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# Fatigue behaviour of friction stir welds without neither welding flash nor flaw in several aluminium alloys

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ABSTRACT

Fully reversed axial fatigue tests have been performed in order to investigate the fatigue behaviour in the friction stir welds of 1050-O, 5083-O, 6061-T6 and 7075-T6 aluminium alloys. In all alloys, the comparative studies on the fatigue behaviour between parent materials and welds have been done. The fatigue behaviour of the welds was sensitive to the microstructures such as stir zone, thermo-mechanically affected zone and heat affected zone. The fatigue strengths of the welds are comparative to or lower than those of the parent materials. The observed fatigue strengths were discussed based on the microstructure and crack initiation behaviour.



## 1. Introduction

Friction stir welding (FSW) is a solid state welding process developed by TWI in 1991, and now being used increasingly for joining aluminium alloys for which fusion welding is often difficult. FSW uses a rotating cylindrical tool with a probe travelling along the weld path, and plastically deforming the surrounding material to form the weld. Since the material subjected to FSW does not melt and recast, the resultant weld offers advantages over conventional fusion welds such as better retention of baseline mechanical properties, less distortion, lower residual stresses and fewer weld defects. The FSW process is summarized in Refs. [1,2].

During FSW process, the rotating tool induces a complex deformation in the surrounding material that varies depending on the joining materials and welding conditions. Recrystallization of the microstructure takes place under severe plastic strain and elevated temperature due to FSW process, usually resulting in a very fine-grained structure in the weld zone. The microstructures of FSWed 1xxx [3,4], 5xxx [3], 6xxx [5] and 7xxx [6,7] series aluminium alloys were investigated in detail in some literatures. It is therefore expected that the complicated microstructure around the weld zone would strongly govern the fatigue properties of FS welds. There are several studies focusing on the fatigue behaviour of the FS welds with welding flash [8,12,17] or flaws such as void or "kissing bond" [9–11,13–16]. In those papers, crack initiation was not governed by the microstructures around the weld zone but by the stress concentration at the flash or flaws. In order to highlight the effect of a complex microstructure on the fatigue behaviour of FS welds, fatigue tests should be conducted using specimens without welding flash nor flaw. Although, in some papers, the upper surface was milled off to remove welding flash, cracks still initiated at voids [9,11] or root flaws [13–16]. Ali et al. [18] reported that fatigue crack nuclei were located within the nugget of mirror polished 2024-T3 FS welds, and Kainuma et al. [17] showed crack initiated in the parent material of A6N01 S-T6 FS welds. Cavaliere et al. conducted fatigue tests using 6082-T6 FS welds [19] and 2024-7075 dissimilar FS ones [20] without welding flash, and discussed the effect of welding parameters on microstructure and fatigue properties. They found fatigue fracture occurred in the advancing side of the tool in 6082-T6 FS welds. However, the effect of microstructure on the fatigue behaviour and fatigue strength of FS welds is not clear. Furthermore, Lomolinoa et al. [12] evaluated the fatigue strengths of several aluminium alloys and showed the strength was dependent on the alloy systems. Thus it is important to understand the fatigue behaviour of several aluminium alloys such as nonheat-treatable or heat-treatable alloys.

In the present study, the fatigue behaviour of the FS welds of 1050-O, 5083-O, 6061-T6 and 7075-T6 aluminium alloys was investigated. Fatigue tests were conducted using the parent

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**Table 1**
Chemical composition of materials (wt.%).

| | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| 1050 | 0.07 | 0.34 | 0.02 | – | – | – | 0.01 | 0.02 | Bal. |
| 5083 | 0.13 | 0.26 | 0.04 | 0.56 | 4.6 | 0.1 | 0.03 | 0.04 | Bal. |
| 6061 | 0.58 | 0.41 | 0.28 | 0.03 | 0.96 | 0.23 | 0.02 | 0.04 | Bal. |
| 7075 | 0.09 | 0.24 | 1.53 | 0.05 | 2.58 | 0.19 | 5.67 | 0.03 | Bal. |

materials and the welds at a stress ratio $R = -1$ under axial loading. The upper and lower surfaces of all welds were milled off in order to eliminate the stress concentration induced by the welding flash or root flaw, and the effects of microstructure on the fatigue behaviour was discussed.

