Anvil Design & Experimental Investigation for Ultrasonic Welding of Thin Dissimilar Metals

A thesis submitted in partial fulfilment of the requirements for the award of degree of

Master of Technology

In

Production Engineering

By

Irshad.K.T

Roll No. 213ME2407

Under the Supervision of

Dr.S.K.Sahoo

Department of Mechanical Engineering

National Institute of Technology, Rourkela-769008

ODISHA, INDIA

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DECLARATION

I hereby declare that the report of work entitled "**Anvil Design & Experimental Investigation for Ultrasonic Welding of Thin Dissimilar Metals**" is based on my own work carried out during the course of my study under the supervision of Dr. S.K.Sahoo.

I affirm that the statements made and conclusions drawn are an outcome of the project work. I further assert to the best of my knowledge and belief that the report does not contain any part of any work which has been already submitted for thesis evaluation in this university.

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CERTIFICATE

This is to certify that the project entitled, "**Anvil Design & Experimental Investigation for Ultrasonic Welding of Thin Dissimilar Metals**" submitted by **Irshad.K.T (213me2407)** is an authentic work carried out by him under my supervision and guidance for the partial fulfilment of the requirements for the award of **Master of Technology (M. Tech)** degree in **Production Engineering** at National Institute of Technology, Rourkela**,** and this work has not been submitted elsewhere before for any other academic degree/diploma.

Date: 29/05/2015

Place: Rourkela

Dr. S.K.Sahoo

Professor

Department of Mechanical Engineering

National Institute of Technology, Rourkela

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Last but not least, I would like to pay high regards to my parents, my friends and Almighty God for giving me strength in all the critical situations and supporting me spiritually throughout my life.

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 multiobjective optimization problem to single one. Then, Taguchi method was further used to optimize the response parameters.

Index Terms—Ultrasonic Welding, Anvil, Taguchi, MOORA

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1 Introduction

1.1 Brief History

The USW process came into existence in the early 1950s [1]. In 1950 Willrich conducted a welding experiment to obtain a cold weld by the application of low frequency mechanical vibrations. But at that time resistance welding was used. In 1953 ultrasonic energy was successfully applied to cold weld a no of specimens [2, 3].Now, at this time we got a clearer picture of the process. But, the USW technique was only proposed in the 1960s. The patent for the ultrasonic method for welding rigid thermoplastic parts was awarded to Robert Soloff and Seymour Linsley in 1965. Soloff was the founder of Sonics & Materials Inc. In 1969 a car which was entirely made out of plastic was assembled. Since then USW technique has been used for variety of applications in different industries starting from computer & electrical and ending up to packaging [4, 5].

1.2 USW Principle

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. The resulting internal stresses cause elastoplastic deformation at the interface. Fig. 1.1 illustrates the process.

A temperature rise is generated locally because of this welding phenomena from combined effects of elastic hysteresis, interfacial slip, and plastic deformation. If the force, power, and time are set correctly the welding process will be completed without having fully completed metal at the interface.

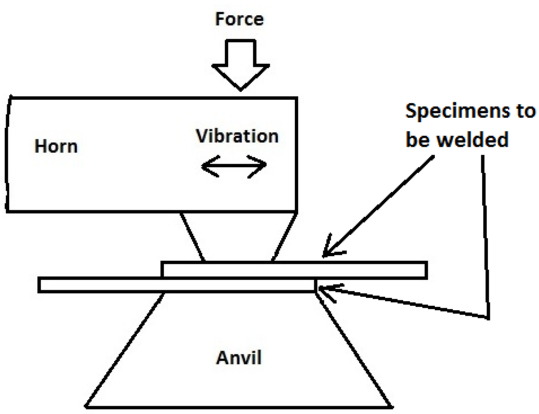

Fig. 1.1 USW Principle

Interface temperature rise is greater for metals with low thermal conductivity, such as steel, than for metals of high conductivity, such as aluminum or copper. Ultrasonic welding of such high conductivity materials requires substantially less energy than resistance welding.

1.3 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, two main configurations which are widely used to weld metals (similar or dissimilar) are explained below.

1.3.1 Lateral Drive System

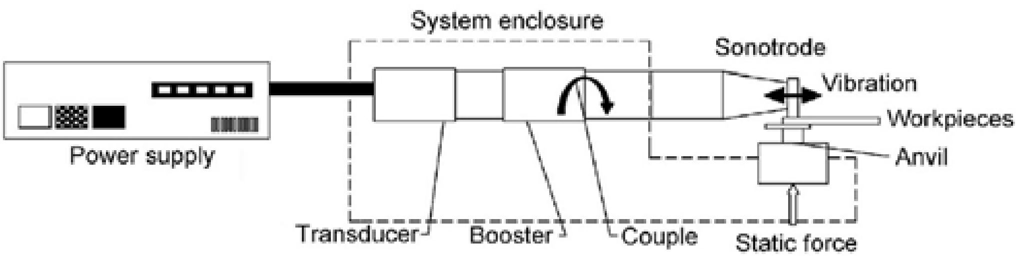

Fig. 1.2 Lateral Drive Ultrasonic Welding System, (*Source*: EWI)

Major parts or components of this system are transducer, booster, sonotrode .These series of components are used to transmit ultrasonic vibrations to the workpiece in a magnified manner. The fixing or clamping of the specimens is done in upper part by the welting tip and lower by the anvil. For fixing, a static continuous force is required which can be accomplished by several methods. One way of achieving it is by a coupling moment created within the system enclosure by a setup of leveraged forces and pivots .Other useful method is by arrangements of weld system mounted on a platform that move on linear bearings with forces applied by a pneumatic cylinder or a servo controlled motor.

An electronic power supply is used to produce HF input voltage and hence to produce ultrasonic vibrations. A typical piezoelectric transducer consists of several piezoelectric disks, most commonly made from Lead Zirconate Titanate (PbZTi) [7] and a rear driver, and the whole assembly is held together by a bolt or screw nut mechanism. The high frequency electrical signal is converted to mechanical vibrations by the transducer because of its piezoelectric properties. The vibration of transducer assembly is in a longitudinal direction at a specified frequency called resonant frequency which is obtained by the properties of materials of the drivers. The transducer is designed such that the maximum amplitude is obtained at the front end of it. Now, the minimum amplitude point is called the “node” and is designed to be located at the flange portion of the assembly. Each of the three components of the assembly namely transducer, booster and sonotrode are having half acoustical wavelength. The vibrations are amplified after each stage to a higher value.

During the welding time, the ultrasonic stack is lowered by the clamping mechanism so that the upper weld coupon is in contact with the welding tip. The anvil supports the lower weld coupon effectively on the opposite face. When the vibrations are applied, weld coupons are tightly held because of the face texture properties which results in the transfer of maximum energy to the weld interface with less friction.

1.3.2 Wedge Reed System

As the name indicates the important parts of this system are transducer, wedge, reed and series of other components. The ultrasonic vibrations are transmitted through these components then to the reed and finally to the workpiece. A force of static in nature is applied at the top end of the mass and anvil will be holding the same in the bottom end. The force magnitude varies from a few Newtons to several kilo-Newtons [8]. As we see in lateral drive system electronic power supply is used to produce the high frequency vibrations. In this particular system, the transducer is in the same form as we see in the Lateral drive system. As a part to replace the booster in the Lateral drive system we have here a wedge. The main function of it is to increase the amplitude of vibration. Welding or brazing is used to attach the reed rigidly to the wedge. Here the vertical reed vibrates in a flexural, or bending mode of vibration. The bending vibration of reed results in transverse vibration of the welding tip against the workpieces [9].

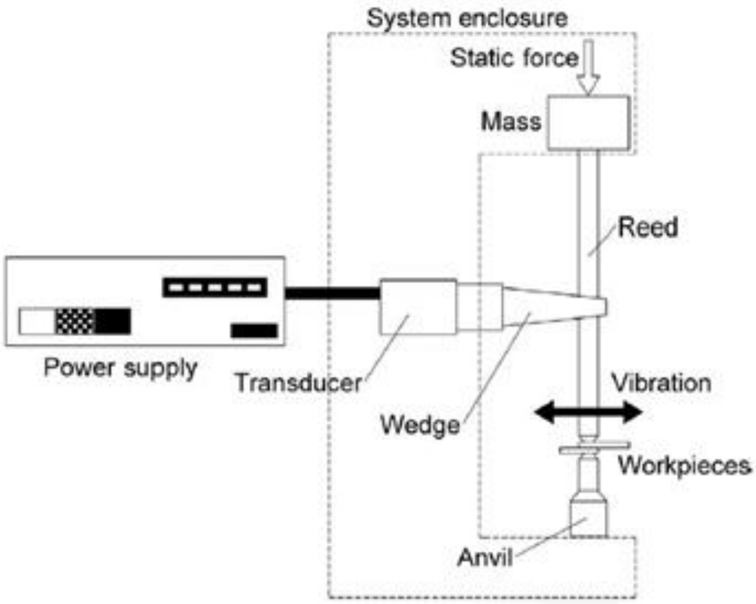

Fig. 1.3 Wedge reed Ultrasonic Welder, (*Source*: EWI)

But one of the drawback of this system is that it does not allow control of parameters accurately and precisely. The weld parameters at the transducer end can be measured by the lateral drive system. But here we can't do that because the vibration here is in a bending mode.

