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# Simulation of Temperature Distribution and Stress Development between Two Overlapped Ultrasonically Welded Copper Plates

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***Abstract* - Ultrasonic welding process is one of the types of solid state welding process for joining two similar as well as dissimilar surfaces. This method can be applied for meatal & non-metal including plastic category material. Heat generation due to temperature stresses in an ultrasonic welding joint is considerable characteristic for the development of strength of these joint. On that event, ultrasonically welded joint had been prepared in ANSYS simulation software for the analyzing the heat generation and temperature distribution throughout the considered section. The joint had been made by copper material (99% Cu with 1% Alloying material). The temperature of joint had been considered to be changing from 25ºC to heating point of 800ºC and then allowed to be cooled naturally up to 200ºC. Also, the convection and radiation phenomena were considered during the analysis of the joint. The results show that the temperature distribution follows the linear path in joint section and heat dissipation rate had been found to be maximum for the joint section. The thermal stresses generated due to the clamping force required to hold or clamp copper plates during ultrasonic welding were evaluated.**

*Keywords- Finite Element Analysis, Heat Generation, Ultrasonic Welding, etc.*

## I. INTRODUCTION

Ultrasonic welding is a process of joining two components by converting electrical energy into heat power by high frequency mechanical oscillations and is commonly suitable for joining of plastics, metals and some non-metals. In this phenomenon, large frequency vibrations are combined with load or pressure to join two materials together rapidly and less risky, without generating significant magnitude of heat. Ultrasonic welding has the capacity to weld metals of significantly variable melting points; metals that usually form brittle alloys at the weld junction, and joints that are in close proximity to heat sensitive components. Finally, ultrasonic welds are made without consumables, such as solder or filler that would ordinarily be used in traditional joining processes and with far less energy usage than conventional joining technologies. There are certain limitations on the types of joints that can be made with ultrasonic welding. It is limited initially to the joining of metals of non-ferrous contents and plastic parts.

## II. LITERATURE REVIEW

During Ultrasonic Metal Welding (USMW), plastic elongation, elastic hysteresis property and friction generate heat at the face of materials to be joined. In the later sections results are studied from previous work of innovators who have invented and evaluated the temperatures at the interface during welding. Performing the temperature measurement generated in the weld area is crucible for finding the Heat Affected Zone (HAZ) and the pattern of temperature generated. Daniels (1965) explained preliminary studies on the parameters that affect the weld strength and suggested the condition for obtaining a good weld. The performance revealed that good weld are totally depends on the power used, force in clamping, and time for welding, size of work piece and physical and mechanical properties of the material to be welded. This work evaluated the temperature at the contact interfaces by evaluating the thermoelectric voltage load between the work pieces during welding process. It was observed that the temperature at the interfaces developed is not more than 40% of the melting point of the base metal.

The work by Joshi (1971) described the production of metal to metal ultrasonic bonds. In pure, face centered cubic metals (Al, Cu, and Au) the development of joints at and near optimum parameter has been found to be essentially devoid of relative motion between interfaces and excess heating. In this research work, temperature investigation was completed using infrared radio meter, liquid crystals and thermocouples.

Dissertation by De Vries (2004) presented the applied mechanics and optimum mechanism of USMW. In this work, temperature was measured during welding of aluminum by infrared camera for different welding positions. It was concluded that interface temperature varied from 40 to 80% of the melting point depending on the value of the parameters used for welding.

Jeng and Horng (2001) had performed the effects of applied load, surface roughness, welding power and welding time on joint strength using an ultrasonic welding machine and a pull type tester. Asperity model was used to compute real contact area and flash temperature between the wire and the pad. The observations revealed that, a decrease in load or ultrasonic power produces a wide weldable range in which the combination of parameters allow the wires and pad to be welded. It was found that the contact temperature plays an important role in joining strength in the initial period, and surface roughness is the dominant factor in the final period. The maximum joint strength occurs in the initial period for different loads and surface roughness values.

Ding et al. (2001) studied the elongation and stress distributions in the wire and bond pad during the ultrasonic wire bonding using the 2D and 3D finite element models. It was observed that the maximum intensity of frictional energy occurred at the periphery of the contact interface where weld is preferentially made. The total frictional energy increased linearly with bond force, but the highest intensity of frictional energy obtained at the periphery of the contact interface did not show a similar increase.

Hazlett and Ambekar (1970) performed preliminary studies on the interference temperature and bonding mechanisms in USMW. Temperature rise during welding cycle was determined by utilizing the Seebeck (thermocouple) effect and ensuring voltage produced between the dissimilar metals being joined and thereby measuring the average temperature over the weld area. Combination of aluminum, brass, copper, stainless steel and nickel were welded under various conditions to determine their response in this study.

