An explained investigation of weld development in multilayer ultrasonic welding and the effect of weld pools on propagation mechanism

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ABSTRACT

Solid-state welding is a group of welding processes that produce sound joints at temperatures essentially below the melting point of the parent materials or without bulk melting of the parent materials. The joints produced by solid-state processes are usually free of various solidification defects such as gas porosity, hot cracking, and non-metallic inclusions, which may otherwise be present during fusion welding processes. No filler metals, flux, or shielding gas is required during solid-state welding process. The metal being joined can have mechanical properties similar to or even better than that of their parent metals due to the absence of defects and heat-affected zone in most of these processes. Unlike various fusion welding processes which are well known, solid-state welding is usually not well acquainted by industrial engineers. The purpose of this research is to determine the effect of various weld and machine parameters on ultrasonic weld strength. In this we are going to use thermosetting material named epoxy which is one of the low density polymers. By considering three main parameters that is amplitude, pressure and weld time we are going to conduct the experiment.

Keywords:.*Welding Processes, Solid-State Welding, Chemical Compatibility, Thermal Expansion, Amplitude, Weld Time, Pressure, Tensile Strength.*

I. INTRODUCTION

During ultrasonic welding of sheet metal, normal and shear forces act on the parts to be welded and the weld interface. These forces are a result of the ultrasonic vibrations of the tool, pressed onto the parts to be welded. Furthermore they determine the weld quality and the power that is needed to produce the weld. The main goal in this study is to measure and calculate the tangential forces during ultrasonic metal welding that act on the parts and the weld interface and correlate them to weld quality. In this study a mechanics based model was developed which included a model for the temperature generation during welding and its effect on the mechanical material properties. This model was then used to calculate the interface forces during welding. The model results were in good agreement with the experimental results, which included the measured shear force during welding. In the experiments the influence of part dimensions, friction coefficient, normal force and vibration amplitude on weld quality and sonotrode adhesion were examined. The presented model is capable of predicting and explaining unfavorable welding conditions, therefore making it possible to predetermine weld locations on larger parts or what surface preparation of the parts to be welded would lead to an improved welding result. Furthermore shear force at the anvil measured during welding could be correlated to changing welding conditions. This is a new approach of explaining the process of USMW, because it is based on mechanical considerations. The principle set up for ultrasonic spot welding is illustrated in figure 1. In this particular illustration what is known as a "wedge reed" welding system is shown. In a typical weld the joining of the overlapping sheets will occur in the deformation zone at the part interface directly beneath the sonotrode.

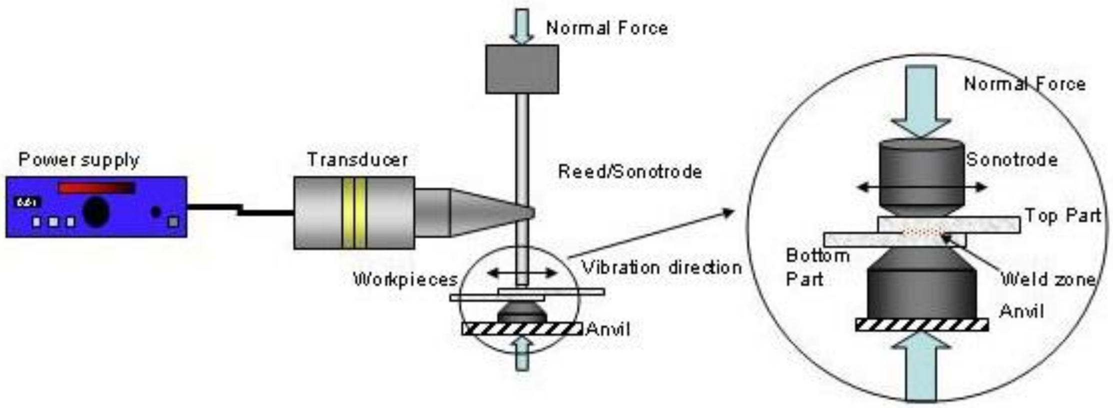

Figure 1: Principle USMW set up for spot welding.