1.4 Welding Parameters

There are a no of parameters which affects the operational behaviour 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.

1.4.1 Ultrasonic Frequency

The transducers which are used in USW system are actually designed to operate at a defined frequency. And this frequency varies from 15 kHz to around 300 kHz. Usually metal welding systems will operate at 20, 30, 40 kHz etc. most commonly 20Khz frequency is used [10].Much higher values are used for micro fabrication or welding works such as 60 to 150 kHz [11].As we have discussed above generators are used to produce ultrasonic frequency, but this frequency will remain constant during the whole welding process.

The above mentioned “constant, operating frequency” can change because of several factors. Some factors or causes are varying static force, different tooling, changing tool conditions due to welding load, fluctuating tool conditions due to wear. Since the feedback control circuitry is available on all new and modern power controllers, it automatically compensates this shifting conditions. It also tracks or find driving frequency of the transducer to maintain or make the system resonance frequency constant [11, 12]. The efficiency of the resonant wave transfer depends on the natural resonant frequency of the horn and is determined by two factors:

- The speed of sound through the material
- The geometric shape of the object

1.4.2 Vibration Amplitude

This parameter plays a very important role to decide the quality as well as strength of the weld. The measure of axial expansion and contraction of excitation actually defines the Amplitude [13]. Energy delivered to the weld zone depends on the amplitude of the welding. It must be noted that the vibration amplitude of a typical US system is in the order of maximum of 80 μm. When we change the amplitude means we are actually changing the amount of current passing through transducers. Also 100% amplitude means power supply will provide 100% system power. Most commonly amplitude ranges in between 10 to 50 microns [1]. Usually wedge reed systems on compared to lateral drive requires less amplitudes. This is because high energy will be transferred to weld zones by this amplitudes. Hence, low amplitude is always used in wedge reed systems because of higher force requirements [14, 15].

1.4.3 Clamping Force

It is also one of the key parameter in the USW. In every solid state bonding mechanism the effect of clamping force is in evitable [16]. The force is commonly applied on the workpieces by the use of anvil at the bottom and welding tip at the top. This clamping force magnitude is greatly dependent on the materials and thicknesses of the welding pieces and also on the size of the weld being produced. This force may vary from 10s to 1000s of Newtons [1].

A high clamping force with low amplitude is recommended for wedge reed system and a low clamping force with high amplitude for lateral drive system [14]. Special care should be taken while selecting the magnitude of force, as insufficient force can lead to slip of the sonotrode tip and excessive force cause deformation of samples and also the dissipation of more energy. This further can result in temperature rise and eventually can cause the damage of the horn part.

1.4.4 Power, Energy and Time

These parameters may seems to be self-governing but they aren't. They are actually dependent on each other [1]. 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.

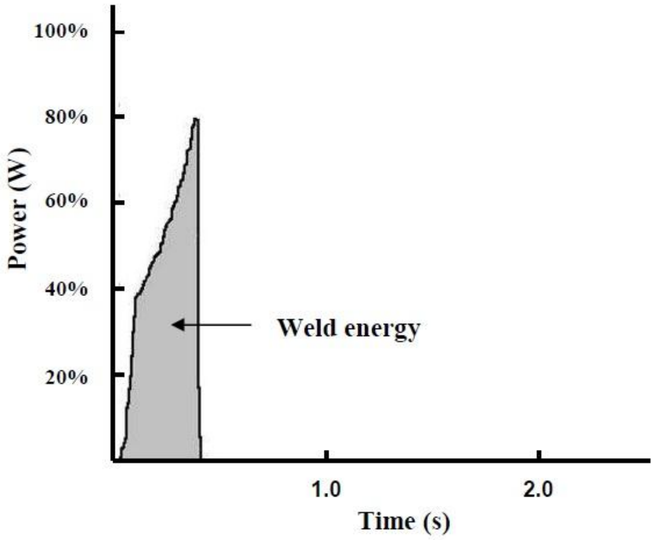

Fig. 1.4 Power vs. weld time for the ultrasonic welding [11]

Depending on the type of welding being used the weld time may become dependent or independent. Thus at a time only one value can be set of them either Power (or energy) or weld time. All systems are designed like this only. The most commonly used welding time for metal welding is 0.25 to 0.5s. The higher value can reach up to 1s. Also longer weld times results in poor surface appearance, internal heating, and internal cracks [17].

Now, the mechanical load and actual power are directly proportional to each other [18]. Without altering any other parameters if we increase the pressure alone, the force exerted on the interface increases and that results in need of an increased power. So, as mentioned earlier much less time is required to cop up with increase power level to transfer the same amount of energy, as seen in Fig. 1.5.

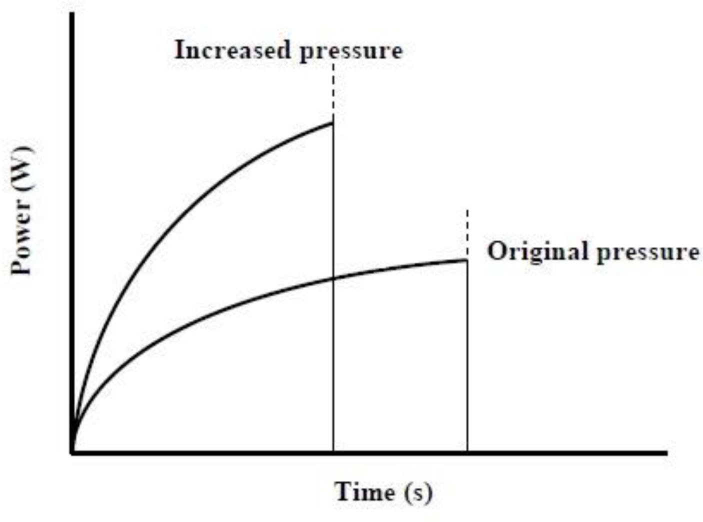

Fig. 1.5 Pressure variables [18]

1.4.5 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, microstructural details etc. Under properties we can have hardness, modulus of elasticity, yield strength etc. [1]. All soft metals like aluminium, nickel, magnesium, gold, copper etc. are easily weldable. The difficulty of welding is increased on increasing thee hardness coefficient [19]. Weldability chart is one chart which depicts which materials can be welded to which materials. One typical chart is shown in Fig. 1.6.

1.4.6 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.

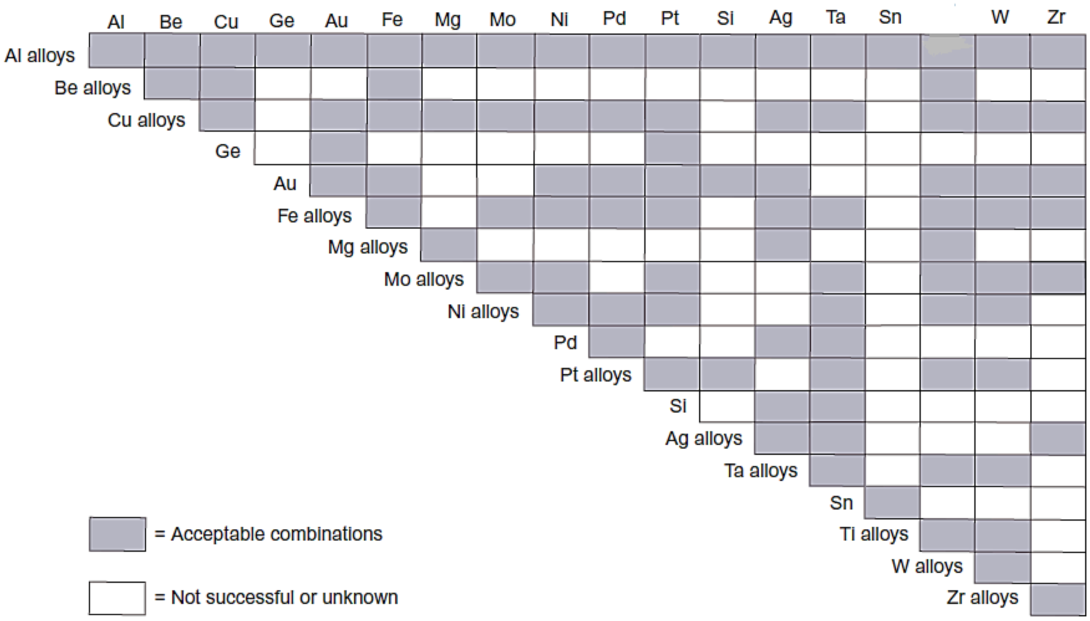

Fig. 1.6 Ultrasonic material weldability (*Source*: Graff et al., AWS (2007), Fig 8.18.)

