ISSN: 3107-6513

# Review of Plastic Ultrasonic Welding Process

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## Abstract
Ultrasonic welding is widely used for joining thermoplastic materials such as polypropylene (PP), ABS, and polyethylene. It uses high-frequency vibrations to generate heat and form strong joints. Welding parameters such as vibration amplitude, pressure, welding time, and energy director design significantly affect joint strength and quality.
However, robotic ultrasonic welding systems involve high initial investment, complex integration, specialized tooling, programming, and longer setup and changeover times. These factors can increase production costs and cycle time, particularly in automotive applications requiring multiple joining points.
This research investigates an alternative heat-stack plastic welding system for PP automotive components. The proposed system uses multiple temperature-controlled heated tips to simultaneously melt and reshape plastic bosses, creating mechanical locking joints. It incorporates pneumatic clamping, a fixed fixture, and directed cooling air.
The study compares both welding methods based on cycle time, equipment cost, energy consumption, joint strength, rejection rate, and production efficiency. The proposed heat-stack system aims to provide .a simpler, faster, and more economical alternative for suitable automotive plastic joining applications.

***Keywords—component; formatting; style; styling; insert (key words) Keywords: Ultrasonic Welding, Heat-Stack Welding, Polypropylene (PP), Robotic Welding, Cycle Time, Cost Optimization, Automotive Plastic Components, Joint Strength.***

## I. INTRODUCTION

Ultrasonic welding is an established joining technique widely used in industries for joining thermoplastic materials because of its fast processing, low heat generation outside the joining region, and suitability for automation. The process uses high-frequency mechanical vibrations to generate heat at the contact interface between plastic components, resulting in localized melting and bonding.

Several researchers have investigated ultrasonic welding with respect to material properties, welding parameters, horn design, temperature distribution, joint strength, and process optimization. These studies provide an understanding of the factors affecting welding quality and production performance. The following literature review discusses important research contributions related to ultrasonic plastic welding and identifies the research gap addressed in the present work. The operational sequence is shown in figure 1 while figure 2 represents the conceptual diagram of ultrasonic welding and heat stack welding process.

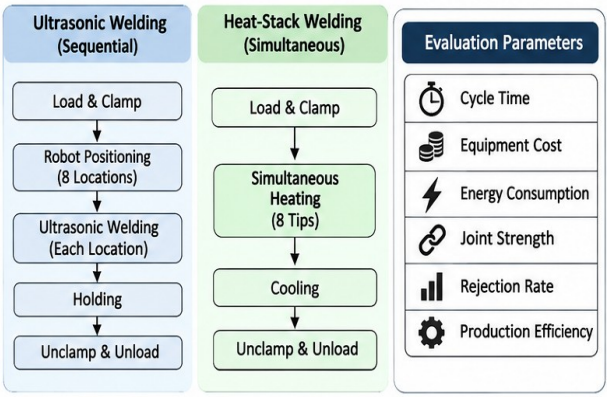


Figure 1 Process flow diagram

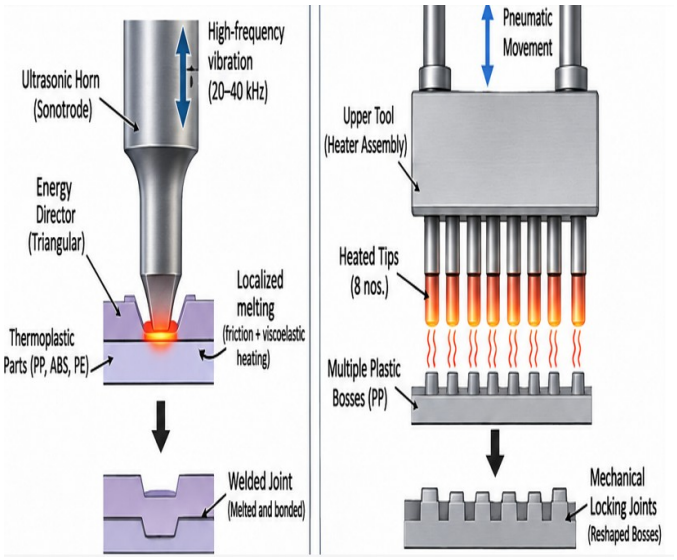


Figure 2 Conceptual diagram of the process

## II. LITERATURE REVIEW

Benatar et al. (1989) studied near-field ultrasonic welding of thermoplastics, including polypropylene (PP). Their findings showed that vibration amplitude, welding pressure and welding time significantly influence energy dissipation and joint strength.

Rani and Rudramoorthy (2013) investigated ultrasonic horn profiles using numerical and experimental methods. They found that horn geometry affects vibration amplitude, interface temperature and joint strength.