## 2. Experimental details

### 2.1. Materials and specimen configuration

Four different parent materials were friction stir welded to themselves. The materials are 1050-O, 5083-O, 6061-T6 and 7075-T6 aluminium alloys whose chemical compositions (wt.%) are listed in Table 1. 1050 and 5083 are nonheat-treatable and 6061 and 7075 are heat-treatable alloys. All alloys are rolled plates with the size of 77 mm × 400 mm and 5 mm thick. The microstructures of the parent materials are shown in Fig. 1. Grains are elongated due to the rolling process in 5083-O, 6061-T6 and 7075-T6, while not in 1050-O. The average grain size measured on the rolling plane is about 36 μm, 28 μm, 43 μm and 43 μm for 1050-O,

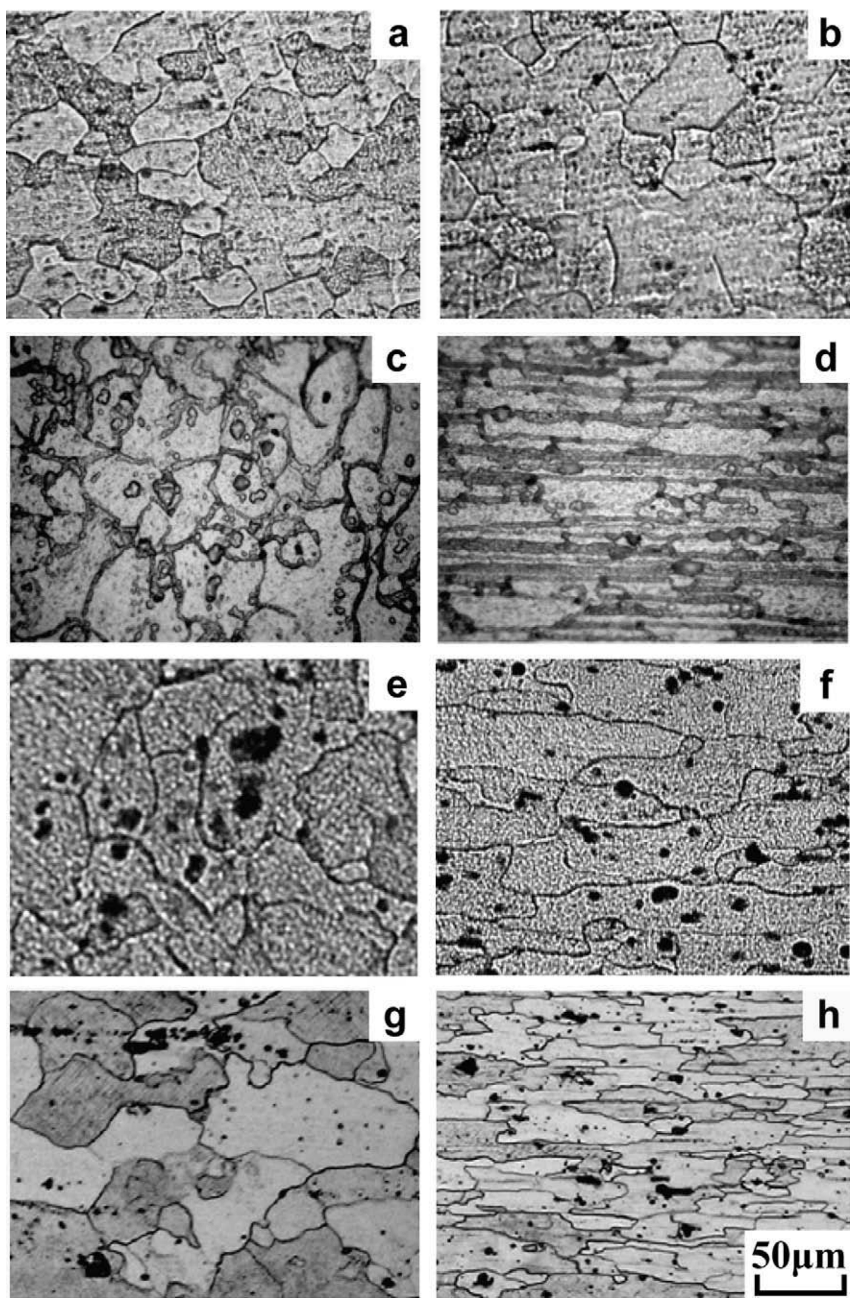


**Fig. 1.** Microstructures of parent materials: (a) 1050-O, rolling plane, (b) 1050-O, cross section, (c) 5083-O, rolling plane, (d) 5083-O, cross section, (e) 6061-T6, rolling plane, (f) 6061-T6, cross section, (g) 7075-T6, rolling plan, and (h) 7075-T6, cross section.