1.4.7 Tooling

Ultrasonic tooling essentially consists of two parts:

- Top part: Sonotrode or Welding tip
- 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 workpieces. 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.

Knurling is normally done to generate frictional surfaces on the anvil. The knurl patterns are usually grooves and lands or surface roughening. Sometimes it is made as a solid component integrated with the sonotrode part. It also aid to avoid slippery between the workpieces. Many variations are there in surface profiling of this welding tip. Some are rounded tips, some are spherical and some others are convex curvature type. Each has its own identity based on the stress pattern.

1.5 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 [21].

In automotive sector USW can be used to join connections in a no. of applications such as contact assemblies, sensor terminations, buss bar terminations etc. Also in capacitors, field coils and electric motors USW is used [22]. Microcircuits are one of the area where new investigation are going on. USW produce reliable bonds into parts without that much of thermal distortion. Bonding of wiring and ribbons of the microcircuits is done by this method only. USW extends its application in the battery and fuel cell manufacturing also. It is found that connections of foil layers, metal meshes, and nickel and aluminium connections are done by this process.

This technique is successfully implemented in aerospace industry also. Aluminium is a material which is used extensively in aerospace sector and it can be very easily welded since it is very soft [24]. It has been also used for the fabrication of carbon fibres 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 [25]. Proper safety concerns are necessary when sealing dangerous chemicals. Now, food items like milk and juice containers can be efficiently sealed with this process.

1.6 Advantages & Limitations

1.6.1 Advantages

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

1.6.2 Limitations

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

2 Literature Review

2.1 Ultrasonic metal welding

Matsuoka [26] done experimental studies on USW by combining metals and ceramics using inserts. This work also brings us the possibility of welding AlN, SiC., Al2O3, etc. at room temperature.

Flood [27] 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. [28] 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. [29] 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 [30] 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 weldable 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. [31] analyzed 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.

2.2 Ultrasonic Tooling

Jahn.R et al. [32] 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 welds.

Watanabe et al. [33] ultrasonically welded 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.

Nishihara et al. [34] investigated the effect of horn tip geometry on the mechanical properties of a ultrasonically welded joint between a mild steel and an aluminium alloy sheet. Two types of tips were used. Cylindrical contact face tip with knurl (C-tip) and flat contact face without knurl are used (K-tip). It is found out that C-tip exhibits twice larger welding strength than K-tip under optimal welding condition. It is also reported that strength of joint increased with increasing welding time and clamping force.

Shao et al. [35] 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.

2.3 Optimization and weld quality

Brauers & Zavadskas [36] proposed a new for multi objective optimization with discrete alternatives: MOORA (Multi-Objective Optimization on the basis of Ratio Analysis). This method was referred to a matrix of responses of alternatives to objectives, to which 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 maximisation and subtracted in case of minimisation. Then, all values are ranked as per the ratios computed. Weightage can also be added as required.

Chakraborty S [37] 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 [38] investigated the usage of X-ray tomography, high resolution SEM, EBSD, and dissimilar alloy welds to track the interface position and characterise 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. [39] ultrasonically welded Aluminium 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 intermetallic 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 Al2Cu at the center and Al–Zn andCuZn5 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.

2.4 Research gap and Objectives

Although some studies have been carried out in the area of effects of sonotrode or weld tip geometry on welding process, a major gap in literature was found in the field of effect of anvil cap geometry on welding. Only few literatures are available in this area. So, more researches are needed in this area for efficient technological improvement of the ultrasonic tooling which in turn enhances ultrasonic welding process.

Based on this findings, the objective of present research are:

- To design the anvil geometry in different ways to find out how it affects the welding process
- Fabrication of anvil based on designed geometry
- To conduct experiments by using a suitable methodology
- Optimize the response variables so that higher the better criteria is chosen and responses are maximized
- Analyses of the microstructure and weld quality.

3 Equipments, Materials & Anvil Design

3.1 Equipments Used

Under this segment the different equipment's that were used as a part of this work were discussed. But, only important ones are explained.

3.1.1 Equipments used for Tool Development

Fabrication of anvil is necessary to conduct experiments for investigating the effects on anvil on USW process. So the machines used for developing or making anvil were explained.

3.1.1.1 CNC Machine

CNC stands for Computer Numerical Control. Milling is a specific form of CNC machining. Milling also require a rotating cylindrical cutting tool like drilling. The difference from drilling is that the cutter can move along multiple axes and also can create variety of shapes holes etc. Also workpiece can also be moved to achieve the desired shape. This type of machines can be operated in 3 axes. CNC milling centers are ideal solutions to everything ranging from prototyping and short-run production of complex parts to the fabrication of unique precision components. Almost all type of materials can be cut using this virtually, but most work done is in metal only.

A CNC milling machine of following specifications was used to make the anvil to the required dimensions by performing operations milling and drilling. Here codes were written manually and it was fed in to the system by typing on to the keyboard attached to the CNC machine.

Specifications are:

X axis travel (longitudinal)	300 mm
Y axis travel (cross)	250 mm
Z axis travel (vertical)	250 mm
Repeatability	± 0.005 mm
Positional accuracy	0.010 mm
Motor power	0.37 kW

3.1.1.2 Wire EDM

It's a type of EDM machine in which a wire is used to cut or machine the workpieces. All electrically conductive elements can be machined using this machine such as tool steel, graphite, copper, Inconel, titanium, carbide, diamond compacts, conductive ceramics etc. The wire does not touch the workpiece, so there is no physical pressure imparted on the workpiece compared to grinding wheels and milling cutters. Wire EDM can be applied to many fields like, parts where burrs can't be tolerated, thin or delicate parts that are susceptible to tool pressure, progressive, blanking and trim dies, extrusion dies, precious metals, narrow slots and keyways, mold components etc.

The specifications of the machine are:

Make	Electronica, EIPULS 15
Model	Ecocut
X × Y	250 × 230 mm
Max Workpiece height	200 mm
Max table size	370 ×600 mm
Max cutting speed	70mm/min
Taper	±8^{o} over 50 mm
Best surface finish	1.2 µ R_a

Wire is of diameter 0.25 mm. This wire was allowed to cut the top surface of the anvil or anvil cap to achieve the required shape. Only 0.6mm depth was given and it's not a through cut.

3.1.2 Equipment for Welding

This machine can be operated in two modes: weld time mode and weld energy mode. Weld time mode was used in this work. By changing the weld time, power or energy cannot be controlled. Many parameters can be set in this particular type of machine. In this amplitude, weld time and pressure was taken as the critical parameters. The welding tip used here was a non-detachable type. But, tip can be altered based on users need. That is 6 different geometrical tips are available to use. Maximum amplitude which can be obtained considering full output is 68 µm. The desired pressure is delivered to the system by using an air compressor.

