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INVESTIGATION ON THE USE OF POWER ULTRASONIC TO IMPROVE THE LASER WELDING OF ALUMINIUM ALLOYS

[1]AHMED TEYEB, [2]PREMESH S. LOWE, [3]JAMIL KANFOUD, [4]TAT-HEAN GAN

[1,2,3,4]Brunel Innovation Centre, Brunel University, Uxbridge, UB8 3PH, United Kingdom
E-mail: [4]Tat-Hean.Gan@brunel.ac.uk

Abstract- There is a rising interest on the autonomous laser welding of Aluminium alloys due to the quality of the weld, productivity and the simplicity of implementation. Unlike high grade alloys (*i.e.* Al 1100 which has excellent weldability), laser welding of low grade Alloys (*i.e.* Al 6063 which has poor weldability) has a higher demand due to material strength and cost benefits. However, laser welding of Alloys such as Al 6063 are challenging due to the material composition which has a poor weldability. Current study investigates the possibility of using high power ultrasonic during the laser welding process, to reduce voids during solidification and optimize the laser welding process. A finite element-based numerical study was undertaken to evaluate the propagation of ultrasonic waves and their interaction with the incremental weld seam. The plate sample (before joining) used in this study is a 300 x 150 x 3 mm (height, width and thickness respectively). A parametric study was conducted to obtain the resonant frequency of the sample plate and the optimum power level in order to tune the power ultrasonic system. A 3-D laser Doppler vibrometry experiment was conducted to validate the finite element results. There is a good agreement between numerical and experimental results. Based on the results, 40 kHz 60 W transducers need to be used for ultrasonication in order to improve the laser welding of Al 6063 using power ultrasonic. Furthermore, transducer topology was also investigated in order to optimize the system performance.

Keywords- Manufacturing optimization, laser welding, power ultrasonic, solidification, Aluminium alloys, porosities

I. INTRODUCTION

Welding of high strength aluminum alloys is generally a delicate operation due to the degradation of the mechanical properties in the Thermally Affected Zone (TAZ) and the presence of porosities in the molten metal. In addition, some of these aluminum alloys are categorized as "non-weldable". In TAZ, the mechanical properties can be reduced by up to 50% compared to the nominal values, depending on the welded alloy and the process used[1].

A laser beam is an extremely concentrated light, which makes it possible to achieve very large values of power per unit of impact surface. When a laser falls on a metal surface, a large proportion is absorbed. Considering the Skin Effect of skin, characterizing the depth of penetration of an electromagnetic wave in a metal, inversely proportional to the frequency and very small for the metals (of the order of one nanometer), most of the power is located around the point of impact, causing the region around it to fuse [2].

Laser welding is a high-energy welding process. Unlike heat conduction welding (*i.e.*arc-welding), the laser beam can provide a very high energy density. This characteristic makes it possible to obtain the formation of a capillary filled with metallic vapors. A bath of molten metal develops around this capillary. The relative displacement of the latter causes the formation of a welded joint [2-3]. This is due to the thermal energy is distributed either on the surface but on the full depth of this "hole" filled with fused metal vapor.

Power ultrasound is often selected for material processing and to some extent in synthesis, owing to its strong physical shear and intense local temperature effects [5]. It is characterized by large bubble resonance sizes followed by intense bubble collapse, often resulting in extremely strong physical effects. This category of ultrasound delivers high energy density in the order of 10–1000 W/cm^2[4,5,9-12].

The ultrasound frequency regime ranges from 16 kHz to 500 MHz, although the frequency range most suitable for processing fluid and semi fluid phase material is typically between 16 and 3000 kHz[4]. When ultrasound is applied to fluids the cavitation effects are highly dependent on the frequency. The intensity of bubble collapse (*i.e.* amount of energy released) and the maximum bubble size prior to collapse (resonance size) are correlated and approximately inversely proportional to the applied frequency [6-6].

Krajewski*et al.*reported the use of ultrasonic vibrations on TIG and MIG methods for process improvements [3]. The experiment included surface-welding and fusing on a 2017A Aluminium alloy waveguide in the form of a cylinder 0.045m in diameter and 0.254 m long using the MIG and TIG methods. The waveguide length was selected so that it was equal to 1λ wavelength (corresponding to a vibration frequency of 20 kHz). The study had the comparative character *i.e.* the structure and hardness of the various welds obtained with and without the participation of ultrasonic vibrations were compared [3].

A typical ultrasonic system is a sequential assembly of four major components: generator, transducer, booster, and horn. When integrated to each other, generates and subsequently transfers ultrasonic vibrations to a desired location of metal during a manufacturing process[6].These components are integrated in a predesignated manner to achieve a desired ultrasonic power transfer efficiency. Efficient transfer of ultrasonic power is extremely vital and depends upon the elaborated and in depth design of the ultrasonic components. The design and selection of component materials depend upon the intended area of ultrasonic application. Detailed knowledge of each component is vital for robust designs and desired results.

