The Influence of Dynamics and Vibrational Characteristics on Weldability of Joining Metals Ultrasonically

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Abstract—Most of engineering processes are significantly affected due to changes in its dynamics and vibrational characteristics during operation. Such one of these processes is welding which the process is carried out on join metals by using suitable manner like welding by ultrasonic technique. The ultrasonic technique has ability to joint parts without need to use any aided, and then this allow the technique to become more reliable and applicable. The technique is mostly provide proper weld, but the weldability of joining similar parts may affects due to any change in vibrational characteristics during operation. This study presents the design, characterisation and test of a lateral-drive ultrasonic metal spot welding device. The ultrasonic metal spot welding horn is modelled using finite element analysis (FEA) and its vibration behaviour is characterised experimentally to ensure ultrasonic energy is delivered effectively to the weld coupon. The weldability is examined through examining weld strength using tensile-shear tests. The results show how the weldability is particularly sensitive to the combination of ultrasonic parameters such as welding force and displacement amplitude.

Keywords—Ultrasonic technique, vibrational characteristics, weldability of joining metals, ultrasonic parameters.
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1. Introduction

ULTRASONIC welding can be defined as a solid-state joining process in which materials are held together by a normal force whilst a high-frequency shear vibration is applied. During this process the vibration deforms, shears, and flattens surface asperities, scatters interstitial oxides and contaminants, and increases the contact area of the parts being welded [1]. The first demonstration of ultrasonic welding was in the early 1950s and was limited to grain refinement and soldering [2], but now the technique can be applied to various softer metals, such as copper and aluminium, as well as harder metals [3]. Ultrasonic welding has become an efficient joining technique for many industrial and scientific applications, using lighter and more versatile equipment to produce a stronger, smaller, and more precise weld [2]. Furthermore, ultrasonic welding does not require any solder or filler and therefore has some associated environmental and economic benefits [4].

Ultrasonic welding systems consist of a power supply, transducer, booster, horn and anvil, Fig.1. The horn is tuned to operate in the longitudinal mode but imprecise design can affect the dynamic characteristics of the device, reducing both vibration amplitude and weld quality. In this study, two investigations have been carried out to improve weldability; numerical design and subsequent experimental characterisation of an integrated ultrasonic spot welding horn to enhance the vibration characteristics at the welding surface, and secondly an experimental study of the effects of process parameters on the weld itself, considering issues such as tool/workpiece adhesion and weld quality. The weld strength is characterised experimentally in terms of the results of repeated tensile shear tests.

2. Design and Characterisation of the Welding System

2.1 Numerical Design of the Ultrasonic Spot Welding Horn

A lateral-drive system has been used to investigate ultrasonic metal spot welding because it can produce high amplitude vibration but yet apply the low forces necessary to weld thinner parts [5]. Several factors are considered in the design of such an ultrasonic horn including resonant frequency, frequency separation, amplitude amplification, amplitude uniformity and stress concentration. High amplification and low stress are obtained through the use of a catenoidal horn, the horn being modelled as steel to take advantage of its high fatigue strength and good wear qualities. An integrated welding tip with knurled welding flats 6 mm in diameter is employed, the horn being clamped at the nodal plane as shown in Fig. 2 (a). This horn is modelled in the FEA package, Abaqus, and a harmonic analysis is carried out through the application of an excitation vibration to the base, to extract the shape of the operating vibration mode and those of some of the surrounding modes.

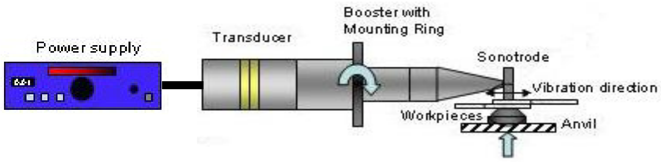
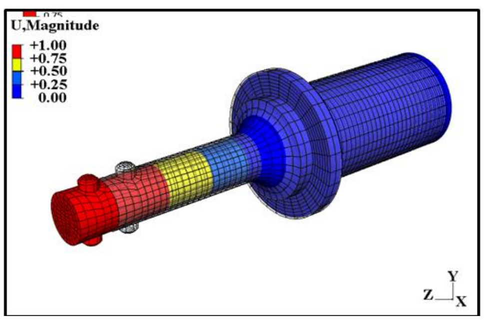