The application of ultrasound to metal joining, for improving grain refinement of fusion welds, and for brazing and soldering, dates back over 60 years. The first steps to the discovery of USMW occurred in the late 1940's when in research at the Aeroprojects Company of West Chester, Pennsylavania, ultrasonic vibrations were applied to conventional resistance welding equipment, with the objective of decreasing surface resistance in spot welding of aluminiums.[5]

II. LITERATURE REVIEW

Due to the ongoing miniaturization in many industrial branches plastics are increasingly applied in Microsystems Technology. To guarantee the functionality of the system suitable joining processes must be applied to join separate components. Most of the welding processes commonly used for series production are not suitable for welding micro parts made from plastics, since either the mechanical or the thermal load of the joining partners during the welding process are too high. Only laser transmission welding and ultrasonic welding are applicable for welding complex micro components. Since with ultrasonic welding a certain frictional load of the components cannot be avoided totally with standard welding equipment, specially adapted machinery has to be used as it could be shown at the Institute of Plastics Processing (IKV) at RWTH Aachen University. While micro parts with two-dimensional weld seams have already been successfully welded in previous investigations, recent research deals with the ultrasonic welding of micro parts with more complex three-dimensional weld seam geometry. It could be shown that for appropriate welding parameters this can be accomplished, whereby the mechanical load of the parts has to be kept as small as possible.[1]

Ultrasonic welding had been widely used in various anufacturing industries such as aviation, medical, electronic device and many more. It offers a continued safe operation, faster and also low cost as it able to join weld part less than one second and also simple to maintain the tooling devices. Though ultrasonic welding brings a lot of advantages in assembly especially in thermoplastic material of manufacturing product, it also has a dominant problem to be deal with. The problem in ultrasonic welding is poor weld quality due to improper selection of ultrasonic welding parameters especially in near field configuration. Thus, an optimal combination of parameters is crucial in order to produce good quality weld assembly for this configuration. In this paper, ultrasonic welding process, ultrasonic weld joint defects and determination of optimal parameters for thermoplastic material had been discussed thoroughly.[2] **Niebuhr et al. [3]]** realized explicitly that the top part, bottom part and anvil are part of the welding system. This is of importance because most researchers assumed that all the energy being transmitted to the sonotrode is also being transmitted to the weld. The most recent equivalent circuit representation of the USMW system was developed by Bilgutay . The basis for the model was a lateral drive system driven by a phase locked loop power supply. The main goal of this study was to find a way of controlling weld quality by controlling current, voltage and frequency. Expressions were found linking the load velocity and the load force to the voltage and frequency, if the current was held constant. The approach in this study was similar to that of **Harthoorn** [4], but **Bilgutay** considered the effect of loading and its effect on the input impedance of the welder. Due to the advances in calculating the equivalent circuit the hope was expressed that knowing the relationship of shear force and velocity dependence at the load to voltage, current and impedance at the input, could lead to a nondestructive, in-process testing method for ultrasonic joints.

IV. THE MECHANICS OF ULTRASONIC METAL WELDING

In this chapter a mechanics-based model for the ultrasonic welding process will be developed. The situation under consideration, first shown as figure 1.1, is represented in more detail in figure 19. Thus, the basic USMW process is shown in figure 20 with an enlarged view of the weld zone shown in figure 21. The static clamping force is the net external force on the weld. In figure 22 a separation of the parts through the weld zone has been made, showing not only the net static force FN, but the net shear force, FI that acts at the interface as a result of the transverse vibration of the sonotrode.

It must be pointed out here that the model developed here simplifies the compressive stress under the sonotrode so that it is uniform and time independent. If a spherical sonotrode is used, the compressive stress is not uniform and it will also be time dependent. But the same development that is shown here could also be done if a spherical or otherwise shaped sonotrode is used.