Typical ultrasonic frequencies range from 20 to 200 kHz. Due to physical size limitations of the magnetostrictive transducer it is inherently limited to operate at frequencies below approximately 30 kHz[6]. Piezoelectric transducers are not frequency limited within this range. The manufacturer can choose the appropriate piezoelectric design and drive it at a selected output frequency over the entire ultrasonic range by utilizing harmonic multiples of the primary resonant frequency. This makes piezoelectric transducers a more versatile choice from the standpoint of frequencies available.

The aim of this work is the investigation of the use of power Ultrasonic as a potential tool to assist the Laser Welding process of high-graded Aluminum alloys.The manuscript is outlined as follow, conducted numerical analysis and results are reported in Section 2, then the experimental validation in Section 3, followed by the conclusions in Section4.

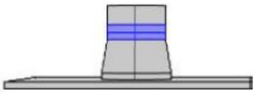
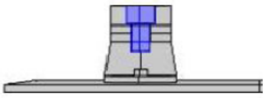
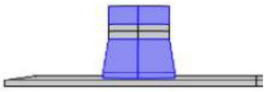
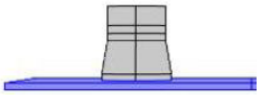
II. NUMERICAL MODELLING

COMSOL Multiphysics is used to run the simulations. It is a powerful tool that couples solid mechanics to piezoelectric modules, required for this investigation. It allows conduct different numerical analysis *i.e.* frequency domain, time domain, modal analysis.

The geometry of the transducer was created on x-z plane and revolved to produce the solid model. The dimensions used for the transducer was that of a typical 40 kHz Langevin bolt clamped transducer. The front mass of the transducer was created using polygon shape with bottom radius 22.5 mm, top radius 17.5 mm and with height of 25 mm. The rest of the transducer was built with rectangles. The piezoelectric rings are of 5 mm thick with inner radius 6.5 mm and outer radius 19 mm. The backing mass has a height of 13 mm and radius the same as the outer radius of piezoelectric rings. The bolt inside the transducer was created with polygon shape. The plate was created with dimensions of 150 x 300 mm and thickness of 4 mm.
The solid domains were defined such as: +Z piezoelectric ceramic ring, -Z piezoelectric ceramic ring, front/back mass, bolt and plate. Explicit for boundary surfaces was used to define the ground and voltage terminals. A union was created with the piezoelectric rings to form a piezo domain. Integration component coupling was used between the transducer and the plate.

Assumed materials in the numerical model are tabulated in Table 1. The piezo domains were assigned with PZT-4 material. The bolts were assigned with steel AISI 4340. The front/back mass were assigned with Aluminium. The plates were assigned with Aluminium 6063-T83.

Table 1: Assumed material properties in the numerical model

Material	Domains assigned
Lead Zirconate Titanate (PZT-4)	
Steel AISI 4340	
Aluminium	
Aluminium 6063-T83	

A finer mesh was built separately for the transducers and the plates using free tetrahedral generator in order to avoid any convergence errors between the transducer and the plate.
The model was simulated at a range of frequencies varying from 30 kHz to 50 kHz. Results were obtained for impedance which allows to confirm the resonant frequency the transducer. The resonant frequency is identified as the frequency at which the impedance is lowest at which the maximum power is generated. Distribution of total displacement was also observed at the resonant frequency and was compared with the different configurations.

Integration of kinetic energy at each frequency was considered. The elastic energy is the energy representing the elastic deformation of a solid object. In order, to apply a solid compression, it is necessary to exert a force that will cause a displacement of the structure. The point of application of the force will thus move, the work of this force makes it possible to determine the energy of compression. To quantify the impact of the ultrasonic processing, it is necessary to study the variations of elastic energy through the whole media. Fig.1 shows the impedance plot of the model with no welded connection. The plot showed the first drop in impedance at 40 kHz which is exactly the expected resonant frequency of the transducer.

At resonant frequency, high levels of displacement with node and antinode regions were observed closer to contact site as seen in Fig. 2.

