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EFFECT OF HORN (SONOTRODE) PROFILE ON WELD STRENGTH OF HDPE PLASTIC WELD BY USING ULTRASONIC WELDING

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Abstract: This work, discusses on design of different shaped acoustic horns like conical, stepped and exponential made from EN24 material for ultrasonic welding of HDPE (High-Density Polyethylene) plastics. First, the theoretical dimensions of different shaped horn are calculated and compared with the dimensions obtained through commercial horn design software CARD. Using this type of horn profile test run on HDPE plastic. Then testing the weld tensile strength of HDPE sample with different welding parameter (pressure, Amplitude, thickness) with respect to different hone profile in ultrasonic welding. in this paper, we will give some overview about the existing effect of horn (sonotrode) profile on weld strength of hdpe plastic weld by using ultrasonic welding

Keywords: Sonotrode (horn) Design, Ultrasonic plastic welding, Ultrasonic Metal Welding (USMW)

I. INTRODUCTION

Ultrasonic is acoustic (sound) energy in the form of waves having a frequency above the human hearing range. The highest frequency that the human ear can detect is approximately 20 thousand cycles per second (20,000 Hz). This is where the sonic range ends, and where the ultrasonic range begins. Ultrasound is used in electronic, navigational, industrial, and security applications. It is also used in medicine to view internal organs of the body. [1, 2]

A. Ultrasonic machine components

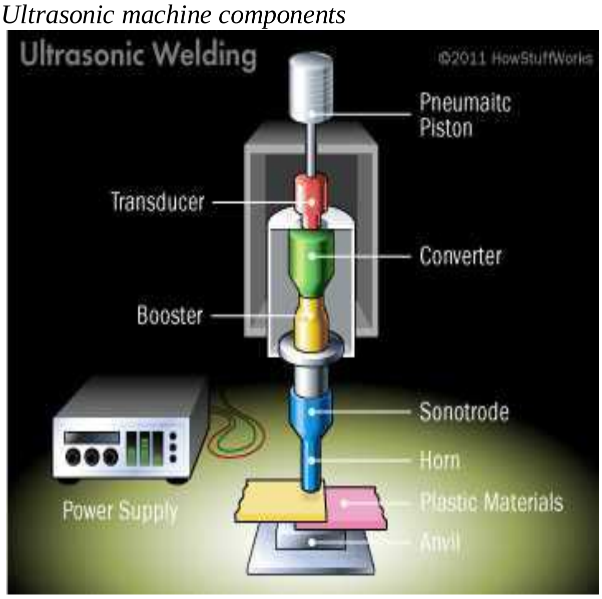

Figure 1.1 Schematic of USW system [3]

a. Generator

It converts frequency of 50/60 Hz, available at the mains to the frequency ultrasonic range, say 20000 Hz or more. The main requirements of generator used in ultrasonic welding applications are,

- Stable frequency which can be evenly regulated over a range,
- Controlled output over a range,
- Higher harmonic should not present in the output voltage curve [4],

b. Transducer

The transducers are a heart of USW. It converts the available high frequency electrical energy into the mechanical energy i.e. in the form of oscillation of transducer material. There are basically three types of transducers which are widely used in ultra sonic welding which are described below [4].

c. Piezoelectric crystal

Piezoelectric transducer converts alternating electrical energy directly to mechanical energy through use of piezoelectric effect. Electrical energy at the ultrasonic frequency is supplied to the transducer by the ultrasonic generator. This electrical energy is applied to piezoelectric elements in the transducer, which vibrate. These vibrations are amplified by the resonant masses of the transducer and directed into the liquid through the radiating plate.
The vast majority of transducer used today for ultrasonic cleaning utilizes the piezoelectric effect. Piezoelectric transducer has high frequency of compression, low power handling capacity, and driving voltages are also low. This generally fined application in the field of measurement, diagnosis, cleaning etc. [4]

d. Magnetostrictive transducers

It works on Megnetostrictive effect. This effect occurs with ferromagnetic material and certain non-metals called ferrites. When a rod or bar of ferromagnetic or ferrimegnetic material is subjected to a magnetic field a mechanical stress applied to a rod or bar, it experiences a change in length. Conversely, mechanical stress applied to a rod or bar causes a change in intensity of magnetization. This effect is prominent for the materials like cobalt, nickel and iron.[4]

e. Sonotrode (horn)

