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Effect of tool edge geometry in ultrasonic welding

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ABSTRACT

Ultrasonic vibration was applied to a single AA1050 aluminum sheet, and relative motion between a weld tool and a specimen during ultrasonic welding was assessed. Weld tools with different knurled edges such as a trapezoidal pattern edge (trapezoidal edge) and a serrated pattern edge (serrated edge) were prepared in this study to investigate the effect of tool edge geometry on weld microstructure. Relative motion behaviors between weld tools and a specimen were analyzed with a high-speed camera and digital image correlation. A large difference was observed under the normal force of 588 N. In this condition, relative amplitude of the serrated edge was larger than that of the trapezoidal edge, and the penetration of the serrated edge was lower than that of the trapezoidal edge. In the serrated edge, plastic flow in the microstructure occurred because of a greater temperature rise. The strength of the joints welded using the serrated edge was greater than that using the trapezoidal edge. In addition, although smaller relative vibration was observed in both of the tool edges as the normal force increased, the serrated edge showed higher joint strength. These phenomena are discussed and related to the relative amplitude and penetration depth. It is suggested that the bonded area was enlarged by the plastic flow, thereby increasing joint strength.

1. Introduction

Ultrasonic welding is a solid-state metal-bonding process in which sheet metals are welded under a normal force and a high-frequency vibration generated by an ultrasonic horn. Because of a short process time and non-flux characteristic of this process, it is used for wire-bonding techniques in the semiconductor industry and for bonding the electrodes of secondary batteries in the automobile industry. The bond microstructure is formed by a solid-state bonding process: interface adhesion, mechanical removal of an oxide film, and formation of a new surface by ultrasonic vibration. Thus, relative motion (caused by vibration) between welded metals is an important factor in ultrasonic welding. A number of researches have been conducted focusing on the interfacial phenomena. Krzanowski and Murdeshwar (1990) observed behavior of dislocation at the weld interface in ultrasonic wire bonding using TEM, and found that dynamic annealing of bonded area was induced by local heating and deformation. Elangovan et al. (2008) proposed a FEA model for ultrasonic welding based on heat generation caused by interfacial friction and deformation. Bakavos and Prangnell (2010) discussed a development of weld microstructure in 6000 series aluminum ultrasonic welding. The study revealed that microwelds initiated in the early stage of welding developed with plastic flow. Fujii et al. (2011) made microstructural analysis of multilayered aluminum alloy builds processed by "very high power ultrasonic additive manufacturing", and revealed that shear deformation of the microwelds caused temperature rise. In addition, Panteli et al. (2012) performed dissimilar joining of AA6111 and AZ31 alloys using a high power ultrasonic welding, and studied interfacial reaction. They confirmed that the temperature rise by the high strain rate deformation resulted in melting of eutectic phase. Shimizu et al. (2014) observed growth of the microwelds in the ultrasonic additive manufacturing of AA6061 alloy. This research indicated that oxide layers are squeezed out during welding, then those are clustered at some points of the weld interface or in voids.

Relative motion, on the other hand, also occurs between the welding material and the horn tip in contact with the material. Weld tools are attached to the horn tip and an anvil. Relative motion at the tool/weld material interface becomes predominant when the motion is constrained by the formation of bond structure. In our previous research (Sasaki et al., 2013), we found that relative motion at the tool/weld material interface causes a temperature increase, resulting in the softening of the entire weld. In addition, plastic flow attributed to the softening significantly

