

CHARACTERIZATION OF ULTRASONIC ASSISTED ADHESIVE JOINTS

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ABSTRACT. Joining experiments using different adhesives were carried out. In addition to the adhesive, the specimens were also treated with ultrasonic waves to improve the load carrying capacity of the joined parts. Lap joint shear tests have been conducted to quantify this improvement.

KEYWORDS: ultrasonic, adhesion, adhesives, epoxy.

1. INTRODUCTION

Products are becoming more complex and sophisticated in order to meet consumer needs while the environmental impact has to be reduced. Focusing on automotive industry components, the challenge is to exploit lightweight design concepts and provide the expected comfort standards. A consequence of this is the multi-material (hybrid) design approach, even for non-crucial sub-components. A particular important process in the assembly of these parts is the joining. For thermoplastics the joining techniques are divided into mechanical joining, adhesive bonding and welding. Joining with adhesives is becoming more popular and proper automated bonding processes without any further time consuming surface preparations are needed [1]. This work presents an advanced ultrasonic assisted joining technique. An external ultrasonic field applied to the bonding area has been shown to improve the adhesive dispersing as well as the curing kinetics [2, 3].

Here, we have adopted the ultrasonic-assisted bonding technology and investigated the influence of the process parameter on the load-carrying capacity. For this purpose, we have selected a polyamide (PA) reinforced with glass fibre and optimized the ultrasonic joining parameters (joining force, time and ultrasound wave amplitude) in order to bond two samples with each other. It should be mentioned, that the selected PA shows no significant bonding strength when it is bonded without ultrasonic-treatment. This observation highlights the capability of the bonding technique.

The objective of this work is to gain fundamental insights of the relationship between the ultrasonic joining parameters and the final joint's load-carrying capacity. This relationship is crucial for the understanding of the potential and limitation of ultrasound assistance during bonding. Consequently, process parameters can be adjusted in order to achieve desired mechanical behavior of the interface.

2. MATERIALS

The studied polymers were polyamide 12 reinforced with 50 vol. % short glass fibre (PA12GF50). They were provided as multipurpose specimen according to ISO 20753-A1. Adhesives based on cyanacrylat, polyurethane and epoxy were tested due to their compatibility with the ultrasonic treatment.

3. ULTRASONIC-ASSISTED BONDING

This section provides a brief introduction to an ultrasonic welding machine and introduces the concept used for the optimization and characterization of the ultrasonic assisted adhesive joints.

3.1. ULTRASONIC-WELDING DEVICE

All the specimens were manufactured on an ultrasonic welding device Stapla K35 XT (Schunk Sonosystems, Heuchelheim, Germany). This device was adopted and modified in order to perform adhesive bonding. Figure 1 shows the machine, which was used to treat the prepared specimen with ultrasonic waves. In this figure the main components of the ultrasonic joining machine are shown. The ultrasonic joining parameters are adjustable on the control unit. A brief description of the parameters which were assumed to be most important for this study is included as follows:

- **Amplitude:** defines the amount of energy transferred into the joint during the process and is adjustable in % of possible maximum.
- **Joining force:** defines the pressure applied on the joining parts during the process and can be adjusted in Newton.
- **Joining time:** defines how long the ultrasound and the joining force are active. Has to be adjusted in seconds.

The actual US welding device consists of a converter which transforms the high voltage output of the control unit to a mechanical wave, a booster and a pneu-

matic cylinder. The sonotrode is the actual "tool" of the machine.

During processing the sonotrode is moved towards the upper surface of the specimen till it establishes contact with the part. After the preselected joining force is applied the ultrasonic generator is activated and the process starts. Figure 2 shows the sonotrode and the clamping system in detail.

