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A Review Paper on Study of Ultrasonic Welding for Thin Different Metals

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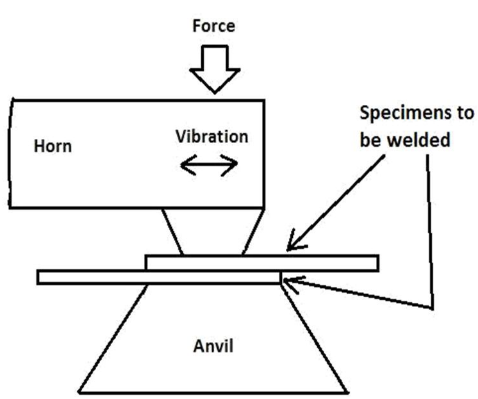
Abstract: Ultrasonic Welding (USW) is a solid-state bonding process that produces joints by allowing transfer of high frequency vibratory energy in to the work pieces which are brought together under pressure. The whole process is done without melting of any of the material. It can be used as a micro-welding technique which is being widely used for vehicles, shipbuilding, and the welding of electric and electronic parts. Ultrasonic tooling is one which greatly affects the performance of whole welding system. Anvil is an important part which includes in ultrasonic tooling. Design of anvil is peculiarly based on the geometry. Very few studies are done on the effect of welding process on the geometrical changes of the anvil. In this work, ultrasonic anvil was designed in two different geometrical shapes with same material SS 304, which was then fabricated by series of operations and investigated the effects of Tensile strength, T-peel strength and weld quality. The experimental design was done in Taguchi method using L9 orthogonal array and MOORA method was used to convert the multi-objective optimization problem to single one. Then, Taguchi method was further used to optimize the response parameters.

Keyword: ultrasonic machine, Force, vibratory Energy, Power supply, Time

I. INTRODUCTION

Welding is defined as a coalescence of metals or non-metals applied locally produced by either heating of the materials to a limited temperature with or without the application of pressure, or by the application of pressure alone, with or without the use of filler metal [6]. The process of ultrasonic metal welding is one in which vibrations of high frequencies (20-40kHz) create a friction-like relative motion between two surfaces that are held together under pressure. The motion deforms, shears, and flattens local surface asperities, dispersing interface oxides and contaminants, to bring metal-to-metal contact and bonding between the surfaces. The input amplitude is very less in this process in the range of (1 – 25 μ m). Here oscillating shear forces are applied at the metal interface where they are held together under limited clamping force.



II. USW PRINCIPLE

A. Types of USW System

There are variety of configurations available in the present industry which is based on metals to be joined, geometry, type of weld etc. Some are Ultrasonic seam welding, spot welding, torsion welding, ring welding Since this work is focused on Ultrasonic metal spot welding.

B. Advantages

1) Can weld thinner-thicker combinations with ease
2) Process is fast and applicable to automation
3) Requirement of filler metals or shielding gases are avoided
4) Less power is required for the process
5) Very less heat generation since solid state welding
6) Similar or dissimilar metals can be bonded
7) Dissimilar materials of extensive range is capable of joining

C. Limitations

1) It is difficult to weld high strength materials
2) It is restricted to lap joints
3) Slight deformation of materials may occur
4) Materials up to limited thickness can only be welded

a) *Welding Parameters:* There are a no of parameters which affects the operational behavior of USW systems. Some of them are frequency, clamping force, welding power, amplitude, welding time etc. This parameters are very important as far as USW is concerned. Controlling these parameters resourcefully can result in tremendous outputs.

i) *Ultrasonic Frequency*: The transducers which are used in USW system are actually designed to operate at a defined frequency. This frequency varies from 15 kHz to around 300 kHz

ii) *Vibration Amplitude*: It must be noted that the vibration amplitude of a typical US system is in the order of maximum of 80 µm.

iii) *Clamping Force:* This force may vary from 10s to 1000s of Newton.

iv) *Power, Energy and Time:* These parameters may seems to be self-governing but they aren't. They are actually dependent on each other. But, these unification is necessary to study their effects. The electric power is transferred across the transducer to the welded specimens at the beginning of the welding process and the same occurs during each welding cycle. There are many factors which affect the dependency between welding time and power supply. For example some of the factors are surface finish, the geometry and the type of material to be welded. By calculating the input electrical power and subtracting the losses estimated in the system actual power can be conveniently estimated. One typical power curve (power vs. time) is depicted in the figure below.

