Effect of tool eccentricity on the properties of friction stir welded AA6061 aluminum alloys

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Abstract
This paper investigates the effect of tool eccentricity on material flow of friction stir welded (FSW) AA6061 aluminum alloy. Samples were butt joined using a threaded conical shaped tool pin with 1200 rpm rotational speed and 63 mm/min travel speed with and without 0.2 mm tool offset. A 0.1 mm thin Al foil was inserted at the faying surface prior to welding process to enhance the observation of faying surface material flow. Results show that tool eccentricity enhances nugget zone’s material flow. Evidence show upward and horizontal expansion of the soft region in the nugget zone due to the eccentric setup. In addition, the pin-driven region of the nugget zone experiences increased softening with the soft region expanding upwards owing to the eccentric setup. However, tensile tests have shown minimal effect of the tool eccentricity to the strength and elongation of the weld joint. It can be concluded that the tool eccentric motion due to the 0.2 mm tool offset can enhance material flow in the nugget zone and expand the soft region of the nugget zone, but has shown no effect on the mechanical properties of AA6061 alloy.

1. Introduction
Friction stir welding (FSW) was invented in The Welding Institute (TWI), United Kingdom in 1991 [1]. Due to the simplicity of the welding operation, since then, the application of this process has been growing exponentially in various sectors such as aerospace, ship building, automotive and structural industry [2,3]. The method exploits heat created from friction between the FSW tool and the workpiece to join materials together by rapid rotation of the tool while traversing along the abutting edges. Advantages of this method includes non-toxicity, low operational cost, and increase in productivity [4].

Tool eccentricity during rotation, i.e. rotation of a tool not fixed on a rotational axis due to tool holder thread wear or improper fit-up of tool is a common phenomenon which is rarely discussed. The improper setup creates a minute ‘wobbling’ at a certain amplitude with each full rotation. Although the oscillation is small and well below the acceptable tolerance limit for common milling operations, Reynolds have argued that even a small tool runout may strongly affect the actual tool advancing rate [5]. Fonda et al. have also demonstrated that the tool oscillation can generate a periodic extrusion of material around the tool and induce reversals of the local shear texture orientations [6]. In addition, Gratecap et al. have suggested that tool eccentricity of 0.03 mm generated oscillatory movement which lead to a discontinuous welding process. They attributed the origin of the eccentric movement to the FSW tool attachment in the tool holder and/or the different transverse forces from the two sides of the weld [7].

Even so, data pertaining to the effect of tool eccentricity on the overall properties of material is scarce. Mao et al. reported the effect of pin eccentricity on FSWed AA7075 aluminum alloy by fabricating the pin to offset the shoulder centerline up to 0.4 mm. They suggested that pin eccentricity of 0.2 mm produces highest tensile strength and elongation due to better interfaces, finer grains and more dispersive secondary phase particles [8]. However, to date, no study has been done to determine the microstructural and mechanical effect of tool eccentricity, i.e. simultaneous wobbling of the tool pin and shoulder, which is a more common phenomenon. This study investigates the effect of tool eccentricity on the microstructural and mechanical properties of friction stir welds in heat-treatable AA6061 aluminum alloy.