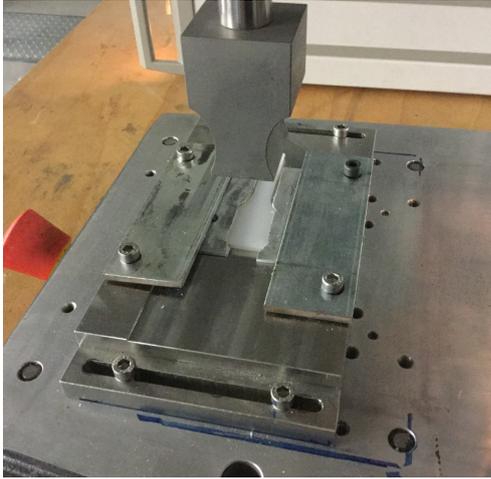


FIGURE 2. Specimen clamping system.

One specimen is placed in the clamps and an adhesive layer is applied on its surface. Before the start of the joining process another specimen is placed on top of the clamped specimen with the adhesive layer between them. The two parts are now fixed and the joining process can take place.

3.1.1. OPTIMIZATION OF JOINT PROPERTIES

A large number of process as well as environmental factors influences the final bonding quality. Figure 3 illustrates the approach to optimize the joint properties. Here, we mainly focused on the parameters of the external induced ultrasonic-treatment in order to enhance the interface between the adhesive and the PA12GF50. The ultrasonic joining parameters were assumed to be the most important factor for the optimization of the bonding quality. Furthermore, a suitable geometry for the joining process and a proper selected adhesive were also considered for the optimization of the joint properties.

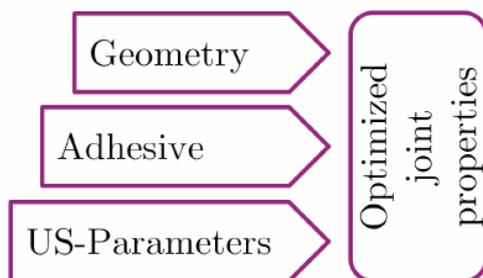


FIGURE 3. Approach for the optimization of the joint properties.

The three factors shown in Figure 3 are systematically studied hereafter:

Geometry

Joining with an ultrasonic device is hardly possible without an optimization of the part geometry. Multipurpose specimens have plane surfaces and hence are hard to process with the ultrasonic joining (welding) technique. In addition, plane surfaces consequently slip during the ultrasonic-treatment. This has to be avoided and an appropriate geometry has to be developed. Only the upper part of the multipurpose specimen is used for this investigation, since preparation cost of the part should be as low as possible. The idea is to find a geometry which prevents slip and offers compatibility with the ultrasonic joining process. A good approach to a suitable ultrasonic joining geometry is to mill the surface and leave a chamfer (ideally triangle shaped with a sharp tip) which prevents slipping and can be molten up easier compared to the plain surface during the joining process. Figure 4 shows one of four (A-D) options for ultrasonic appropriate geometry which had been tested. As already mentioned the surface was prepared with a milling tool and on the edges a chamfer was left over. The left side of the figure shows the specimen after milling. On the right side a partial cut through the chamfer can be seen. As already mentioned slipping of the parts during the ultrasonic joining process is problematic. The chamfer prevents the slipping and contributes to properly conduct the ultrasonic joining process.

Selection of a proper adhesive

To evaluate which of the studied adhesives (cf. "Materials") are suitable for the treatment with ultrasonic waves, optical assessments after ultrasonic-treatment were conducted. For the purpose of studying the influence of ultrasonic-treatment on the adhesive, the polymeric specimens were not bonded. So, the final mechanical properties of the adhesives were not determined and remain unknown. A thin film of each adhesive was applied on the surface of a specimen and treated with ultrasonic waves. The sonotrode established contact with the surface of the adhesive and ultrasound was induced directly into it. A reference sample was also prepared under the same environmental conditions, but without ultrasonic-treatment. After the adhesives were cured, the ultrasonic-treated specimen were compared to the reference sample. The main criteria for this optical comparison (assessment) were:

- appearance of the adhesive after curing (colour)
- crack formation through adhesive layer
- compatibility with material.