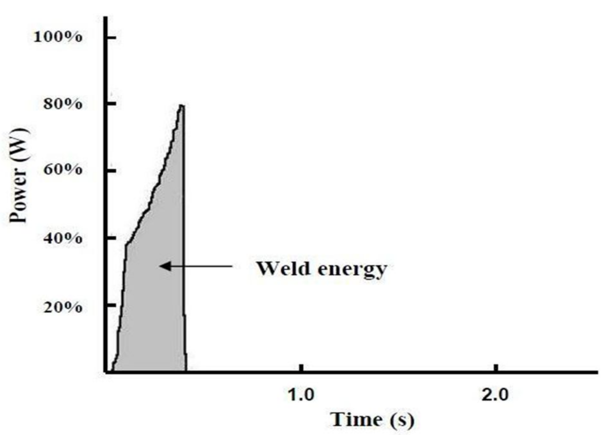


Figure. Power vs. weld time for the ultrasonic welding

v) *Materials:* Under this category the materials which can be welded by this USW process are discussed. Although this work is under dissimilar metal welding, similar metals can also be welded using USW process. Selecting a material for welding requires consideration of some important features. They are the properties of materials, micro structural details etc. Under properties we can have hardness, modulus of elasticity, yield strength etc. All soft metals like AL, nickel, magnesium, gold, copper etc. are easily welding. The difficulty of welding is increased on increasing thee hardness coefficient..Weldability chart is one chart which depicts which materials can be welded to which material

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vi) *Part Geometry:* Part geometry refers to the shape or dimensions of the part to be welded. Here specimen's thickness plays a vital role. As we go on increasing specimen thickness it become difficult to weld them. Also thinner sections are very easy to weld. Whenever part becomes thicker, then requirement of high amount of weld power will be there. Depending on the power levels suitable and the nature of welding material how much thickness up to which we can weld may be decided. In general spot welding applications, an overlapped shape parallel to the vibration direction is used to place the specimens. In this work we have used sheets having dimensions 20×80 mm.