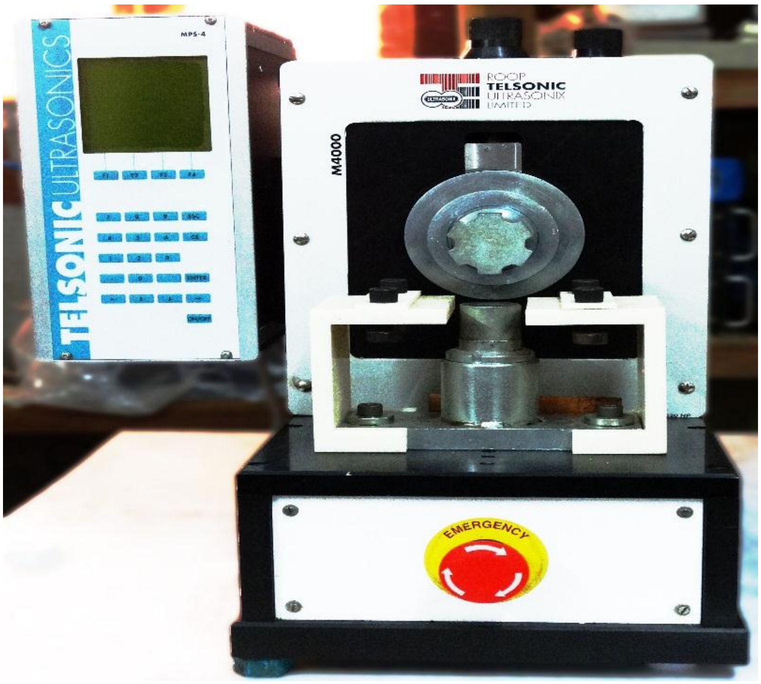

Fig. 3.1 Telsonic M4000 Ultrasonic Metal Welder

The welding equipment has the following specs:

Manufacturer:	Telsonic
Sound transformer / converter:	Piezoelectric
Operating frequency:	20 kHz
Vibration direction:	Longitudinal / linear
Maximum power output (generator):	3.0 kW eff.
Booster (mech. amplitude transformer):	Material: titanium
Translated welding amplitude:	20µm < A < 40 µm
Welding force generation:	Pneumatic

3.1.3 Equipment for Mechanical Testing

Mechanical testing machine Instron 1195 was used to measure the Tensile and T-peel strengths of welded specimens. For that, specimens were loaded on to the machine between the holders and some preliminary settings were done such as:

- For Tensile test: 2mm/min crosshead speed, 0.3mm thickness, gauge length=100mm
- For T-peel test: 5mm/min crosshead speed, 0.3mm thickness, gauge length=10 mm

Fig. 3.2 Instron 1195 Universal Testing Machine

After that the tensile test starts. At the time of breakage of specimen machine automatically stops. The readings were recorded in the machine. This process was repeated for rest of the specimens also. Same procedure was followed for T-peel test also. The specifications of the machine are:

Load Cells:	5 N - 100 KN
Crosshead Speed Range:	0.5 - 500 mm/min
Return Speed:	500 mm/min
Crosshead Speed Accuracy:	±0.1% of Set Speed
Space between Columns:	560 mm
Testing Type:	Tension and Compression
Drive Unit:	Lead Screws

3.2 Materials

3.2.1 Workpiece Materials

Since our work is concentrated on welding of dissimilar materials, Cu and Al of 0.3 mm were selected as work piece materials. They were chosen because with their combination appreciable welding strengths were obtained. Several trial experiments were done to decide the thickness of them and 0.3 mm was finalised by investigating the quality of weld and weld strengths. Aluminum 1100-H16 & Oxygen-free Electronic Copper (OFE), UNS C10100, OS025 were used for the experiments. This UNS C10100 OS025 Cu contains around 99.99 % Cu only. Hence it almost pure Copper. Chemical composition data for Aluminum 1100-H16 is shown in the following tables 3.1.

Table 3.1 Aluminum 1100-H16 chemical composition

Component Elements Symbol	Composition (%)
Al	≥ 99
Be	≤ 0.008
Cu	0.05-0.20
Mn	≤ 0.05
Other, each	≤ 0.05
Other, total	≤ 0.15
Si + Fe	≤ 0.95
Zn	≤ 0.10

3.2.2 Tool Materials

Ultrasonic tooling essentially consists of sonotrode and anvil. Anvil material selection is something which is of utmost importance. Commonly used anvil material is tool steels. In that D2 steel is one good choice. D2 steel anvil is the one which came along with the existing spot welding equipment. So, anvil-1 was decided as D2 steel. Bohler-Uddeholm AISI D2 Cold Work Tool Steel was used for this work. The properties and chemical composition table of this grade D2 steel are given in table 3.2 & 3.3 respectively.

For other anvils D2 steel as tool material is not feasible because making D2 steel is a lengthy process and D2 steel is also not readily available in the market. So the next best alternative is Stainless steel. Stainless steel pieces are not only readily available in the market but it also can be machined without the use any special tools. Hence SS 304 was selected. Mild steel was also considered as a choice, but because of hardness considerations it was rejected. One added advantage was that the properties of SS 304 was ideal for anvil making because of its wear resistance, corrosion resistance and good hardness. The properties and chemical composition tables for SS 304 are shown in table 3.2 and 3.3.

Table 3.2 D2 Steel & SS 304 Properties

Property	D2 steel	SS 304
Young's modulus (GPa)	210	195
Poison's ratio	0.30	0.29
Density (g/cc)	7.67	8.00
Specific heat capacity (J/g-°C)	0.460	0.500

Table 3.3 D2 Steel & SS 304 chemical compositions

Component Elements Symbol	Composition (%)	
	D2 steel	SS 304
C	1.55	≤ 0.080
Cr	11.8	18-20
Fe	-	66.345-74
Mn	0.40	≤ 2.0
Ni	-	8.0-10.5
P	-	≤ 0.045
Si	0.30	≤ 1.0
S	-	≤ 0.030
Mo	0.80	-
V	0.80	-

3.3 Anvil Design

3.3.1 Significance of Anvil Design

The quality of welding will be good only if:

- The power requirement is fulfilled
- The compressor delivers proper air so that pressure fluctuations will not happen
- The design of transducer-booster-horn combination is correct

• The design of ultrasonic tooling is accurate

So, from this it is clear that ultrasonic tooling plays a key role in deciding the quality and strength of welding. By ultrasonic tooling it is referred to sonotrode tip and anvil. Anvil is one of the important member of ultrasonic tooling. Anvil has the following functions:

• To provide proper friction to the weld coupons

• To avoid slippage of the weld coupons during the welding process.

These functions can only be fulfilled if the anvil cap is designed in such a way that geometry itself can provide these above mentioned functions. Only few literatures are available in this topic. But, none of them discussed about the effect of anvil cap geometry in detail by changing the weld times.

3.3.2 Design Specifications

Here, the dimensions of the Anvil was decided according to the suitability of ultrasonic spot welder. As shown in the following figure 1, the diameter was set as 32 mm, depth of drill as 12 mm from bottom surface and dia of hole to be drilled as 6.9 mm. Also a 14.8 mm dia step was created for 2 mm depth as shown the figure. The total length of anvil is 25.6 mm.

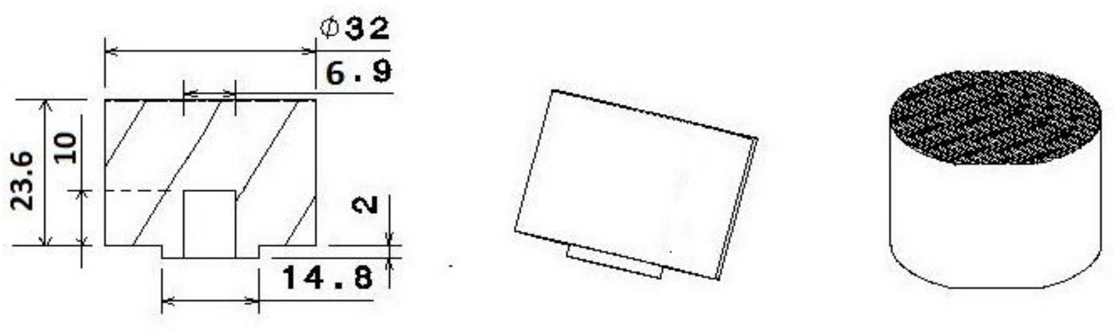

Fig. 3.3 Anvil Design

3.3.3 Fabrication of Anvil

Various operations performed for fabrication of anvil are:

- Cutting

A long rod of SS 304 was cut into two pieces with slightly more than the required dimensions (i.e. 32 mm) so as to give the sufficient tolerances. Cutting was done by using a power saw. Since normal cutting blade can't be used to cut SS 304, a bi-metal blade was used to accomplish the task. Adequate amount of coolant was given at the time of cutting, otherwise there was a chance of blade breakage.

- Turning & Facing

Carbide tipped tool was used to machine the SS 304 workpiece as the hardness of HSS tools are matching with that of SS 304. Since SS 304 made materials were very sharp edged it is recommended to wear goggles at the time of machining. First of all workpiece was gripped on a 3 jaw chuck. Then centering was done by making the tool at the centre of the workpiece by adjusting the tool post. After that machining starts. Turning was done on a Lathe in which water was used as coolant. Water had to be given in an excess amount since more heat generation was there while machining. Then, anvils were turned to required dia of 32 mm. Now, the tool post was rotated to a definite amount & facing operation was conducted to reduce the anvil length to 25.6 mm.