Thus, from literature review it is observed that research activities are buoyant in USMW and there is enough scope to carry out studies on "Temperature and stress distribution in ultrasonic metal welding" as such a work seems to be not reported and hence the relevance of this work.

## III. OBJECTIVES

The objectives of this study are Specific He

1. To simulate the temperature distribution at weld interface, sonotrode and anvil during ultrasonic welding of metallic materials (Copper alloy).
2. To simulate the stress distribution in the joint and sonotrode during USMW.
3. To simulate the temperature distribution for varying work piece thickness, and surface properties (coefficient of friction). These simulations are done using ANSYS.
4. To study the effect of clamping force, weld time, material thickness and co-efficient of friction on temperature at the interface and HAZ by simulation.

When new metals and weld conditions are encountered and they pose difficulties in achieving quality welds, a study of this nature can provide a direction for the researchers to proceed towards optimum values of parameters. In this work, copper is considered as a work piece.

## IV. MATERIALS AND METHODOLOGY

The following assumptions are made in simulating the temperature distribution using ANSYS 20.0.

1 The sonotrode that was used in this analysis had a uniform cross-sectional area (circular) at the tip.

2 There was no air gap between the two aluminum sheets (perfect contact).

3 At the end of the weld, the area of the sonotrode $A$ will be equal to the area of the deformation zone $A$ and will be equal to the area of the weld $A$.

4 The room temperature is assumed to be uniform and it is taken as 30◦C.

The material properties considered were coefficient of thermal conductivity ($k$) specific heat ($c$) and density ($\rho$) for performing thermal analysis. Young's modulus, Poisson's ratio and coefficient of thermal expansion were considered for performing structural analysis. The properties of the materials (ASM Handbook vols.1&2,1990 and 1998) used for sonotrode, work piece and anvil are listed in Table 1. The size of the joint as follows:

Length = 50 mm

Width = 25 mm

Thickness = 5 mm

Table 1 Thermal and Physical Properties of the copper materials

| | |
|---|---|
| Thermal Conductivity | 393 |
| Specific Heat | 385.2 |
| Density | 8900.00 |
| Young modulus | 117 |
| Thermal expansion | 1.66 $\times 10^{-5}$ |

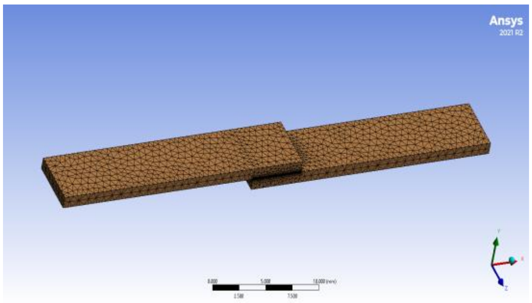


Fig. 1 Meshed Model of ultrasonically joint

## V. RESULTS AND DISCUSSION

The performance of the ultrasonically joint was tested by creating the solid model in Creo and then utilized ANSYS 20.0 (Fig. 1) to observe the temperature distribution and heat flux rate in the model. The Fig. 2 represents the contact connection between the interfaces of the joint.

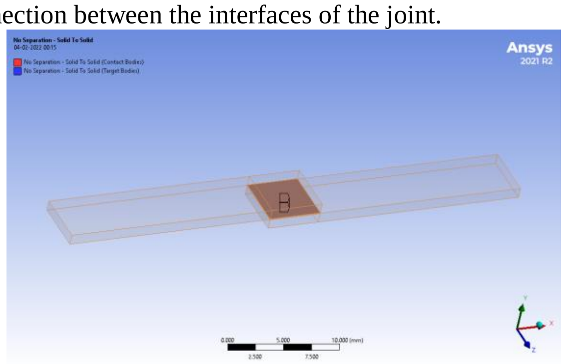


Fig. 2 Contact of interfaces of joint

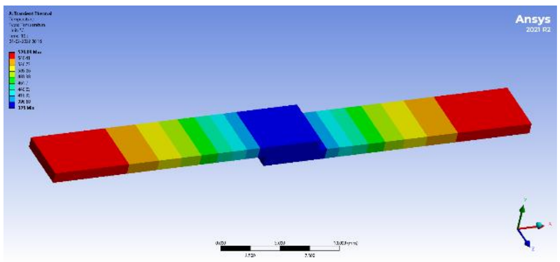


Fig. 3 Temperature in Transient Thermal Analysis of joint

The Fig. 3 represents the transient thermal analysis of the developed ultrasonically welded joint. The analysis observed that the maximum temperature obtained in analysis is $570^0$C. The minimum temperature observed for the joint analysis is $375^0$C. The Table 2 represents the temperature, heat flux, deformation and stress at certain design points in a welded section with time.