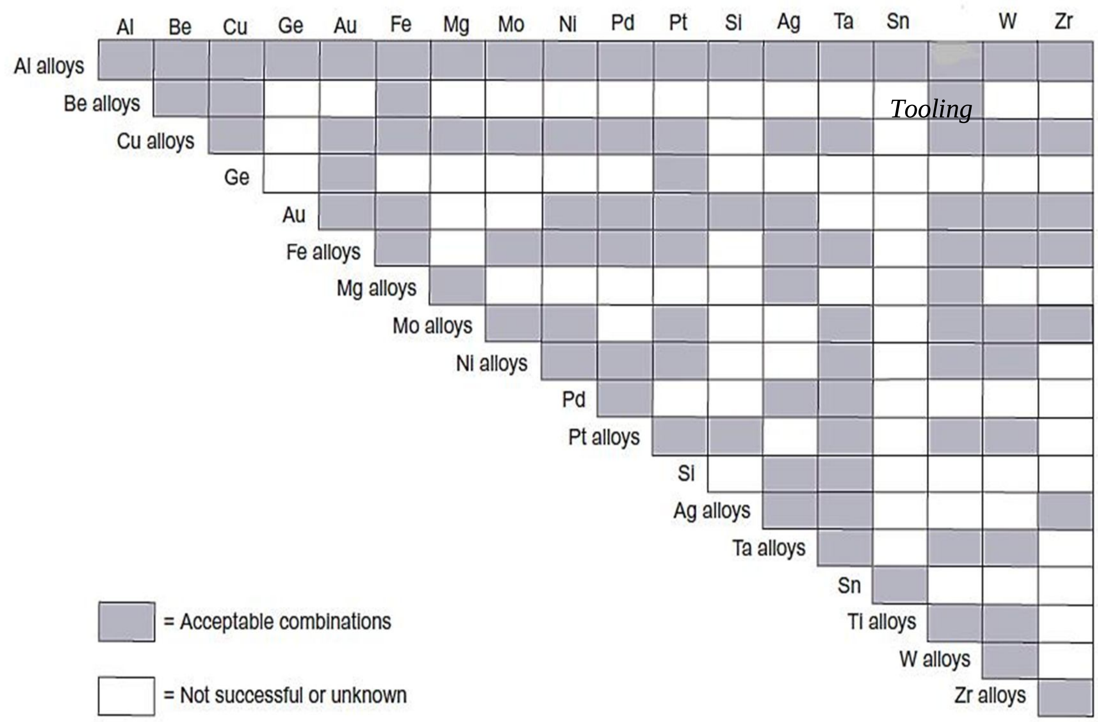

Figure- Ultrasonic material weldability (*Source*: Graff et al., AWS (2007)

III. ULTRASONIC TOOLING ESSENTIALLY CONSISTS OF TWO PARTS

1) *Top Part :* Sonotrode or Welding tip
2) *Bottom Part:* Anvil

If the tooling system is not properly set it can affect the overall welding process. The main function of tooling is to transfer the ultrasonic vibrations and also to support the parts being welded. The tooling experience less temperature rise compared to work pieces. Now, anvil is one important among them. Since this work is concentrated on tooling, it will be discussed later. Welding tip can be of different types like detachable tip, replaceable tip etc.

A. Applications

USW finds applications in multitude of industries and sectors. Some of them are electrical & electronics, automotive, medical, aerospace, packaging as well as medical sector also. Joining metals is the application which we are concerned. But, one of the main peculiarity is that this metal joining can be done in any medium such as in vacuum or in water medium also.

This technique is successfully implemented in aerospace industry also. Al (Aluminium) is a material which is used extensively in aerospace sector and it can be very easily welded since it is very soft . It has been also used for the fabrication of carbon fibers which is a well-known composite material.

In packaging field, sealing containers blister packs etc. are welded with this. Treacherous items like fireworks, explosives, and some chemicals are also ultrasonically welded. Butane lighter is one of the example.. Here butane lighter container not only must be able to withstand high pressure and stress but also it must be very tightly packed. Proper safety concerns are necessary when sealing dangerous chemicals. Now, food items like milk and juice containers can be efficiently sealed with this process.

IV. REVIEW

A. *Ultrasonic metal Welding*

Matsuoka done experimental studies on USW by combining metals and ceramic using inserts. This work also brings us the possibility of welding AlN , SiC , Al2O3, etc. at room temperature.

Flood conducted experiments on copper and Aluminium and suggested some methods. It also describes the effect of weld strength on different process parameters. The applications in various fields are also discussed.

Watanabe et al. ultrasonically joined aluminum and alumina ceramic by means of a pulse of 1.5s. They analyzed the atomic interaction across the weld interface by using Auger Electron Microscopy to find out the occurrence of chemical bond across the interface of bonded specimens. The results suggest that chemical bonding exists across them.

Park.D.S et al. designed and fabricated a horn by using the vibration equation and FEM study. Further they determined maximum shear force by using a tensile testing machine and hence weldability of Ni sheets were found out depending upon the weld parameters. They reported that tensile force reduction after a certain weld time was because of crack development on the surface of the weld.

Jeng &Horng studied the effects of surface roughness, applied load, welding power and welding time on wire strength of wire bonded specimens. Real contact area and flash temperature between the wire and the pad was computed using the asperity model. The experimental investigation conveys that a decrease in load or ultrasonic power produces a larger weld range. The theoretical as well as experimental studies conducted reveals that contact or interface temperature have a vital role during initial stages and surface roughness is dominant factor during the final stages. It is suggested that bond strength of ultrasonic wire bonding can be explained based on the input energy per real contact area.

