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Ultrasonic Welding Technology: A Review

Duong Van Thiet[1]
1.Thai Nguyen University of Technology
duongthiet@tnut.edu.vn

Abstract
Welding is a technological process of joining components to form a permanent, non-disassemblable bond. Numerous welding methods have been developed to suit various types of components, materials, and technical requirements. Ultrasonic welding is a modern and efficient welding method widely used in joining thermoplastic materials. It operates based on the principle of converting high-frequency mechanical vibrations into localized thermal energy, which causes the melting of the materials at the joining position. The equipment comprises a power supply, converter, booster, and horn which transmits the vibrations and applies pressure for localized melting and fusion. The success of ultrasonic welding is contingent upon meticulous joint design and the optimization of welding parameters such as amplitude, pressure, and welding time. In this paper, we summarize several research achievements in the field of ultrasonic welding and discuss some research directions.
Keywords: *Ultrasonic welding; ultrasonic metal welding, optimization of ultrasonic welding*

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I. Introduction

Ultrasonic welding technology is widely applied in the in the automotive, electronics, medical, packaging, textile, toy, and consumer goods industries. Its ability to create strong, reliable, and durable bonds has solidified its position as an indispensable joining method in modern manufacturing. With numerous remarkable advantages, ultrasonic welding has become a popular and favored method in the industry. The welding process is rapid and efficient, boosting production speed and saving time. By eliminating the need for adhesives, it reduces costs and protects the environment. The weld quality is high and consistent, leading to improved product quality. Additionally, the process consumes minimal energy, resulting in cost savings. Its versatility allows it to be applied to various materials, enhancing flexibility in manufacturing. Moreover, the ease of controlling welding parameters contributes to increased efficiency and product quality. However, alongside those advantages, ultrasonic welding still has some drawbacks, such as limitations in the variety of materials, material thickness, and product shape for welding, technology equipment costs, control of precision, and stability.

II. Introduction of ultrasonic welding

In ultrasonic welding technology, a wide variety of materials are used, many studies have been presented. Plastics and thermoplastic materials are highly common in ultrasonic welding, with examples such as PVC, PET, PE, PP, PS, and others [1-6]. Composite materials can also be effectively joined using this method, resulting in strong and consistent mechanical bonds [7-11]. Within the textile industry, fabrics, fibers, and synthetic materials are suitable for ultrasonic welding applications [12-15]. However, due to their properties, metals are less compatible with this welding method compared to the aforementioned materials. Nevertheless, in specific cases, ultrasonic welding remains effective for joining thin metal sheets or small components [15-17].

