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Optimization of Ultrasonic Welding of Polypropylene Sheets

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Abstract

Nowadays, polymers have grown into a leading group of materials. Accordingly, many technical polymers are used in industry. As the ending knee absorption increases, the binding design is also being studied continuously. In addition to mechanical and glued joints, different welding processes stand out, such as laser welding, stirrer friction welding, and ultrasound welding. The research was carried out on polypropylene, the plastic called PP. The aim of the study is to examine the ultrasonic welding of polypropylene sheets. During welding processes, we examine the effect of parameters such as welding time, amplitude and main load on the strength of the welding seam. Based on the test results, it was possible to create high-quality joints. The highest seam strengths were obtained with a welding time of 1.2 s and an amplitude of 55 µm. The effect of the main load on the strength of the seams was minimal.

Keywords: *ultrasonic welding, polypropylene, PP, welding strength.*

1. Introduction

Plastics have emerged as a dominant material group in recent decades, making it challenging to find an industry untouched by their application. Alongside their widespread distribution, the development of high-quality, economical, and efficient bonding technologies for plastics has become essential. Among established bonding techniques, adhesive bonding and welding are particularly prominent. Both methods remain significant areas of research, with a continuous stream of publications addressing advancements in these fields. In adhesive bonding, investigations frequently emphasize the impact of various surface treatment methods and the application of different adhesive materials **[1, 2]**.

In the field of plastic welding, notable techniques include laser welding **[3]**, friction stir welding **[4]**, and ultrasonic welding. Ultrasonic welding possesses several advantageous properties—such as high joint quality, speed, cost-effectiveness, and suitability for automation—that facilitate its widespread industrial application for both metals and plastics (e.g., in the automotive industry) **[5, 6]**.

The broad industrial adoption of ultrasonic welding provides a robust foundation for ongoing research and publications aimed at advancing and optimizing this technology. Key research areas include studies on welding various material combinations (e.g., copper and aluminium **[7]**, metal-polymer interfaces **[8]**), welding plastic matrix composites **[9]**, and optimizing welding parameters **[10]** Additionally, the widespread use of polymeric materials and ultrasonic welding technology has led to a marked increase in studies specifically focused on the ultrasonic welding of plastics.

Kiss and his team **[9]** conducted an investigation into the ultrasonic welding of polypropylene matrix composite plates (APPC). The variable modified during the experiments was the welding time, which ranged from 0.1 to 1.0 seconds. Following the welding process, the strength of the seams was assessed. Based on the results obtained, it was determined that the bond strength of the raw material was effectively achieved.

Kawasaki and his team **[10]** investigated the temperature distribution during the ultrasonic welding of a carbon fiber-reinforced polypropylene matrix composite (CF/PP). In their experiments, the amplitude of the sonotrode and the welding time were varied at three levels. In addition to measuring the temperature and its distribution, single-shear tests were conducted on the welded joints. The results confirmed that the amplitude of the sonotrode significantly influences both the temperature distribution during welding and the quality of the joint, thereby affecting the mode of failure.

Raza and his team [11] investigated the ultrasonic welding of polypropylene (PP) and acrylonitrile butadiene styrene (ABS) sheets using a Taguchi experimental design. During the experiments, in addition to the two different thermoplastic materials, two types of energy control geometries (triangular and semicircular) were varied, along with welding time, amplitude, and pressure. After the welding process, the tensile strength of the seams was evaluated using a shear test. Additionally, welding energy was considered as a parameter. Based on the test results, both PP and ABS exhibited similar trends concerning the various parameters, and in both cases, the triangular energy-opening geometry produced superior bond quality.

Rajput and his team [12] investigated the effects of welding variables (e.g., welding time, holding time, amplitude, etc.) during the ultrasonic welding of H110MA polypropylene. The authors varied these parameters at three levels each. The Taguchi method was employed to plan the measurement points, while analysis of variance (ANOVA) was utilized for evaluation. The primary output parameter tested was the separation resistance. Based on their measurements, the authors demonstrated that amplitude had the most significant effect on detachment resistance.

As demonstrated in the aforementioned publications, the ultrasonic welding of polypropylene (PP) materials is a prevalent research topic. It is noteworthy that PP is the second most widely produced polymer and is utilized extensively in leading industries, including the automotive and medical sectors [13].

The purpose of this study is to investigate the ultrasonic welding of PP material, optimize the input parameters, and determine their effect on the strength of the weld seam.