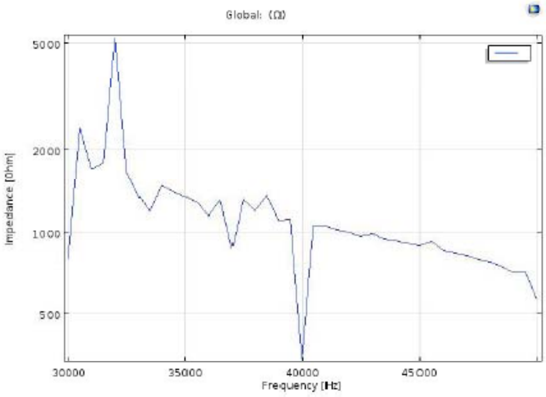


Fig. 1. Numerical results – Impedance curve

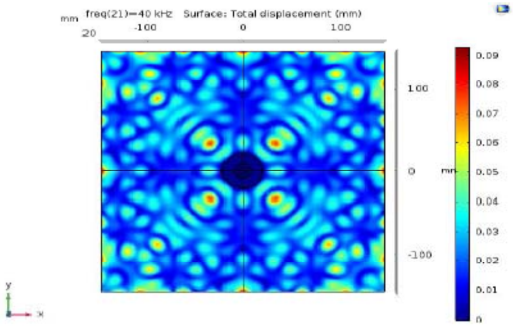


Fig. 2. Numerical results – Displacement at the resonant frequency

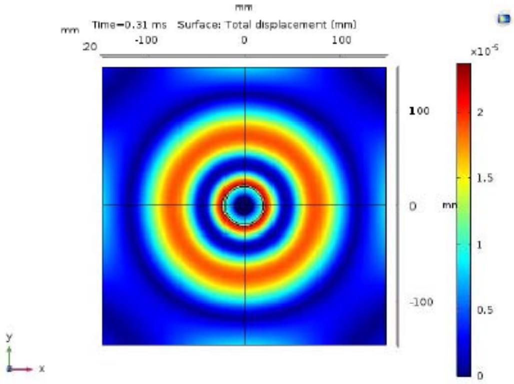


Fig. 3. Numerical results – uniform propagation of ultrasonic waves caused by the compression vibration

Fig. 3 illustrates the uniform propagation of ultrasonic on the Aluminium plate. A 5 cycle Hann modulated sine wave of 39.5 kHz frequency was used as the excitation and 240 v amplitude was applied. The aim was to visualize wave propagation through the plates, to make sure that ultrasonic transducer will create enough vibration to enhance a Laser welding manufacturing process.

III. LABORATORY EXPERIMENTS

Experimental tests consist in an analysis of the out of plane surface vibration following the propagation of an ultrasonic wave. This wave is generated using a40kHz ultrasonic transducer (similar properties to the transducer in the numerical model). The visualization of the wave propagation is carried out using a 3D laser vibrometer.The transducer is excited by a power amplifier allowing the automatic adjustment of the excitation *i.e.* amplitude, frequency and number of cycles.

The frequency domain study to determine the resonant frequency of the plate and the transducer. Results show a perfect agreement between experiments and numerical simulation. 40 khz is the best frequency to used, for further investigation with time domain analysis, or for final implementation into a manufacturing process.

Fig. 4. Experimental setup

To carry out time domain experiments, the plate surface was discretized into nodes were vibration is measured (100 points per 100 mm in both plane directions).

As shown in Fig. 5, experimental results shows an uniform out-of-plane vibration on the plate surface which will result in better quality welds compared to the conventional laser welding process. Furthermore, uniform propagation of ultrasonic sound on the plate studied in the numerical model (Fig. 3) can be validated from the results shown in Fig. 6.

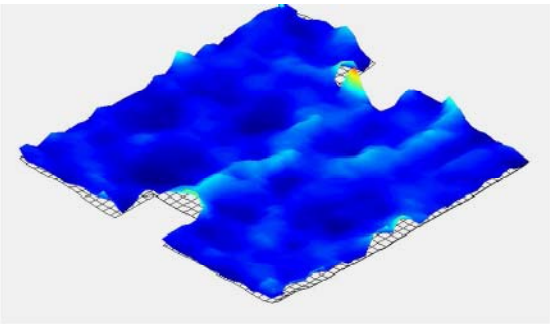
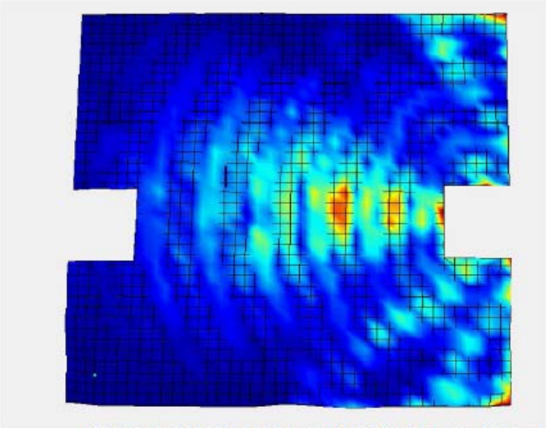


Fig. 5. Experimental setup – Frequency domain results showing uniform out-of-plane vibration



Experimental setup is illustrated in Fig. 4.

Fig. 6. Experimental setup – Time domain results

CONCLUSIONS

Preliminary tests were conducted to study the applicability of ultrasonication to improve the laser welding of Al 6063.Numerical study was conducted to study the propagation of the ultrasonic waves through aluminum plates, using the piezoelectric transducers for the selection of appropriate transducer. Based on the parameters studied, most suitable transducer for this case was a 40 kHz Langevin bolt clamped transducer. This was validated using a controlled experiment and this behavior has been studied using the 3D laser Doppler Vibrometer. After the validation of the numerical model, this can be used to conduct a parametric study for further optimization of the process.

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