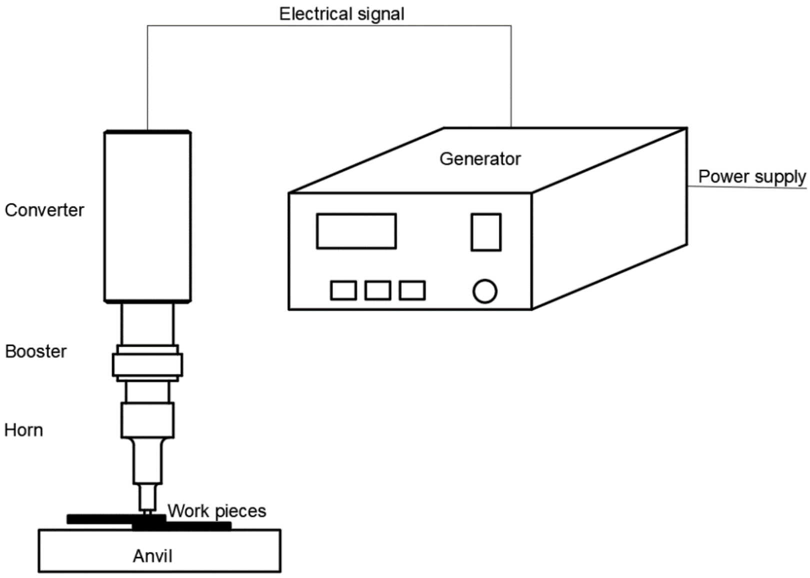


Figure 1. Schematic diagram for ultrasonic welding process device

Optimizing the parameters in ultrasonic welding is a critical process to ensure the quality and efficiency of the welding operation. Key parameters such as ultrasonic frequency, welding pressure, welding time and the design of the ultrasonic horn must be carefully controlled and adjusted to achieve strong and reliable welds without compromising the integrity of the materials. The ultrasonic frequency, when properly chosen, determines the size of the ultrasonic range and is crucial in matching the welding requirements for small or complex components. Welding pressure needs to be precisely regulated to avoid damaging the parts while ensuring adequate bonding strength. Welding time must strike a balance to achieve a strong bond without causing material damage. Additionally, the design and shape of the ultrasonic horn play a significant role in welding performance and should be tailored to match the specific requirements of the components to be welded. The optimization process demands a combination of expertise, technical knowledge, and the use of appropriate equipment to ensure high-quality welds and maximize welding efficiency

To optimize the welding parameters, several methods have been researched and presented by authors, among which experimental methods have been widely utilized to determine appropriate technological settings. These sets of parameters are often tailored to suit specific materials or a particular group of materials.

III. Applications and usage of ultrasonic welding

Sooriyamoorthy Elangovan, K. Prakasan, and V. Jaiganesh published a research paper on optimizing the parameters of the ultrasonic welding process for copper to copper using the experimental design method [18], The authors Karthik.R, Ramachandran.N, Aravind.A, and ChandanuRaj.C conducted experiments to identify the optimal parameters for ultrasonic welding of Delrin material [19], the implementation of statistical analysis of variance method (ANOVA) also used for parameter optimization [20].

The response surface methodology is also used by many authors in their studies, Zhen Yao, Kaijie Liu, Rongjie Ding, Zilun Luo, Jian He (2022) [21]. The response surface method is mainly divided into a central composite method (CCD) and BoxBehnken method (BBD). The central composite design is a test method drawn up based on two-level full factorial and fractional experimental design, which needs a combination number to fit the model. Box-Behnken experimental design is an experimental design method that can evaluate the nonlinear relationship between indicators and factors It is distinct from the central composite design. BBD is not necessary to carry out multiple tests continuously, and in the case of the same number of factors, the number of test combinations of BBD test is less than that of central composite design, which is more convenient and economical.

Sooriyamoorthy Elangovan, Anand Kumarasamy, Kannan Prakasan (2012) published research on Parametric optimization of ultrasonic metal welding using response surface methodology and genetic algorithm [22], B. Ganesamoorthi, S. Kalaivanan, R. Dinesh, T. Naveen kumar, K. Anand (2015) presented a study on optimizing the ultrasonic welding parameters of copper metal sheet and copper wire, in this study the Central Composite Design (CCD) is adopted and the experiments are conducted based on the design matrix so obtained. Parametric optimization is done through Response Surface Methodology and Excel solver [23]. The response surface method (RSM) with genetic algorithm (GA) was used by S. Elangovan, S. Venkateshwaran, K. Prakasan (2012) in research on optimization of copper and brass ultrasonic welding parameters [24].

In ultrasonic welding technology, besides finding suitable technological parameters, the design of the ultrasonic welding horn is crucial and has garnered significant research attention. Key factors in the horn design include material selection, shape, size, oscillation structure, and connectivity. The horn is typically made from sturdy and durable materials such as tool steel, titanium alloys, aluminum, or contact alloys to withstand continuous oscillation and bending.