- CNC Machining

The SS 304 rod which has the length of 25.6 mm and dia 32 mm were now needed to be machined to make the step of 14.8 mm and the drill of 6.9 mm. For that, the workpiece was set on the machine and offsetting was done to match the coordinate system to new coordinates of the workpiece. Then, a manually written program was inputted to the system by using a keyboard.

CNC Milling was started to machine top surface to dia 14.8 mm for 2mm depth by using a profile milling end mill cutter. For drilling, new program was entered into the machine and the cutter was also changed. Drilling of 6.9 mm dia hole was done by means of a 7mm HSS end mill cutter to a depth of 12mm. Sufficient amount of coolant was given while performing both operations.

- Internal Threading

Internal threading of SS 304 anvil was performed with the help of 8 mm HSS tapper. Firstly, the tap was fixed on a tap holder. Then, anvil was fixed on a bench vice tightly and tap was inserted to the 7 mm drilled hole. Three different taps are available for successful threading. These taps were to be used one after the other so that thread was tight after the action of each tap. Each taps were rotated CW and CCW alternately to finish the process. Finally, the whole process was repeated for the second anvil also.

- Wire EDM cutting

Table 3.4 Cutting specifications for Wire EDM

Anvil cap no.	Material	Cutting width (mm)	Non cutting (mm)	Angle (degrees)
1	D2 steel	0.55	0.65	75
2	SS 304	0.55	1	45
3	SS 304	0.55	1	75

Fig. 3.4 Wire EDM cutting (status: M/C OFF)

A Wire EDM machine was employed to cut/machine the anvil cap according to the specification setting in table 3.4. As per the above given values, a program was written which consists of G codes and space coordinates to machine the two SS 304 anvils. Wire has the dia of 0.25 mm. First of all, the workpiece had to fix on to the machine. But, there was no holding device for that because of length considerations. So, to overcome this we have designed a holding device from a scrap piece of Mild Steel.

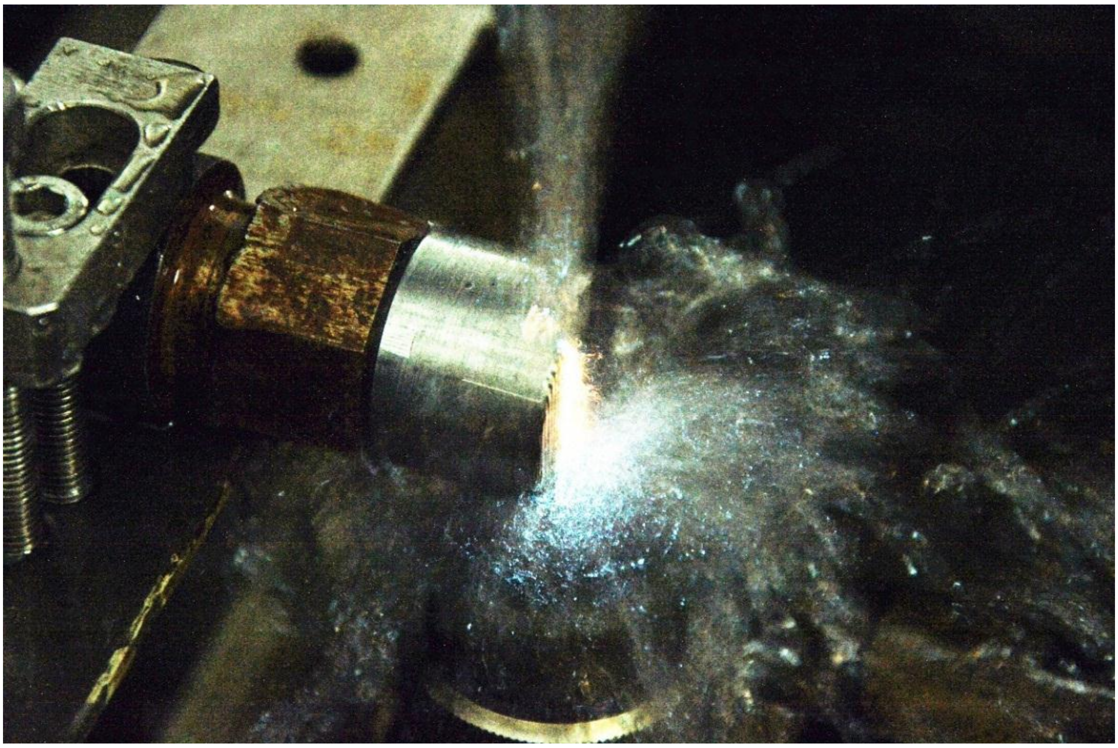

Fig. 3.5 Wire EDM cutting (status: M/C ON)

Now, the program written was transferred to the machine by using a USB disk. The machining process was started by executing the program. First straight cut was completed by giving depth of 0.6 mm and all other parameters as shown in the table 3.3. During second cut, only the angle changes as per the table and all other parameters remains the same. Distilled water was used as a coolant at the time of machining.

4 Experimental Design & Methodology

4.1 Preparation of Weld Coupons

Weld coupons of thickness 0.3 mm each of Al and Cu were chosen as specimen piece. Length and breadth of coupons were decided as 80 mm × 20 mm respectively. Now, series of actions were performed to make the coupons ready for final operation (i.e. Welding).

- The Cu and Al sheets were cut as per the above said dimensions. Cutting was done by using a sheet cutter snipping tool which can cut sheets easily by hand.
- Then, the cut sheets were straightened by using a hammer. Only required portions which had a bend or bulging were hammered. Excess hammering was also not desired for the reason that it deforms the material too much.
- The weld coupons were now cleaned to remove from surface impurities or contaminants. From the literatures it was found that, ethanol solution can be used as the cleaning agent and it can improve the welding strength up to 50%.
- Finally, marking was done on weld coupons so that proper positioning of weld coupons can be accomplished on the anvil cap. A cross mark is done on Al coupons since it is placed on the top during welding process.

4.2 Experimental Design

- ***Design of Experiment***

To study the effect of anvil geometry on welding process experiments have to be conducted with a particular design. This design must be feasible also. Design of Experiments (DOE) is a statistical tool for achieving this. By using DOE we can study the effects of multiple variables on the performance of welding process. This method requires only limited experimental runs for good precision or accuracy. Also, if there is interaction effects coming into picture those effects can be studied by this particular process.

In this work two performance characteristics are considered: Tensile strength and T-peel strength and process parameters as amplitude, weld pressure and weld time. So, 3 factors are set and it is decided to vary these in 3 levels. So, experimental domain table will be:

Table 4.1 Domain of experiment

Factors	Notation	Unit	Level 1	Level 2	Level 3
Amplitude	A	µm	54	60	68
Weld Pressure	WP	bar	1.4	2.4	3.2
Weld Time	WT	sec	0.22	0.24	0.26

- ***Taguchi's Orthogonal Array (OA)***

Orthogonal Arrays are actually meant for improving process as well as product quality and the experimental runs required is also less. Thus, much amount of time and resources can be saved. It also gives an idea about the dependency of process variables on mean and variance of response characteristics. The method can optimize performance characteristics through determination of best parameter settings and reduces the sensitivity of the system performance to sources of variation.

Since 3 factor 3 level was decided suitable orthogonal array will be L9 and the table is shown below.

Table 4.2 Taguchi's L9 orthogonal array

Run No.	A	WP	WT
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.3 Methodology for Data Analysis

Optimization is basically the art or procedure of picking the best alternative among a given set of finite or infinite options available. It has become a vast topic which extends to many areas like mathematics, engineering, natural sciences, etc. Every optimization problem will have an objective function which have to be maximised or minimised under a specific no. of constraints. The process of optimizing two or more differing attributes simultaneously subject to certain restrictions is called Multi-Objective Optimization (MOO). The application of MOO is very wide. In the fields of automobile design, oil and gas industry, manufacturing sector etc. MOO can be successfully applied. MOO is the only tool available to decide one or more options from the given set of different factors.

Numerous methods are available to optimize the output parameters and to find out which is the best setting for the given DOE based on the input set. Since we are considering two response parameters, the problem becomes a multi-objective optimization one in which we have to maximize or minimize the output. Next task was to find out the multi-objective optimization technique to be followed. So, there came one of the newest and efficient method known as MOORA. Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) method can be applied to problems related with manufacturing environment. MOORA method converts a multi-objective optimization problem to single one. The steps for MOORA method was discussed in the next section.

