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Characteristics and performance of ultrasonic welding process: A review

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Abstract. *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 of ultrasonic welding on characteristics and performance welding process.*
Keywords: *Ultrasonic welding; optimization of ultrasonic welding; mechanical properties*

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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].

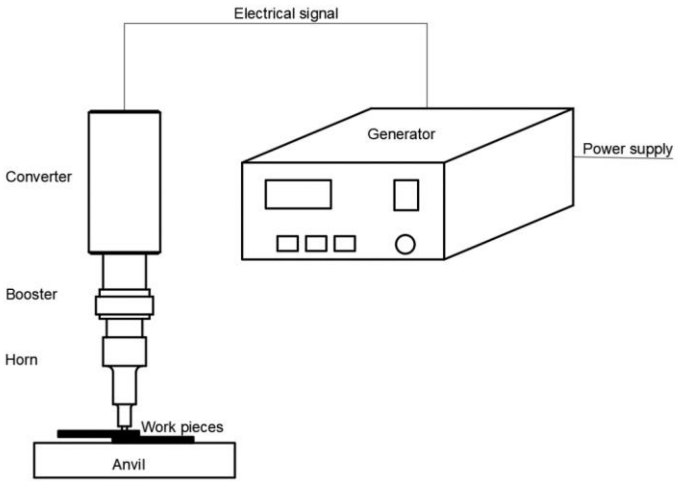

Fig. 1. Schematic diagram for ultrasonic welding process device.

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. 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.

III. Applications and usage of ultrasonic welding

In ultrasonic welding technology, weld quality is of paramount importance. To assess weld quality, several criteria are introduced, such as: mechanical strength, surface quality, microstructural integrity of the weld, dimensional accuracy, and stability of the weld. Mechanical strength is of interest in most ultrasonic welds, tensile and shear strength are often tested to verify weld quality.

T. Chinnaduraia, S. Saravanan, N. Prabaharanc, M. Karthigai Pandiana, S. Deebikaa presented a research study on analyzing the weld strength of ultrasonic polymer welding using Artificial Neural Networks. In this study, the authors provide a model to predict the tensile strength of welds based on the parameters of the ultrasonic welding process [18]. L. Zhou, J. Min, W.X. He, Y.X. Huang and X.G. Song published a study on the effect of welding time on the structure and mechanical properties of the weld when welding AL-Ti with spot welding [19].

The addition the of an interlayer between surfaces has changed the compound type and microstructure distribution state in the interface and improved the mechanical properties of the joints. The welding energy was reduced while gaining a higher quality joint with the remarkable energy saving effect, this is the research result of Xiaoyan Gu, Chenglong Sui, Jing Liu, Donglai Li, Zhengyu Meng, Kaixuan Zhu.

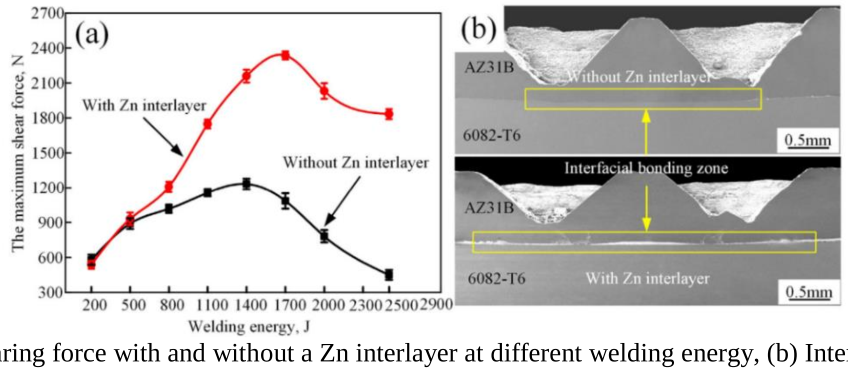

Fig. 2. (a) Shearing force with and without a Zn interlayer at different welding energy, (b) Interfacial bonding zone with and without a Zn interlayer [20].