A sonotrode (also referred as concentrator velocity transformer or horn) is the element of the ultrasonic machine that supplied energy to the component being welded. Some typical commercially available sonotrode are shown in figure 1.3

Figure 1.2 Sonotrode [6]

Design of the sonotrode is critical to successful application of ultrasonic energy. It is designed to resonate at the frequency of the ultrasonic system. When it vibrates, it stretches and shrinks in length by a small amount. This motion is referred to as the amplitude of the sonotrode. Sonotrode are required to bridge the gap between the converter and the work or point of application and to transfer the ultrasonic energy to the point of application. sonotrode are essential for each application. Also, the amplitude of vibrations for some application like machining and welding is amplitude of the vibrations has to be amplified by designed the sonotrode with specific gain. [5] The transducer is mounted on the larger end of the sonotrode and the tool is mounted on the smaller end. It works on the principle which states that velocity of sound wave is directly proportional to decrease in cross-sectional area. Thus to amplify the wave entry area is made larger and the exit area is made smaller. Various taper functions can be implemented to obtain this. The most common taper function is,

- Double cylindrical (step cylindrical)
- Conical (linear taper),
- Exponential (exponential taper),
- Catenoidal (hyperbolic taper)

B. Concept of ultrasonic plastic welding

Ultrasonic plastic welding is the joining or reforming of thermoplastics through the use of heat generated from high-frequency mechanical motion. It is accomplished by converting high-frequency electrical energy into high-frequency mechanical motion. That mechanical motion, along with applied force, creates frictional heat at the plastic components' mating surfaces (joint area) so the plastic material will melt and form a molecular bond between the parts. Plastics assembly is a fast, clean, efficient, and repeatable process that consumes very little energy. No solvents, adhesives, mechanical fasteners, or other consumables are required, and finished assemblies are strong and clean. Ultrasonic Welding is the fastest and most cost effective method used today to join and assemble plastic parts and non-ferrous metals. Ultrasonic welding uses an acoustic tool called an ultrasonic horn made to match your parts design. Ultrasonic Welding is converted to heat through friction that melts the plastic or metal. The main components of an ultrasonic welding system are the actuator and power supply, converter/booster & ultrasonic horn called the stack, part holding weld fixture/jig. Material selection, Surface contact, Field of weld, Joint design, and Welding amplitude are all factors in determining the proper booster and horn design for any given application. [6]

C. Process principal

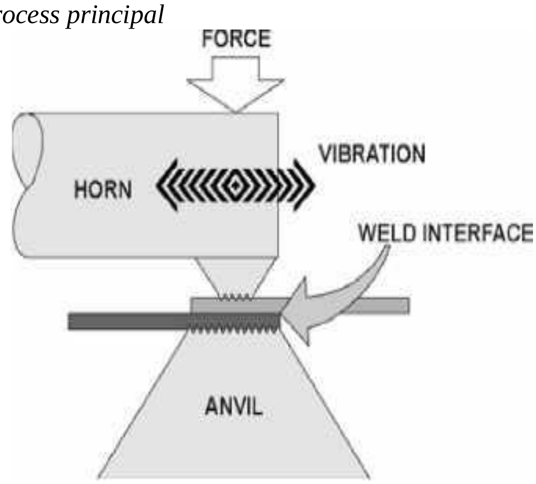

Figure 1.3 Ultrasonic plastic welding principal [6]