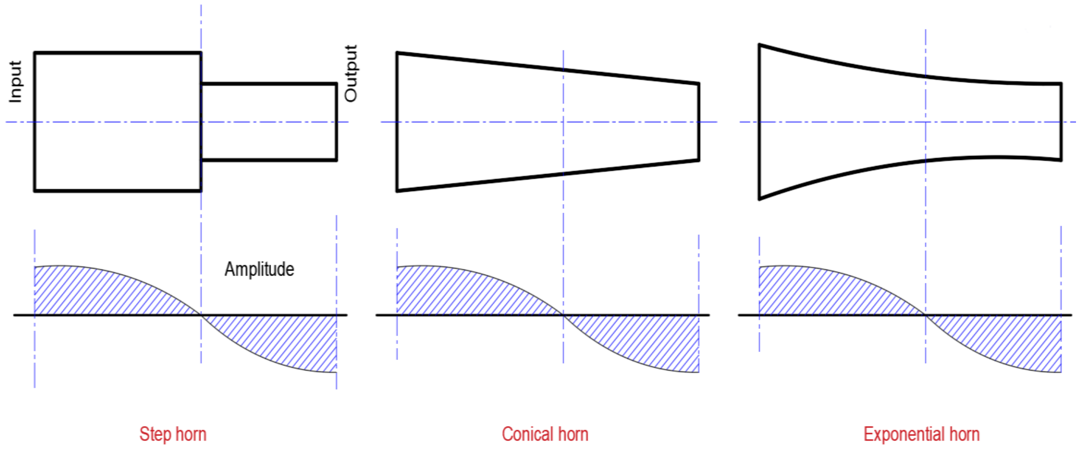
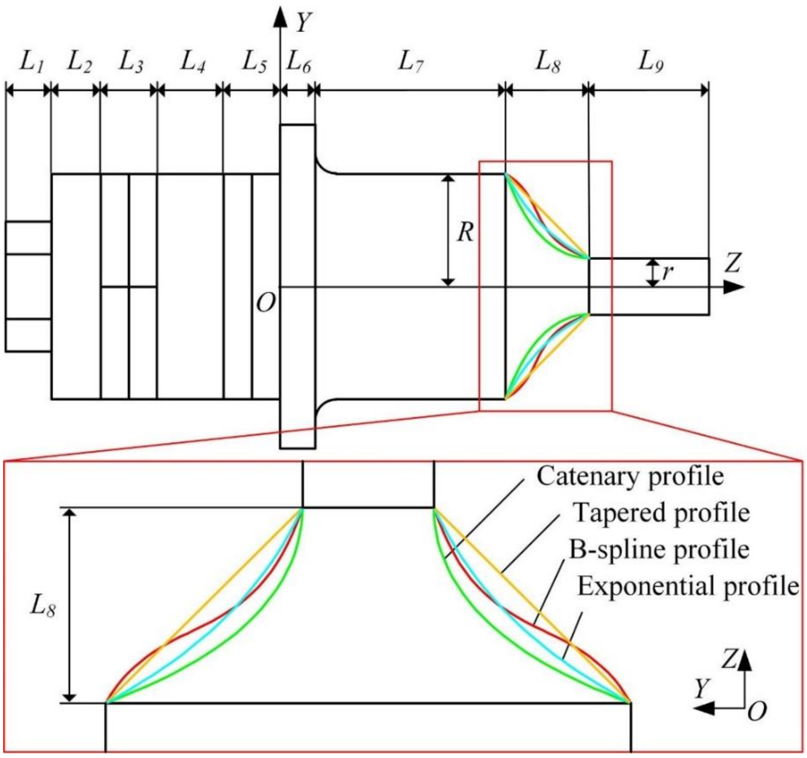


Figure 2. Basic shape design of half wavelength horns

The shape and size of the horn must be customized to match the components to be welded, ensuring maximum accuracy and efficiency during the welding process. The oscillation structure design directly impacts the frequency and amplitude of the ultrasonic oscillations, thus influencing the welding performance and quality. Stable and uniform oscillation is critical for consistent welding results.



Figue 3. Geometries of the Two-dimensional ultrasonic vibration systems composed of the horns with different transition sections [25].

The horn must be designed for easy connection and disconnection from the ultrasonic generator, ensuring reliable power transmission. Effective heat dissipation design is crucial to cool the horn during operation and protect internal components from overheating. Designing the ultrasonic welding horn is a complex process that requires a combination of technical expertise and modern technologies to achieve optimal welding performance and quality [26-29]. The process of designing ultrasonic welding horns is currently strongly supported by computer tools, CAD software for design assistance, and FEM and FEA tools for simulation and evaluation of designs before experimental production

IV. Conclusion

It must be acknowledged that there have been significant achievements in the research and development of ultrasonic welding technology and its applications. However, this technology still faces several challenges that require further investigation. For instance, research is needed in the area of welding materials, limitations concerning size, and the capabilities of the welding equipment. There are some limitations on the thickness of the sheet that is in contact with the welding tip of the sonotrode. The limitation depends on the delivered power of the machine, the tool geometry and the material that is used. Besides ultrasonic welding, ultrasonic cutting technology also has many issues that need to be researched for its further development and broader application.

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