From the output of MOORA method Taguchi method was used for further optimization. Taguchi method is a very common technique implemented to optimize the response data. The main peculiarity of this design is that noise factors are also included. Taguchi method utilizes a statistical quantity called Signal-to-Noise (S/N) ratio, in order to test the results. After drawing S/N ratio plots optimum setting of the data can be found out. After that, a prediction is performed based on the optimal setting. The predicted optimum setting need not correspond to one of the rows of the matrix experiment in Taguchi method for parameter design Therefore, an experimental confirmation is run utilizing the predicted optimum levels for the process parameters being investigated.

4.3.1 Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA)

Brauers and Zavadskas (2006) presented Multi-Objective Optimization by Ratio Analysis (MOORA) method on the basis of former studies. This is a very simple method which can be used for MOO in manufacturing area. The given multi-behavioural performance factors there may be having different objectives in which some may be following beneficial criteria (max. values are desired) and some non-beneficial (min. values are desired). This method converts the MOO problem to Single Objective Optimization (SOO) one by following a series of procedures and then optimizes it. The steps are as follows:

Step 1: The first step in this technique is to select the objective and to identify the appropriate response attributes.

Step 2: Then symbolise all the experimental values for the attributes in the form of a decision matrix. Here matrix is of the order m × n.

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} \end{pmatrix} \tag{4.1}$$

Where,

x_{mj} = the response value of ith alternative on jth attributes

m = number of alternatives

n = no. of response attributes

Then a ratio is calculated in which each response value of an alternative is compared to a denominator which is representative of all the alternatives concerning that response.

Step 3: Brauers et al found out that for this denominator, the best choice is the square root of sum of squares of each alternative per response. The ratio can be expressed as:

$$x^{*}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x^{2}_{ij}}} \tag{4.2}$$

Where, i=1, 2, 3………., n

And x^{*}_{ij} is a dimensionless number which belongs to the interval [0, 1] representing the normalized performance of i^{th} alternative on jth attribute.

Step 4: For multi-objective optimization, these normalized performances are added in case of maximization (for beneficial outputs) and subtracted in case of minimization (for non-beneficial outputs).then the problem becomes,

$$y_i = \sum_{j=1}^{g} x^{*}_{ij} - \sum_{j=g+1}^{n} x^{*}_{ij} \tag{4.3}$$

Where, g is the number of responses to be maximized, (n-g) is the number of responses to be minimized, and y_i is the normalized assessment value of ith alternative with respect to all the responses. In some circumstances, it is often observed that some responses are more important than the others. In order to give more importance to a particular response, it could be multiplied with its corresponding weight. When these response weights are taken into consideration, above equation becomes:

$$y_i = \sum_{j=1}^{g} w_j x^{*}_{ij} - \sum_{j=g+1}^{n} w_j x^{*}_{ij} \tag{4.4}$$

Here, w_j is the weight of jth attribute, which can be determined using Analytic Hierarchy Process (AHP) or entropy method.

Step 5: The value y_i can be positive or negative depending of the totals of its maxima (beneficial responses) and minima (non-beneficial responses) in the decision matrix. An ordinal ranking y_i of shows the final preference. Thus, the best alternative has the highest y_i value, while the worst alternative has the lowest y_i value.

4.3.2 Taguchi Method

Taguchi method was developed by a Japanese engineer and statistician named Genichi Taguchi. Taguchi method mainly emphasise on increasing quality and reducing wastage. Many variety of engineering managing problems which we see today can be solved by using this. It actually does this by optimizing response values by adjusting the alternatives and also decreasing the wastage or loss. Any modern manufacturing firm will implement Taguchi if they want off-line quality control and continuous rise in quality standards. Taguchi's view on quality is widely accepted one and is given below:

1. Quality should be designed into the product and not inspected into it.
2. Quality is best achieved by minimizing the deviation from the target. It is immune to uncontrollable environmental factors.
3. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Taguchi suggested a 3 stage design methodology for the parametric evaluation of a definite process: System design, parameter design and tolerance design. Since we have to find out the best parameter settings, parameter design is adopted in this work.

Taguchi formulates a new function called Quadratic quality loss function for the efficient evaluation of performance parameters. Then a robust design can be achieved by coalescing this quality loss unction with experimental design model. Fig. below illustrates the quality loss function.

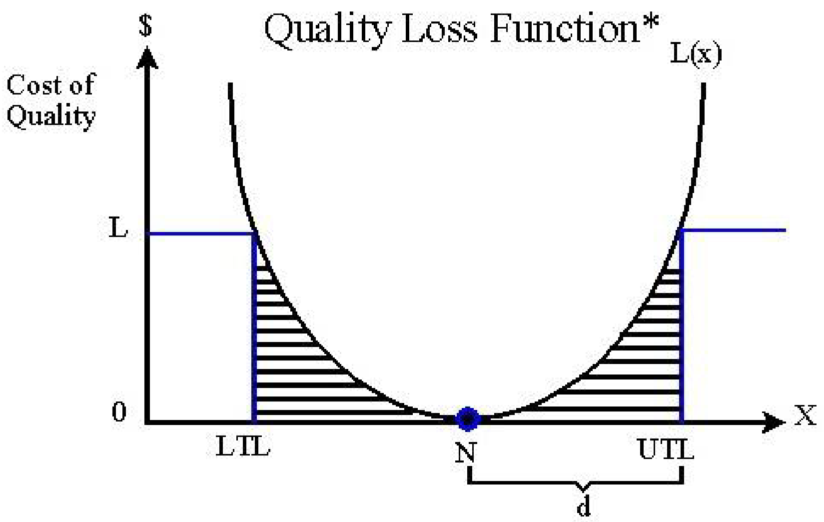

Fig. 4.1 Taguchi's Quality Loss Function, (*Source*: Anderson & Sedatole's Fig. 2, page-218)

L = Loss associated with producing outside of tolerance limits in the traditional quality loss Function

L(x) = Loss associated with producing anything other than the nominal specification in the Taguchi Loss Function

LTL = Lower tolerance limit

UTL = Upper tolerance limit

N = Nominal specification

d = Difference between nominal specification and tolerance limit

- *S/N ratio for Performance Evaluation*

Taguchi articulated a performance or response measure statistically called S/N ratio, to study the outcomes effectively. A signal of a particular effect can be defined as variation in quality characteristic of a product in response to a factor introduced into the experimental design. The effect of external causes of consequence of the quality characteristics is known as noise. The electrical engineering theory defined by ratio of signal power to noise power corrupting the signal has now become a global statistical concept.

The responses obtained from experimentation are then converted to S/N ratio by using certain equations. S/N ratio can also be defined as the measure of deviation from the desired value. But this can only be calculated for one variable problem. So, multi-objective optimization problem must be converted to single one. Then the highest value of S/N ratio is taken as the as the best choice, because signal is very much greater than noise factors. Signal to noise ratios are of 3 types based on the quality characteristic:

1. Nominal- the-Best (NB) or Target-the-Best (TB)

   The closer to target value, the better is quality. Here quadratic deviation is assumed. The formula for this is:

$$ {}^{S}\!/_{N}\, Ratio = 10 \log \left(\frac{y}{S^2{}_y} \right) \tag{4.5} $$

2. Lower-the-Better (LB)

   This criteria is used when smaller values are preferred by the response data. Formula is

$$ {}^{S}\!/_{N}\, Ratio = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y^2 \right) \tag{4.6} $$

3. Higher-the-Better (HB)

   This is used when higher values of a particular responses are preferred.

$$\frac{S}{N}\, Ratio = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right) \tag{4.7}$$

Here,

y = Average of observed values;