A solid state welding process in which coalescence is produced at the faying surfaces by the application of high frequency vibratory energy while the work pieces are held together under moderately low static pressure. Ultrasonic welding, one of the most widely used welding methods for joining thermoplastics, uses ultrasonic energy at high frequencies (20 – 40 kHz) to produce low amplitude (1–25μm) mechanical vibrations. Electrical Energy is transformed into high frequency mechanical vibration. This mechanical vibration is transferred to a welding tip through an acoustically tuned horn as shown in Fig (1.3). The parts are scrubbed together under pressure at 20,000 cycles per second. This high frequency vibration, applied under force, disperses surface films and oxides, creating a clean, controlled, diffusion weld. As the atoms are combined between the parts to be welded, a true, metallurgical bond is produced. A process flow diagram can be found at the end of this section illustrating the ultrasonic metal welding process. [6]

D. Principles of Ultrasonic Metal Welding (USMW)

The principle of the welding operation occurs from creating an oscillating shear force at the interface between the mating surfaces, to disperse oxides, voids, liquids and contaminants, and offer new contact at many points. During the supply of vibration at a local area, the resultant oscillation causes an increase in diffusion across the interface, resulting in a weld similar to that produced by diffusion welding. At the bonding area, dynamic shear stresses are generated due to the combined influence of static load and ultrasonic vibration. The effects of interfacial slip and plastic deformation will increase the temperature of the scrubbing area, which itself is always lower than the melting point of base metal. [7]

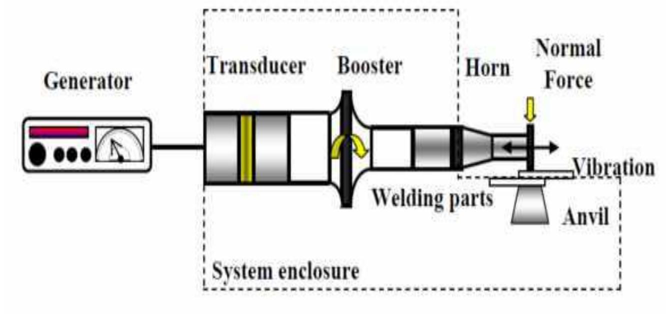

Figure 1.4 Schematic of USMW system [7]

The set-up of an USMW system is illustrated in Figure From the figure it can be seen that the system components consist of ultrasonic generator, transducer, booster and a horn, in addition to other welding components such as a rigid anvil, fixing tools and fixtures.

Important parameters of the welding process

- The duration of the welding operation, the welding time, ranges from 10ms up to several seconds.
- The clamping pressure in the weld area.

This pressure equals approximately 0.1 to 0.3 times the Vickers hardness of the material to be welded. The requirement values of the welding parameters (vibration, amplitude, welding time, pressure) depend upon:

- The thickness of the work piece contacting the welding tip, i.e. the upper work piece.
- The material properties of the materials to be welded. [8]

II. LITERACTURE SURVEY

A. Analysis of Different Shaped Sonotrode used for Plastic Welding

They described procedure of sonotrode design for conventional shape profile by classical method and by CARD software and presented comparison of results. They carried out analysis for step-cylindrical, conical and exponential shape profiles of sonotrode. [9]

B. Computational modelling and experimental studies of the dynamic performance of ultrasonic horn profiles used in plastic welding

They described the design of different type of horn profile like Cylindrical, Gaussian, Catenoidal, Stepped, and Bezier. They have done the harmonic analysis. Temperature developed during the welding of ABS test parts using different horns is recorded using sensors and National Instruments (NIs) data acquisition system. The recorded values are compared with the predicted values. They conclude that welding using a Bezier horn has a high interface temperature and the welded joints had higher strength as compared to the other horn profiles. The used Alloy AA 6351 material for horn fabrication. [10]

C. Ultrasonic horn design for ultrasonic machining technologies

They carried out theoretical numerical analysis of various horn profiles the natural frequency and amplification factor of sonotrode in resonant state was study for different geometrical shapes and dimensions. Detailed graphical presentation of result of the effect of horn shape parameters were presented in such a way that it can be useful for selecting suitable sonotrode shape with require properties. [11]

