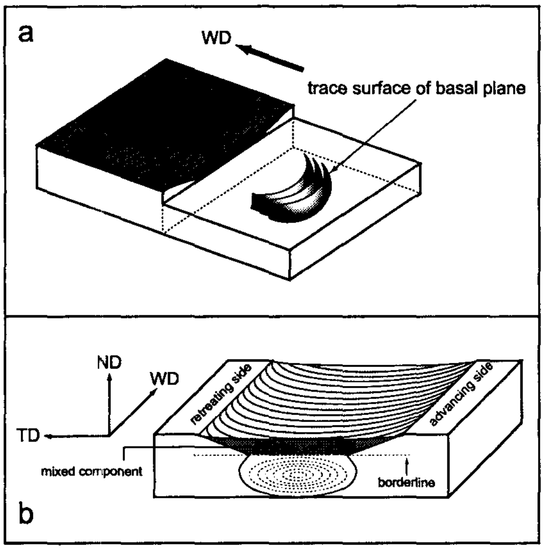

Fig. 9 Ellipsoidal distribution of basal planes in FSWed AZ61 Mg alloy [10].

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