$S^2{}_y$ = Variance of y;

n = Number of observations

4.4 Proposed methodology for data analysis (MOORA combined with Taguchi)

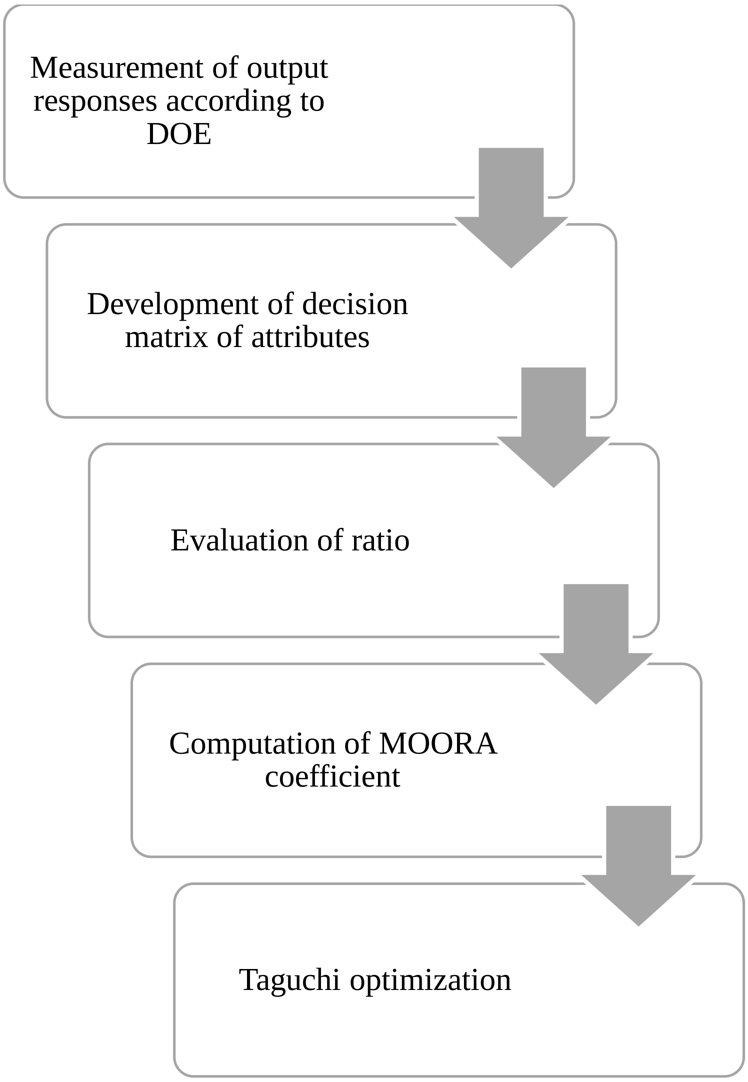

Fig. 4.2 Proposed methodology for data analysis

5 Data analysis & Optimization

5.1 Data Analysis

The input parameters in this experiment are amplitude, weld pressure and weld time. These are varied in 3 levels as fixed earlier. The optimal parameter setting was obtained by combining MOORA with Taguchi. The table below shows the uncoded values of each alternative corresponding to each factor level using L9 orthogonal array.

Table 5.1 L9 Orthogonal Array (uncoded values)

Run No.	A	WP	WT
1	54	1.4	0.22
2	54	2.4	0.24
3	54	3.2	0.26
4	60	1.4	0.24
5	60	2.4	0.26
6	60	3.2	0.22
7	68	1.4	0.26
8	68	2.4	0.22
9	68	3.2	0.24

The response values of performance parameters Tensile strength (TS) and T-peel strength (TS) are measured by using mechanical tester for each anvil and tabulated in table below:

Table 5.2 Experimental data for 3 anvils

Run No.	A (μm)	WP (bar)	WT (sec)	Anvil-1		Anvil-2		Anvil-3	
				TS (N)	TP (N)	TS (N)	TP (N)	TS (N)	TP (N)
1	54	1.4	0.22	183.37	61.87	269.6	83.63	363.8	98.12
2	54	2.4	0.24	312.61	115.83	347.4	124.69	560.7	132.69
3	54	3.2	0.26	149.51	65.3	590.9	136.63	631	147.44
4	60	1.4	0.24	308.25	86.12	387.6	89.63	415.3	112.36
5	60	2.4	0.26	264.55	93.3	540.7	136.53	580.9	139.56
6	60	3.2	0.22	349.03	103.39	570.8	153.69	640.8	173.26
7	68	1.4	0.26	231.87	66.72	427.7	99.67	432.3	122.47
8	68	2.4	0.22	461.33	133.3	560.7	148.96	600.9	169.34
9	68	3.2	0.24	345.63	96.87	646.1	183.37	670.9	202.86

- ***MOORA Method***

Step 1: The decision matrix is obtained by allocating the row of this matrix to one alternative and each column to one response value and are given in table 5.2.

Step 2: The values of normalized ratios for each alternative for each anvil has been calculated and presented in Table 5.3.

Table 5.3 Computed Normalized Ratios for 3 anvils

Run No.	Anvil-1		Anvil-2		Anvil-3	
	TS*	TP*	TS*	TP*	TS*	TP*
1	0.202	0.219	0.181	0.211	0.219	0.222
2	0.344	0.41	0.233	0.314	0.337	0.3
3	0.164	0.231	0.396	0.344	0.38	0.333
4	0.34	0.305	0.26	0.226	0.25	0.254
5	0.291	0.33	0.362	0.344	0.35	0.315
6	0.384	0.366	0.383	0.388	0.386	0.391
7	0.255	0.237	0.287	0.251	0.26	0.277

8	0.507	0.472	0.376	0.376	0.361	0.383
9	0.38	0.343	0.433	0.462	0.404	0.458

Step 3: The MOORA coefficient (MC) for each anvil has been computed separately as illustrated in Table 5.4 so that it can be further analysed by Taguchi method.

Table 5.4 MOORA Coefficient corresponding to 3 anvils (MC)

Run No.	MOORA Coefficient (MC)		
	Anvil-1	Anvil-2	Anvil-3
1	0.421	0.392	0.441
2	0.754	0.547	0.637
3	0.395	0.741	0.713
4	0.644	0.486	0.504
5	0.621	0.707	0.665
6	0.75	0.77	0.777
7	0.491	0.538	0.537
8	0.979	0.751	0.744
9	0.723	0.895	0.862

5.2 Optimization by Taguchi Method

- ***For Anvil-1***

Now, the problem becomes single objective optimization. So, from MOORA Coefficient corresponding S/N ratio has been computed utilizing Higher-is-Better (HB) criteria. Further optimal setting of parameters has been determined from main effect plot of S/N ratio.

Table 5.5 MOORA Coefficient and corresponding S/N ratio

Run No.	MC	S/N Ratio	Pred. S/N Ratio
1	0.421	-7.524	0.0149
2	0.753	-2.47	
3	0.395	-8.059	
4	0.644	-3.827	

5	0.621	-4.138
6	0.75	-2.503
7	0.491	-6.178
8	0.979	-0.185
9	0.723	-2.819

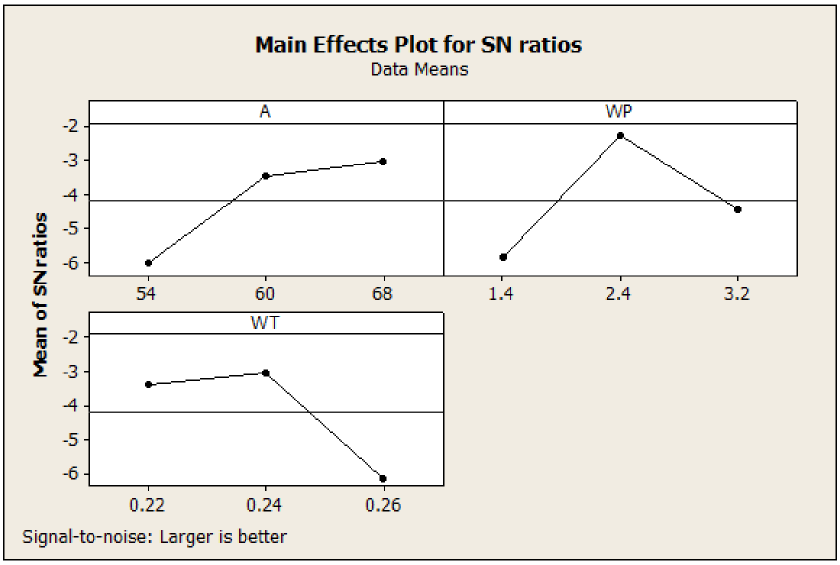

Fig. 5.1 Main effect plot of S/N ratio for anvil-1

The optimal setting obtained from Main effect plot corresponding to the highest value of S/N ratio is given in table 5.6.

Table 5.6 Optimal setting of process parameters

Factor	A	WP	WT
Level	68 µm	2.4 bar	0.24 sec

- ***For Anvil-2***

The MOORA coefficient and corresponding S/N ratio for anvil 2 is given in the table below.