2. Material and methodology

During our experiments, 4 mm thick DOCAPRÉN-H polypropylene plates were welded together. The welding was conducted using a BRANSON ultrasonic welding machine. Each plate measured 10 mm in width, and the overlap was also 10 mm; consequently, the area of the point joint was 100 m², with a length of 70 mm (see Figure 1).

Fig. 1. *The welding machine used during the experiments*

Based on the literature review, we conducted two series of experiments. In the first series, the amplitude (55 μm), preload (0.2 MPa), and main load (0.4 MPa) were maintained at constant values while the welding time was varied between 0.7 and 1.3 seconds in increments of 0.1 seconds. Using the results obtained from this series, we designed the second series of experiments, in which the main load and amplitude were modified at three levels each, as outlined in Table 1.

Table 1. *The values of the welding parameters*

Parameters		Levels		
		–1	0	1
x_1	Welding pressure in psi	45	50	55
x_2	Amplitude, μm	50	55	60

The quality of the seams formed during the welding tests was characterized by the load required to induce failure. The tests were conducted using an ELT-Schaltschrank tensile testing machine, with a displacement rate set at 10 mm/min.

3. Results

3.1. Effect of welding time

In the first series of experiments, we changed the welding time. The obtained results are illustrated graphically in Figure 2.

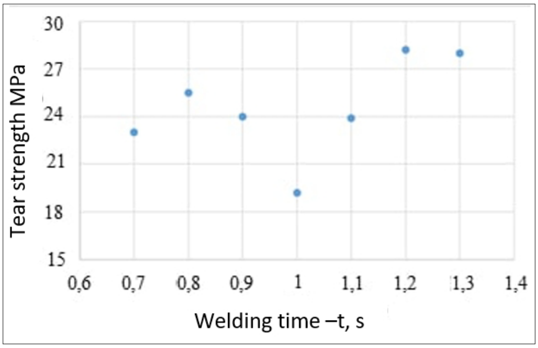

Fig. 2. *Development of the strength of the seams as a function of time.*

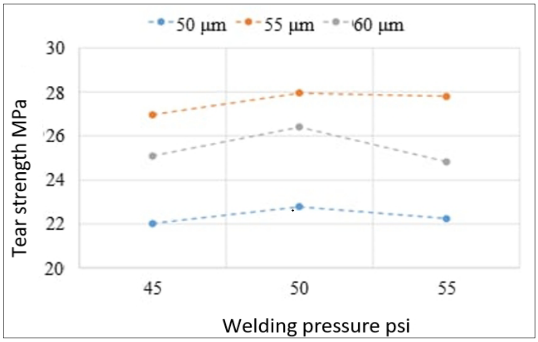

Fig. 3. *The strength of the seams as a function of the amplitude and the main load.*

The figure clearly illustrates that welding time significantly influences the strength of the seam. During the experiments, 15 welds were performed at each test point, and the figure displays the average values. The lowest quality joint was obtained with a welding time of 1 second, yielding a strength of 18.5 MPa, while the highest strength of 28.2 MPa was measured at a welding time of 1.2 seconds.

Additionally, the figure demonstrates a fluctuation in welding quality associated with the characteristic of ultrasonic welding, which is also reflected in the variation of the hardness parameter as a function of distance [7].

3.2. Effect of main load and amplitude

Based on the results of the first series of experiments, we established that the highest weld strength was achieved at a welding time of 1.2 seconds, given the same welding parameters. Therefore, with this welding time held constant, we conducted the second series of experiments, incorporating the input variables presented in **Table 1**. A comprehensive experimental design was employed, allowing for the examination of all parameter combinations across nine measurement points.

The results are illustrated graphically in **Figure 3**.

The figure clearly demonstrates that the main load has a significantly smaller effect on seam strength compared to amplitude. However, when varying the amplitude, it is evident that the highest breaking force was achieved at an amplitude of 55 µm, while seam strength values for amplitudes below 50 µm were comparatively lower.

4. Conclusions

Based on the experimental results, further investigations are necessary to draw definitive conclusions. The welding of polypropylene sheets in the industry is currently an extensively researched area, thus supporting the continuation of this study, with the findings aligning with existing literature. The conclusions derived from the measurements of the current research are as follows:

- The highest tear strength was obtained with a welding time of 1.2 seconds.
- Changing the amplitude had a greater influence on the holding capacity of the seams than changing the main load.
- The highest seam strength was measured at an amplitude of 55 µm.

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