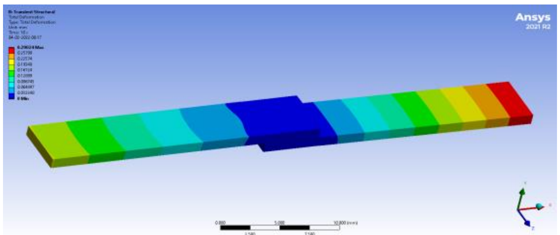


Fig. 4 Total Deformation in Transient Structural Analysis.

The Fig. 4 shows the total deformation in the ultrasonically welded joint. The maximum deformation of 0.29 mm was observed to one end of the joint. The deformation at the center of the joint was zero or minimum since the joint had been fixed and negligible plastic deformation was observed at the center of the joint. The von miss stress was observed to be 11.56 GPa in case of combined transient thermal analysis and transient structural analysis (Fig. 5). The stress is more indicating that the joint is subjected to thermal load up to $800^0$C and a clamping load of 7 bar pressure.

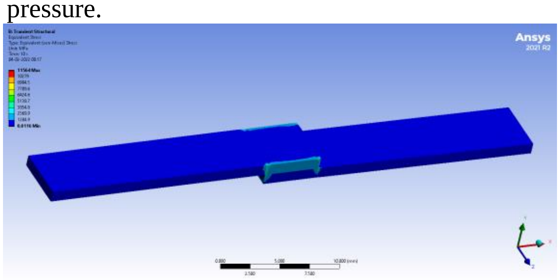


Fig. 5 Von Miss Stress in joint.

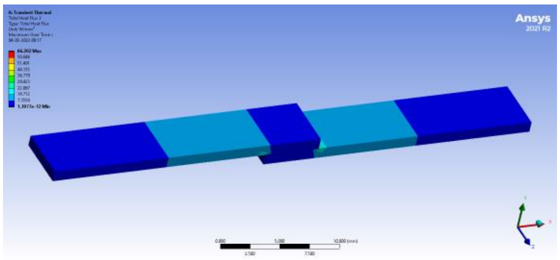


Fig. 6 Total Heat Flux in the joint.

Table 2 Observations from the Simulation of Joint

| Time [s] | Temperature [°C] | Heat Flux [W/mm²] | Deformation [mm] | Stress [MPa] |
|---|---|---|---|---|
| 0.1 | 50.833 | 12.978 | 1.88E-02 | 974.41 |
| 0.2 | 76.667 | 19.565 | 3.54E-02 | 1839.7 |
| 0.5 | 154.17 | 31.157 | 8.58E-02 | 4420 |
| 1 | 283.33 | 43.511 | 8.58E-02 | 4420 |
| 1.5 | 412.5 | 52.166 | 8.58E-02 | 4420 |
| 2 | 541.67 | 58.396 | 0.17214 | 8724 |
| 2.5 | 670.83 | 62.915 | 0.17217 | 8724.1 |
| 3 | 800 | 66.202 | 0.17217 | 8724.1 |
| 3.5 | 800 | 39.766 | 0.17217 | 8724.1 |
| 4 | 800 | 27.941 | 0.17217 | 8724.1 |
| 4.5 | 800 | 20.149 | 0.2606 | 13047 |
| 5 | 800 | 14.63 | 0.2606 | 13047 |
| 5.5 | 800 | 10.644 | 0.2606 | 13047 |
| 6 | 800 | 7.7486 | 0.2606 | 13047 |
| 6.5 | 800 | 5.642 | 0.2606 | 13047 |
| 7 | 800 | 4.1083 | 0.3508 | 17390 |
| 7.5 | 767.55 | 12.818 | 0.3508 | 17390 |
| 7.9382 | 752.82 | 20.359 | 0.3508 | 17390 |
| 8.3765 | 727.1 | 25.6 | 0.3508 | 17390 |
| 8.8765 | 686.69 | 29.85 | 0.3508 | 17390 |
| 9.3765 | 638.06 | 32.923 | 0.44221 | 21750 |
| 9.6882 | 605.13 | 34.474 | 0.44233 | 21750 |
| 10 | 570.09 | 35.731 | 0.44233 | 21750 |

## VI. CONCLUSION

An FEM based model for USMW has been developed, which can predict the temperature developed during welding process with parameters like material thickness, clamping force, weld time and coefficient of friction. This model, based on the forces and temperatures that occur during welding is applicable for a wide variety of ultrasonic welding problems. The limitations are given by the particular geometry of the sonotrode surface.

It is concluded that, the temperature observed in the joint is $570^0$C which is less than the melting point of copper. The deformation observed in the joint is 0.29 mm for the thermal and structural loadings. This improves the stability of the joint. Also, the heat flux found to be 66 watt/$m^2$ indicating that the joint is suitable for engineering applications.

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