Table 5.7 MOORA Coefficient and corresponding S/N ratio

Run No.	MC	S/N Ratio	Pred. S/N Ratio
1	0.392	-8.143	-0.474
2	0.547	-5.236	
3	0.741	-2.608	
4	0.486	-6.270	
5	0.707	-3.015	
6	0.770	-2.268	
7	0.538	-5.384	
8	0.751	-2.482	
9	0.895	-0.959	

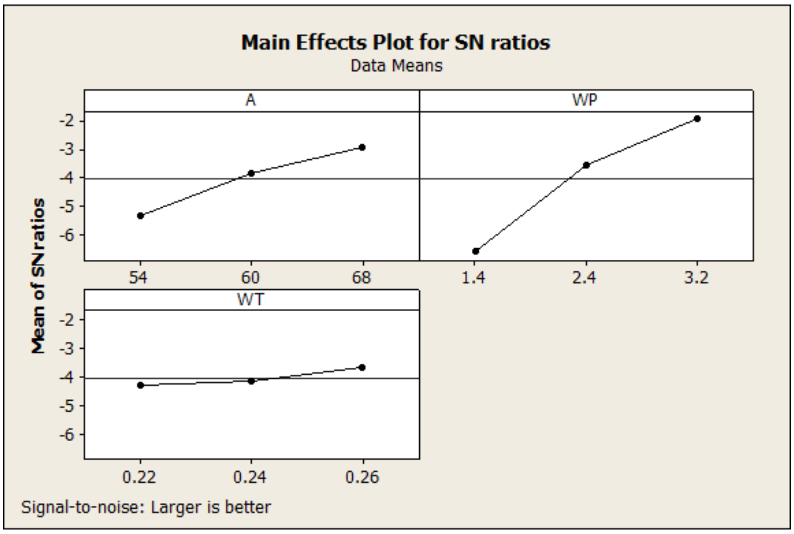

Fig. 5.2 Main effect plot of S/N ratio for anvil-2

The optimal setting obtained from Main effect plot corresponding to the highest value of S/N ratio is given in table 5.8.

Table 5.8 Optimal setting of process parameters

Factor	A	WP	WT
Level	68 µm	3.2 bar	0.26 sec

- ***For Anvil-3***

The MOORA coefficient and corresponding S/N ratio for anvil 3 is given in the table below.

Table 5.9 MOORA Coefficient and corresponding S/N ratio

Run No.	MC	S/N Ratio	Pred. S/N Ratio
1	0.441	-7.121	-1.187
2	0.637	-3.916	
3	0.713	-2.942	
4	0.504	-5.957	
5	0.665	-3.547	
6	0.777	-2.193	
7	0.537	-5.405	
8	0.744	-2.568	
9	0.862	-1.291	

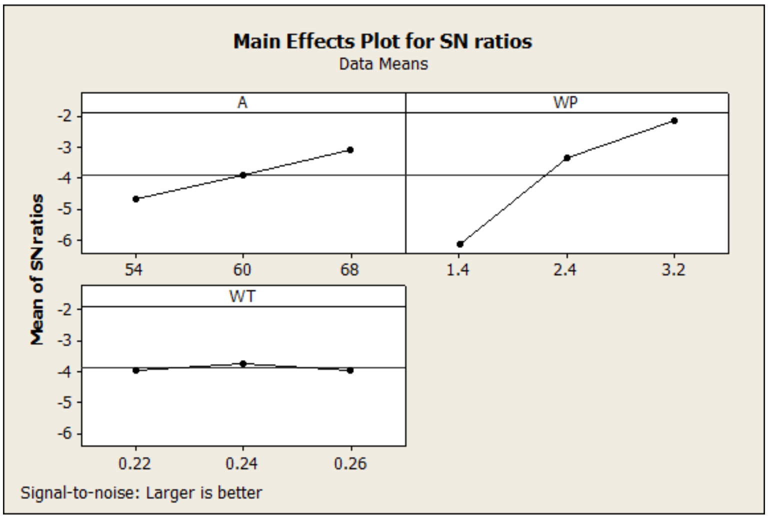

Fig. 5.3 Main effect plot of S/N ratio for anvil-3

The optimal setting obtained from Main effect plot corresponding to the highest value of S/N ratio is given in table 5.10.

Table 5.10 Optimal setting of process parameters

Factor	A	WP	WT
Level	68 µm	3.2 bar	0.24 sec

6 Results & Discussion

6.1 Impact on Anvil

Since many more no. of experiments have been conducted using anvil-1 it is difficult to explain the impact on this particular cap. However, the the projected portions are almost damaged due to continuous application of ultrasonic vibrations and projections are cut off by a definite amount also. Hence breakage points are there in the anvil. Since the experiments which we have conducted was very less, the impact does not fully account only for our experimental runs.

Good no. of experiments have been done using anvils 2 & 3. But, before that some trial experiments were also done on each for the proper selection of welding process parameters. For, Anvil-2 it is very clear that the shining portion or top layer is totally removed because of the high intensity of vibrations. The damage or shape change didn't takes place for anvil-2. The face of anvil-2 was made diamond or rhombus shaped, so that the spot welding area will be more. But, it have no greater difference as far as impact is concerned.

Anvil-3 was the one which is parallelogram shaped. Here also the topmost shining portion or top layer is totally removed from the surface after welding process. Also some damaged portions are also found as we move along the surface of anvil-3. Sticking of workpieces and anvil was not at all found at any time during welding process. Hence, anvil wear was almost same for both anvils 2 & 3.

6.2 Effect on Welding Strength

Welding Strength is the most important performance factor in any welding process. In this work, welding strength is taken as the combination of Tensile strength (TS) and T-peel strength (TP). SS 304 material is far better when compared to D2 Steel. Because SS 304 is having much good properties needed for anvil making like good wear resistance, good hardness and good corrosion resistance. Following is the % increase calculation for TS & TP. Only maximum values of the entire TS or TP column was considered here.

Percentage increase of TS btw anvil 1 & 2 = 40.05 %

Percentage increase of TS btw anvil 1 & 3 = 45.43 %

Percentage increase of TS btw anvil 2 & 3 = 3.8 %

Percentage increase of TP btw anvil 1 & 2 = 37.5 %

Percentage increase of TP btw anvil 1 & 3 = 52.18 %

Percentage increase of TP btw anvil 2 & 3 = 10.6 %

Anvil 2 & 3 corresponds to same material. Only geometrical difference or shape difference is there between them. Percentage increase calculation suggests that the geometrical changes in the anvil cap do affects the welding strength. 10.6 % increase was found in TP and 3.8 % increase in TS. Although the TS value is small, TP value can't be neglected. The overall study reflects that highest strengths are obtained for anvil 3.

6.3 Effect on Weld Quality

- ***Anvil-1***

On closely examining the interface geometry of the welds the weld quality can be easily recognised. On the basis of quality of weld interfaces, it can be classified into three: good weld, over weld and under (low) weld.

Over weld: Al particles are deformed more compared to Cu. Some irregular peaks are also found in the Al portion. This may be due to increased weld energy or weld times so that they got enough time to deform.

Good weld: The upper portion of Al spreads across the surface uniformly and without any gap between the interfaces of Cu. No overlapping was found in this area. Interface is almost straight with minimum waviness.

Under weld: There is small gap between the contact surfaces in this particular weld. This is called parting line. Also Al is not uniformly distributed over the Cu surface. There is much waviness seen here which may be because of the pressure gradient grooves on the anvil cap and the sonotrode tip.

- ***Anvil - 2&3***

For anvil-2 the peaks are almost irregularly shaped. An undercut was seen in anvil-3. Wake features are high in this weld interface. Al particles was never seen overlapped with

Cu. The undercut may be occurred due to the sharpness property of SS 304. Anvil-2 possess better contact surface than anvil-2 in this particular case, because at some potions Al particles are missing in the weld islands. But, both are over welded specimens only.

The good welds are shown in the figure below. These type of contact surfaces will be having very good strength. Waviness is found in good amount in both anvils. Penetration of Al particles into Cu particles is dominantly seen in anvil-3.

In low welded specimens the projections or spot welded peaks are very rarely seen. The Al portion doesn’t have peaks or projections at all. It becomes almost plain. Same is the case in anvil-3 also. Bottom Cu part is very well shaped but have no advantage, since the strength will be less. An unwelded region is found in anvil-2.

6.4 Confirmatory Test Results

Confirmatory tests are conducted for the 3 anvils separately based on the optimal setting parameters obtained from Taguchi method. On this condition, highest weld strength must be obtained. Again, with that combination, one more experiment was carried out and the corresponding S/N ratio was also found out. The value obtained from the experiment was compared with the predicted value and percentage error was found out.

7 Conclusions & Future Scope

In this work, anvil geometry was successfully designed and effect of the same on response parameters was studied. Fabrication of anvil was done effectively with good accuracy. 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. Design of an acoustic horn also can be carried out with different tip geometry and the effects of same can be compared with previously collected results.

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