Fig. 1 Main Components of USMW system

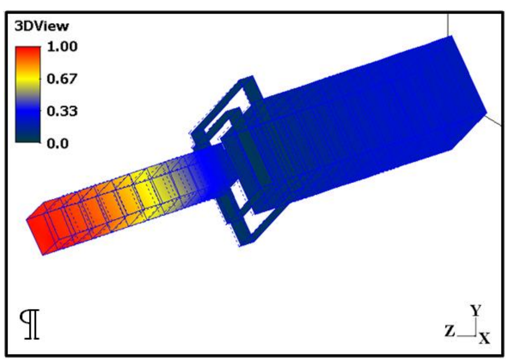
2.2 Experimental Characterisation of the Ultrasonic Spot Welding Horn

The numerical results are compared to the results of an Experimental Modal Analysis (EMA), shown in Fig. 2 (b), carried out using a Polytec 3D-Laser Vibrometer and random excitation over a frequency range from 0 to 40 kHz. The amplifications, resonant frequencies and mode shapes of the horn are found to be in agreement and the system is therefore considered to operate as designed.



(a)

Numerical shapes of the longitudinal (20.59 kHz) mode



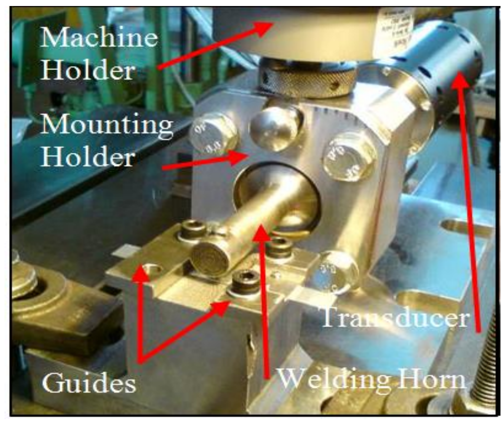
(b)

Fig. 2 EMA shapes of the longitudinal (20.59 kHz) mode

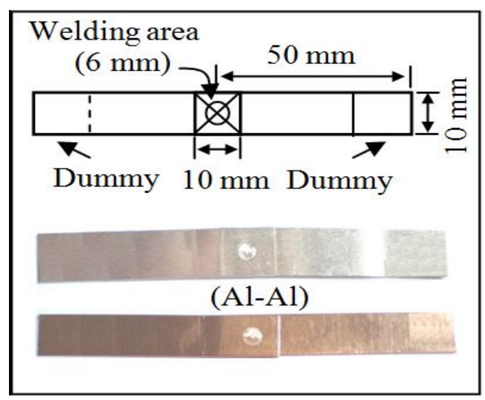
3. Welding Experiments

3.1 Experimental Set Up

A 1 kW ultrasonic generator (Sonic Systems L500/3-20) is used to drive the transducer and hence the welding horn, known together as the welding stack. A tensile test machine (Zwick Roell) is employed to secure the stack by holding it at the nodal plane, as shown in Fig. 3 (a), and also to measure the clamping force and weld time. The 5 mm knurled flat contacts the upper specimen during welding, while the lower specimen is secured by a knurled anvil. The specimens themselves are 0.1 mm and 0.5 mm thick aluminium and copper strips, as shown in Fig. 3 (b), and their properties are obtained from ASTM [6] and BSI [7] codes. Five tensile tests at each set of weld conditions are carried out, the results are averaged, and the standard deviation for the tests is obtained. Tests of both similar and dissimilar metals and of different thicknesses, are performed with different arrangement or stacking order. Several tests are also carried out to ameliorate the problem of horn sticking.