Ding et al. analysed the deformation and stress distributions in the wire and bond pad during the ultrasonic wire bonding using the 2D and 3D finite element methods. It was reported that the maximum energy intensity occurred at the periphery of the contact interface, where weld is preferentially made as shown by experimental evidence. The total frictional energy increased linearly with bond force, but the high frictional energy intensity obtained at the periphery of the interface did not show a similar increase.

B. *Ultrasonic Tooling*

Jahn .R et al. investigated the spot welds formed by ultrasonic welding by means of a single-transducer unidirectional wedge-reed welder. They have done experiments by changing the anvil cap geometry and the microstructures and weld strength were also studied. It is found that anvil cap size and knurl pattern were insensitive to welding strength, but changes in the wake surface was found. Weld failure in lap shear tensile tests occurred due to interface fracture for low-energy welds and by button formation for high-energy weld

Watanabe et al. ultrasonic welding A6061 Al alloy sheet using two different types of welding tips and also with different geometries and investigated their effects. A cylindrical contact faced tip without knurl (C-tip) and a flat contact tip with knurl (K-tip) was used for study. It is reported that C-tip has higher weld strength than K-tip and fluctuation in C-tip was smaller. The unbounded regions remained at the weld interface due to concavity on the weld tip face.

Shao et al. presents some preliminary results in characterizing, understanding and monitoring tool wear in micro ultrasonic metal welding. 4 different anvils are used as part of the study to describe the tool wear at different stages. A relationship between tool condition and online monitoring signals was established using statistical models and a Bayesian framework model was also proposed.

C. *Optimization and Weld quality*

Brauers & Zavadskas proposed a new for multi objective optimization with discrete alternatives: MOORA (Multi-Objective Optimization on the ratios are applied. Authors used another method for comparison, namely the reference point method. It was also demonstrated that MOORA is the best choice among the different methods available. The denominator was calculated by taking square root of sum of squared responses. The ratios are added in case of maximization and subtracted in case of minimization hence all values are ranked as per the ratios computed. .Weightage can also be added as required.

Chakraborty S investigated the applications of MOORA method for decision making in manufacturing environment. Six decision-making problems which include selection of (a) industrial robot (b) FMS (c) CNC (d) the most suitable non-traditional machining process (e) rapid prototyping process (f) automated inspection systems are explained in the paper. It is also reported that results obtained matches with those derived by past researchers.

Bakavos D & Prangnell P B investigated the usage of X-ray tomography, high resolution SEM, EBSD, and dissimilar alloy welds to track the interface position and characterize the stages of weld formation and microstructure evolution. It is revealed that optimum conditions produce high quality welds, showing few defects. The origin of the weld interface 'flow features' characteristic of HP-USW are discussed.

Balasundaram et al. ultrasonically welded AL and Copper. The microstructure and mechanical properties of welded joints are studied by making an interlayer with and without zinc to analyse the effect of Zn interlayer. It is revealed that the ultrasonically welded Al-Cu joints did not produce any inter metallic compounds and only swirls and voids were observed. It was further reported that using energy dispersive X-ray spectroscopy and X-ray diffraction scans, the welds with a Zn interlayer placed in-between the faying surfaces of the base metals formed a composite-like eutectic structure of Al and Al_2Cu at the center and Al–Zn and$CuZn_5$ at the edges of the welded joint. It is also found out that the Al-Cu joints welded with a Zn interlayer in-between displayed lap shear tensile strengths 25–170% greater than those of the welds without any interlayer.

V. CONCLUSIONS & FUTURE SCOPE

In this work, A multi-objective optimization problem known as MOORA has been solved by finding an optimal parametric combination in which appreciable weld strength was obtained. Taguchi Method is further implemented to find out the optimal sequence of input parameters that maximizes the output. Confirmatory tests shows error of 2 %, 2.47 % and 1.66 % respectively which shows a good agreement with the predicted results. From the weld quality studies, the difference in wake features of different anvils and the type of welds were studied and analyzed. Changes in the anvil geometry was investigated in this work using SS 304 material. With the same geometry and with different material the study can be further extended and the ideal material for this geometry can be found out.