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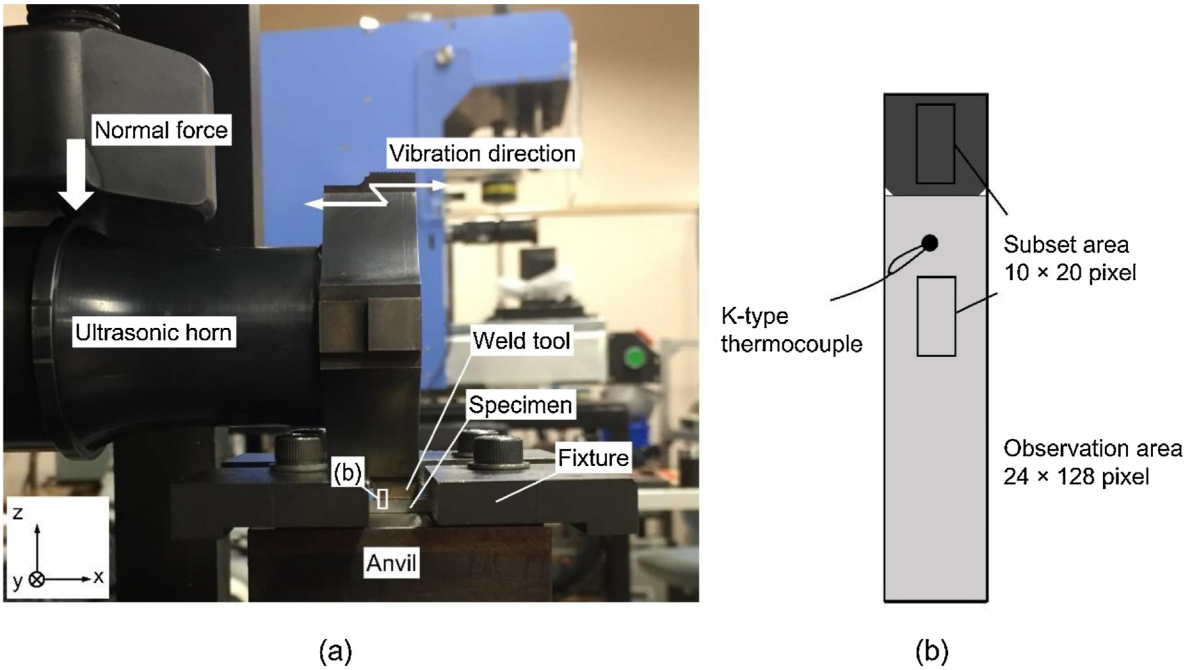
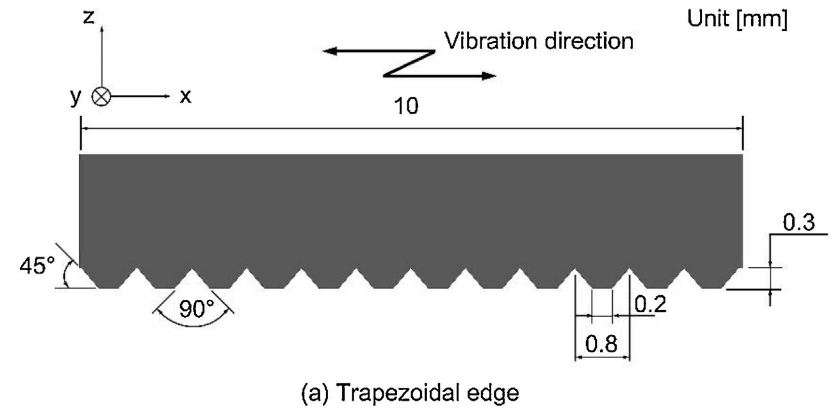
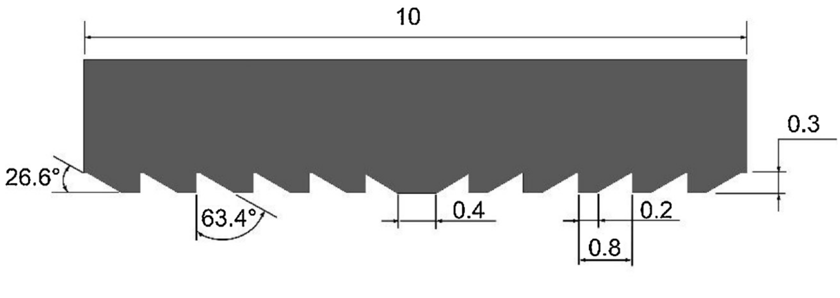


Fig. 1. Photograph of the vibration test: (a) the ultrasonic welding machine, and (b) the observation area and positions of subset areas for displacement analysis.

increases joint strength. The surface of a weld tool is generally machined into a knurled surface with pyramid-like edges to suppress slippage between the tool and the welding material. Jahn et al. (2007) performed the ultrasonic welding using anvils with different knurled patterns, and indicated the effect of anvil geometry on weld microstructure. Watanabe et al. (2010) revealed that a weld tool with round shape (without knurled edge) significantly improved joint strength. Lum et al. (2006) proposed a model to explain the relation between the microstructure and a "weld footprint" formed on the weld material by the tool edge. Moreover, Takahashi et al. (2012) analyzed stress distribution at weld interface in ultrasonic wire bonding using FEM and found that the stress concentrates at the weld interface, just below the edge, and the weld begins to form at this stress-concentrated area. These previous researches



(a) Trapezoidal edge



(b) Serrated edge

Fig. 2. Tool surface geometries of (a) the trapezoidal edge and (b) the serrated edge.