D. Parametric Effect of Ultrasonic Plastic Welding On Tensile Strength for ABS, Acrylic and Polycarbonate Materials.

They describe tensile strength of polycarbonate, acrylic and ABS material welded by ultrasonic welding with different parameter. They use taguchi method for experiment analysis. They conclude that the weld time is most significant control factor on Tensile strength during ultrasonic plastic welding. They did ANOVA analysis also.[6]

E. Ultrasonic welding of advanced Thermoplastic composites: an investigation on energy directing surfaces

They describe different energy directing surfaces for ultrasonic welding of advanced thermoplastic composites. They used continuous carbon fiber reinforced polyetherimide (CF/PEI). They used three types of energy directors; the basic transverse energy director, T1, was compared with the single parallel, P1, and with the double parallel, 2P½. They conclude that

- The coverage of the overlap area can be enhanced when using multiple energy directors, provided that their location and size do not hinder the flow of resin.
- Multiple energy directors significantly reduce the disturbance of the fibers in the outermost layers of the welded parts.
- Transverse energy directors provide less scatter in the amount of welded area than parallel energy director configurations.
- An excessive amount of resin at the welding interface leads to decreased strength of the weld. There is, however, a wide range of resin volumes for which welds with a satisfactory strength level can be obtained. [12]

F. Process robustness of single lap ultrasonic welding of thin, dissimilar materials.

This process robustness study of ultrasonic welding of thin metal sheets. Quality of the welded joints is evaluated based on mechanical tests and the quality criterion is then applied to evaluate the weldabilty. These results were used to determine both the optimal weld parameters and the robust operating range. In this they use 0.2mm thick copper sheet & 0.2mm thick nickel plate. They done T-peel test for weld quality, pressure and welding time are selected by them as control variable. They conclude the output response decreased in the region where there was a long welding time and high welding pressure because of crack around the weld caused by the excessive mechanical vibration. While the output decreased at the region at a short welding time and a low welding pressure because of insufficient energy. [13]

G. Direct welding of different metals used ultrasonic vibration

This ultrasonic welding of aluminium and copper alloy. The ultrasonic welding of Al/Cu can be accomplished when the conditions of amplitude: 15μm, welding pressure: 20MPa, at a required duration of 1.0 s under the water bath. Furthermore, the oxide film and organic coating are periodically removed from bonded interfaces by ultrasonic wave vibration, and it can be expected to form transition layer of 1–2μm at the bonded interface

They conclude that:

- Tests of welding of Al alloys with different properties show that satisfactory welding is possible in any test and, in particular, That the magnitudes of the welding pressure and plate thickness largely affect the welding properties.
- Underwater welding requires a somewhat larger welding pressure and longer welding time compared with atmospheric welding, however, the obtained strengths of the welded materials are equal and can suppress heat at the heat-affected part in the vicinity of the welding interface.
- SEM observation of the welding interface shows that oxide films and organic films on the material surface can be removed along the frequency of vibration, allowing welding of newly formed faces. A satisfactory welding interface can be obtained causing neither hollow pores nor exfoliation. [14]

III. CONCLUSION

The condition of same area ratio between its' two ends Cross sections the transformation ratio of them is in descending order for the exponential shape, conical shape and step-cylindrical shape respectively. A stepped shape horn produced lower amplitude, since it produced low strength. Tensile strength results show that for ultrasonic plastic welding, conical shaped horn and exponential shaped horn are better than step-cylindrical shape horn. Where manufacturing cost and time is important parameters exponential shape horn is rarely use because of cost of manufacturing & design of horn is more costly compare to other type horn have near to same amplitude and gain Conical horn shape is easy to manufacture and also has almost nearest amplitude as exponential shape horn. Therefore, conical shaped horn is extensively used in industry. It can be clearly observed that both values calculated by theoretical equation are slightly exceeding the values by CARD software. From above results one can conclude that transformation ratio or gain of horn by using CARD software and by using theoretical equation is closer. Hence CARD software may be useful tool for horn design.

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