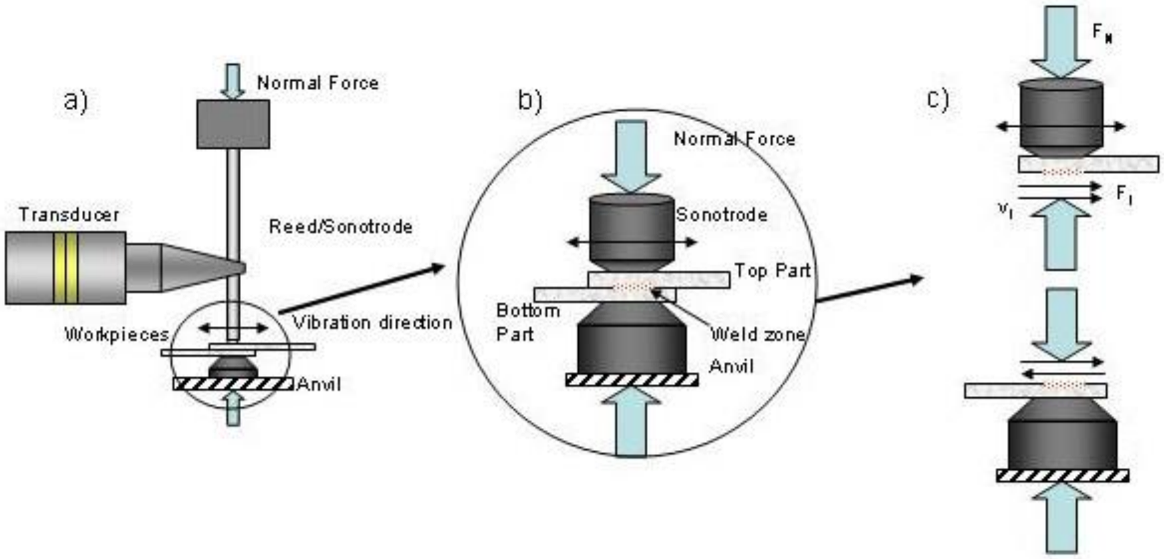

Figure 19: Overview of the net forces acting at the weld interface.

It is the primary objective of this work, in investigating the "Mechanics of USMW" to arrive at a process model that permits prediction of the weld-producing shear force FI. Encompassed in the model will be factors such as the effect of the distribution of the static force FN at the interface, the critical issue of heating caused by the welding action, both at the weld interface and at the sonotrode-top part interface, and the influence of the part mass and geometry on the welding process.

The stresses occurring during welding at the weld interface and the sonotrode top part interface will be reduced to a two dimensional state and the heating occurring during welding will be reduced to a heat flux from the deforming material at the interface and the friction between the parts into the parts/tooling. The resulting model will predict the forces that occur during USMW and from that predict unstable welding conditions .A key attractive feature of USMW is that it is a solid-state bonding process, so that the issues involving melting, resolidification of the base metals, with resulting impact on material properties, are not present. This becomes clear when the ultrasonic process is compared to resistance spot welding (RSW) of aluminium.[3]

V. CONCLUSION

The experimental results will show that the welding parameters will be important factors for the strength of the welded joint which may increase or decrease the strength of the welding joint also the optimal results will be achieved. Time, Amplitude and Pressure are most significant for this experiment.

A mechanics based model for USMW has been developed which can successfully predict the interface forces during welding and their effect on the weld quality. This model, based on the forces and temperatures that occur during welding is applicable for a wide variety of welding problems. The limitations are given by the particular geometry of the sonotrode surface. In this case a knurled flat sonotrode was used, which made it possible to use the two dimensional stress state to calculate the yield condition.

The model explains the influence of material properties and surface conditions as well as process variables such as vibration amplitude and normal force on the weld behavior. It is now known what forces are necessary to produce a weld and how they are influenced.

The surface condition, in particular the friction coefficient of the material has been found to be very important on weld quality and avoidance of sonotrode welding. The influence of the geometry of the welded parts on the weld quality has been known for a long time, but has not received proper attention. The top part dimensions and boundary conditions have a crucial influence on the weld quality. In this study the forced vibration problem for the top part has been solved. The solution for the problem of longitudinal vibrations serves as an example how much more complex problems can be tackled. This result also showed that the length of the extension of the top part has to be considered as compared to the total part dimensions. The forced vibration problem predicted exactly for what top part extension dimensions welding is not possible. It is expected that for complex structures FEA methods are needed to solve for the "ideal" weld locations, i.e. locations were the driving point impedance is as low as possible. FEA methods were also used to model the heat generation and conduction during the USMW process, because an analytical description would become very complicated. With the presented model and calculations, two very unfavorable welding conditions could be explained and predicted. First, the case of top part anti-resonance was calculated and it was shown that for that condition welding is impossible. By measuring the anvil forces the judgment can be made if extrusion and sonotrode welding occurred due to high interface forces or, if it occurred because of top part anti-resonance.

Second, it has been shown that excessively high interface forces due to high friction or very rapid weld area growth can also lead to an unstable welding condition. The results of this study lead to first trials of ultrasonic projection welding (USPW). The use of USPW (Appendix E) can theoretically lead to a great improvement in weld quality consistency and sonotrode sticking issues. The greatest advantage would be that the forces at the interface can never exceed the maximum sonotrode force, because of the temperature gradient within the parts and the lack of friction outside the weld area. Initial trials indicated a great improvement in weld strength when thicker sheet material was welded. Further research is necessary about this process variation, but theoretical advantages are evident.

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