In 2020, Yang Li, Bo Yu, Baicun Wang, Tae Hwa Lee and Mihaela Banu published research study on Online quality inspection of ultrasonic composite welding by combining artificial intelligence technologies with welding process signatures, this study investigates the prediction of the failure load and weld quality level in ultrasonic carbon -fiber -reinforced thermoplastic (CRFTP) welding simultaneously using artificial intelligence (AI) technologies, including rtificial neural network (ANN) and random forest (RF) models. The findings of this study can contribute to the online quality inspection of ultrasonic composite welding [21]. There are several studies on weld strength between multiple thin strands joined by ultrasonic welding technique. The study provides useful knowledge for the wire harnesses in electrical systems, where a reliable connection technique is desired [22-23]. The study of Pravat Ranjan Pati, Mantra Prasad Satpathy, Basant Kumar Nanda, Bharat Chandra Routara, Ashutosh Pattanaik explores the effect of impelling factors like interlayer types; it's thickness and condition on the tensile shear load in joining of Al/SS sheets with interlayers by ultrasonic spot welding [24].

The majority of the documented research employs a variety of methodologies to establish the optimal technological parameters required for the welding process in order to fulfill specific criteria, often centered around weld quality. Nonetheless, the derived parameters tend to be applicable solely to a singular or limited subset of analogous materials, making the identification of universally applicable process parameters a persistent challenge. In 2019, Muhammad Bilal Shahid, Seung-Chang Han, Tea-Sung Jun & Dong-Sam Park conducted a comprehensive investigation into the assessment of input parameters for welding processes, X = P×A×T in which Pressure (P), Amplitude (A), and Time (t) [25].

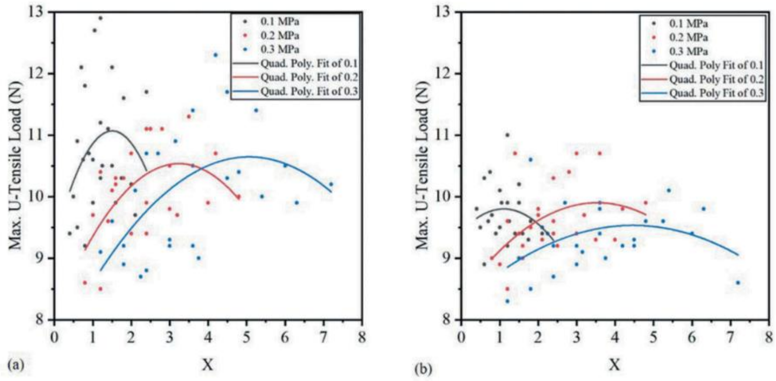

Fig. 3. Parameter 'X' plotted against strength for different values of pressure (a) Ni-Cu (b) Cu-Cu.

Another study on preloading and the effect of preload on weld quality. The results showed that under the given welding parameters, the preload can greatly improve the joint strength, especially in the case of a gap between workpieces. Therefore, the application of a preload is recommended during ultrasonic welding of composite materials in manufacturing practical applications. However, the welding parameters and magnitude of the preload should be optimized experimentally to ensure effective joining with different materials, plate thicknesses, and types of ultrasonic welding machines.

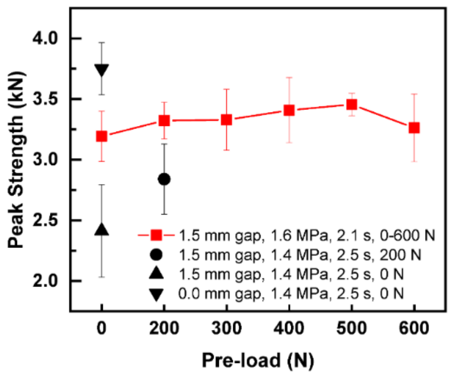

Fig. 4. Effect of preload on the strength of joint with a gap [26].

In certain scenarios, there is a heightened need to focus on fatigue strength or the tightness of the weld. Rana Tehrani Yekta, Kasra Ghahremani, and Scott Walbridge conducted research to investigate the impact of technological parameters on the fatigue strength of ultrasonic welds [27].

To control weld quality, numerous parameters require careful consideration. The selection of optimal criteria for enhancing weld quality depends on factors such as materials, equipment, and technology. As a result, methods, approaches, as well as tools, warrant further research to achieve the desired efficiency.

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, to enhance and optimize the efficiency of ultrasonic welding, the optimization of parameters to ensure weld quality is always given significant attention. For each type and category of materials used, a set of specific optimal parameters is typically associated. Customizing material utilization also requires convenient and effective methods for determining technological parameters. The application of new technologies in research to improve the quality and efficiency of ultrasonic welding promises substantial benefits.

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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