VI. ACKNOWLEDGEMENTS

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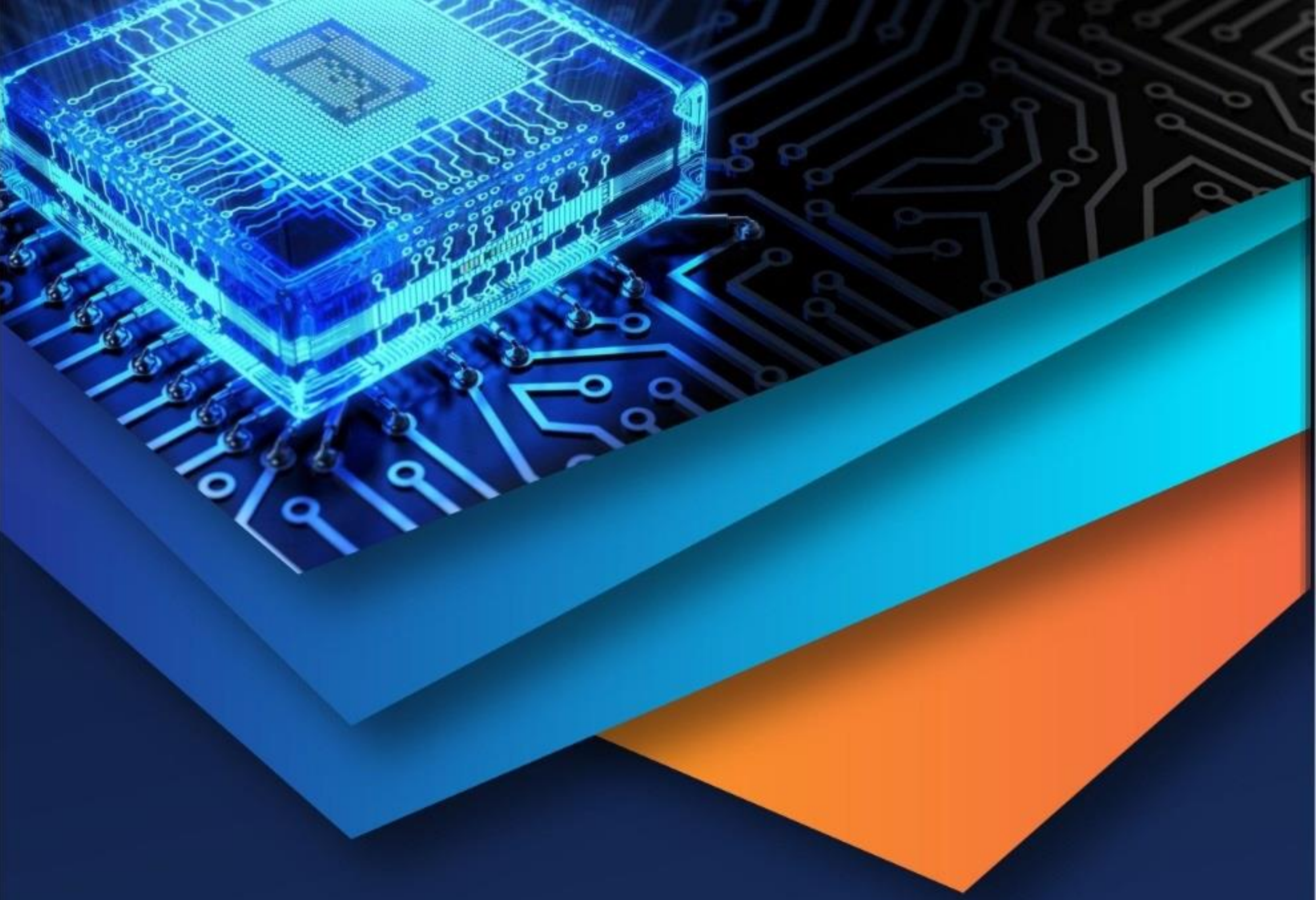

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