Liu et al. (2023) investigated ultrasonic joining of aluminium and carbon-fibre-reinforced thermoplastic

composites. Their results demonstrated that surface treatment and interface design improve joint strength.

Tsujino et al. (1996) developed different ultrasonic vibration systems for joining metals and plastics. Their work highlighted the importance of vibration-system configuration and equipment design.

Raza et al. (2019) optimized ultrasonic welding parameters for ABS and PP using Taguchi methods. Their findings showed that energy director geometry, welding pressure, vibration amplitude and welding time significantly affect joint strength.

Bose et al. (2023) studied submerged ultrasonic welding of PVC and PP. Their research demonstrated that environmental and cooling conditions influence interface temperature and joint strength.

Rani et al. (2007) investigated the statistical effects of welding parameters. They identified welding time and welding pressure as important factors influencing ultrasonic welding performance.

Raza (2015) studied ultrasonic welding of ABS and PP, demonstrating the influence of energy director geometry, welding time and static force on joint strength.

Hongoh et al. (2006) examined ultrasonic welding at different frequencies. Their results established a relationship between operating frequency, temperature rise and welding characteristics.

Rani et al. (2015) investigated the thermal and mechanical behaviour of ultrasonic horns. Their findings highlighted the importance of horn material selection, temperature control and resistance to cyclic loading.

Benatar and Marcus (2023) reviewed ultrasonic welding principles, equipment and applications in plastics and polymer composites, providing a theoretical understanding of vibration, heat generation and joint formation.

Rani et al. (2008) investigated far-field ultrasonic welding of HDPE and highlighted the effects of component geometry and energy transmission on temperature distribution and joint strength.

Wang and Lin (2019) studied vibration uniformity in large ultrasonic welding tools using phononic crystal structures, demonstrating improved vibration distribution through optimized tool design.

Zhao et al. (2020) investigated ultrasonic-assisted friction stir welding and explained the influence of ultrasonic vibration on heat generation, material flow and plastic deformation.

Chen et al. (2017) studied interface friction and plastic deformation during ultrasonic spot welding of copper and aluminium, explaining their contribution to joint formation.

## III. Research Gap Identification

Previous studies mainly focused on improving ultrasonic welding quality through process parameters, horn design, vibration and joint strength. However, limited attention has been given to reducing cycle time and production costs in robotic ultrasonic welding, especially for automotive PP components with multiple joining points.

The major research gaps include high equipment investment, additional robot movement, longer processing time and limited studies on simultaneous joining and overall manufacturing cost.

## IV. Relevance of the Present Research

The present research proposes an multi-tip heat-stack welding system as an alternative to robotic ultrasonic welding for PP automotive components. It uses multiple temperature-controlled heating tips to join multiple plastic bosses simultaneously through melting and reshaping.

The study compares both systems in terms of cycle time, investment cost, energy consumption, joint strength, rejection rate and manufacturing cost to evaluate the technical and economic feasibility of heat-stack welding.

## V. RESEARCH FINDINGS

1. The existing robotic ultrasonic welding process should be studied to identify its limitations related to equipment investment, tooling requirements, robot movement and production cycle time.

2. The equipment and tooling costs associated with robotic ultrasonic welding, including the robot, ultrasonic generator, transducer, booster, sonotrode, fixtures and automation systems, should be analysed.

3. The design and working principle of the proposed heat-stack welding machine, incorporating eight heating tips, pneumatic clamping, trolley-loaded tooling and cooling-air arrangements, should be studied.

4. The feasibility of simultaneous multi-point joining of PP components using eight heating tips should be investigated to reduce repeated operations and unnecessary machine movements.

5. The heat-stack process parameters, including heating temperature, heating/contact time, pneumatic pressure and cooling time, should be optimized to achieve reliable joint formation.

6. The production cycle time and output of robotic ultrasonic welding and the proposed heat-stack welding system should be compared.

7. The joint quality and mechanical strength of components produced using both welding methods should be evaluated and compared.

8. The energy consumption and operating costs, including electrical energy, compressed air, maintenance and tooling expenses, of both welding systems should be analysed.

9. The economic feasibility of the proposed heat-stack welding system should be evaluated by comparing initial investment, production cost and cost per accepted component.

10. The production advantages and limitations of heat-stack welding for automotive PP components should be assessed based on technical and economic performance.

## VI. CONCLUSIONS

The above findings aim to develop and evaluate a production-optimized heat-stack plastic welding system as an alternative to conventional robotic ultrasonic welding for PP automotive components. The study focuses on machine design, simultaneous multi-point joining, process parameter optimization, cycle-time reduction, joint quality, energy consumption and cost analysis. The overall objective is to determine whether the proposed heat-stack system can provide a faster, economical and reliable welding solution for automotive production

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