(a)



(b)

Fig. 3 Experimental set up of welding tools, knurled surfaces, specimen layout and welded coupons

3.2 The Effect of Process Parameters on Weld Strength in Similar Materials

Fig. 4 shows the average measured values of weld strength against clamping force applied for various welds with different vibrational amplitudes and specimen thicknesses. The error bars represent one standard deviation of the five tests for each parameter set. Welding strength is seen to increase with clamping force although it is noted that excessive clamping force may generate high friction and suppress the relative motion of the surfaces, resulting in reduced weld strength [8]. Al-Al welds appear to be slightly stronger than Cu-Cu welds created under identical process parameters, regardless of sample thickness. Scattering of weld strength across the five tests tends to become proportionally smaller as clamping force is increased.

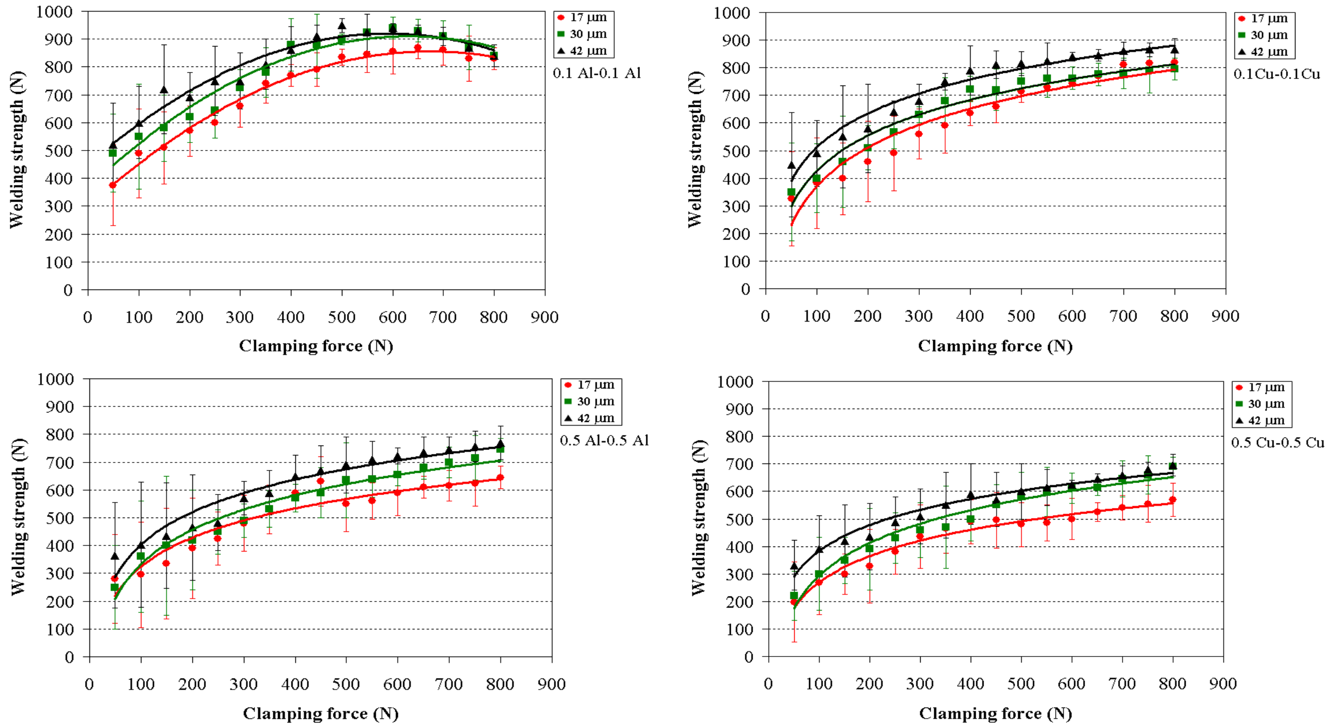


Fig. 4 Variation of weldability strength vs. clamping force for joining similar materials

4. Conclusions

Design and fabrication of a lateral-drive ultrasonic spot welding system has been carried out to investigate the welding of thin metal strips. It has been observed that vibration amplitude, clamping force and, in some circumstances, material arrangement order, have a significant effect on weld strength. Al-Al welds are stronger than Cu-Cu welds and weld strength in both cases tends to increase with clamping force within the range of forces examined. In general, there is a decrease in weld strength when clamping forces above approximately 500 N are applied, which directly influenced on the weldability of joining metlas.

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