Influence of ultrasonic joining device parameters

As already mentioned the joining time, amplitude and joining force were assumed to be the most important parameters for the investigation. The joining force defines the pressure applied by the sonotrode

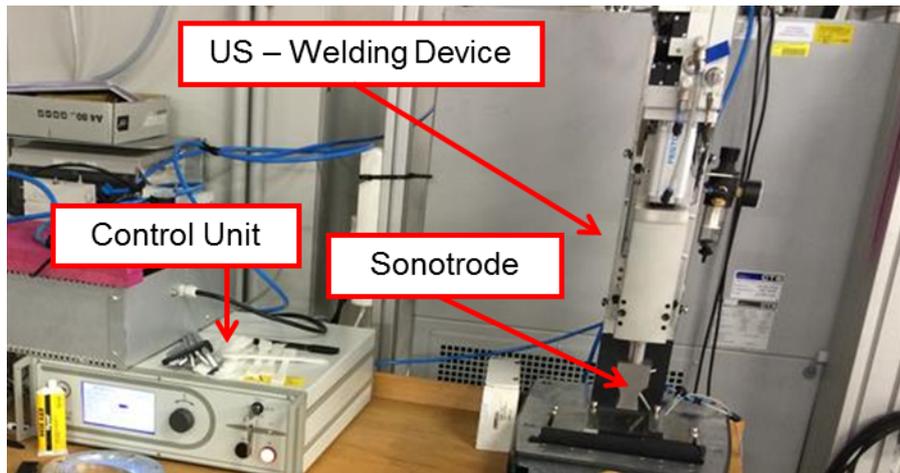


FIGURE 1. Ultrasonic joining device.

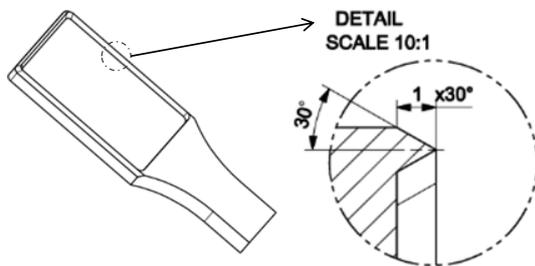


FIGURE 4. Geometry option A.

onto the surface of the part and using a higher joining force usually results in a greater mechanical strength of the bonding. Here, we bonded two specimens of same material and realized a lap shear joining. The displacement resulting from the melting of the specimens in contact is defined by either the force or the time parameters (depending in which mode the process is operated). The specimen created in this step had an adhesive layer between them. The ultrasonic stimulus should also have a positive influence on the interface quality between the adhesive and the PA12 surface. We conducted a pre-study to determine the optimized ultrasonic joining parameter in order to achieve joints with enhanced load-carrying capacity.

By focusing on these three main factors during the conducted experimental studies, the process sensitivity regarding changes of these factors is analysed. Consequently, the impact of these factors (process parameters) on the final mechanical behaviour of the bonding is determined.

3.2. TESTING

The lap joint shear test was done on a modular test setup (TestBench, Bose Corp., ElectroForce Systems Group, MN, US). Figure 5 shows the lap joint shear test setup in detail. In this illustration the lap joint shear test setup can be seen with a mounted specimen in the clamp. For all the experiments a testing speed of 5 mm/min was used according to ASTM D1002-01.



FIGURE 5. Specimens bonded by the adopted ultrasonic joining device.

To meet all the prerequisites for the lap joint shear test the lower side of the clamping unit, where the load cell was mounted, was aligned in order to avoid (minimize) bending loading at the bonded area.

4. RESULTS

4.1. FIRST ULTRASONIC JOINING PARAMETER OPTIMIZATION

After the pre-study was done specimen with the found parameters were created. The adhesive best suited for the ultrasonic treatment was a two component epoxy type which was used for all the conducted experiments. A part of the results is shown in Figure 6. This figure illustrates some of the results generated from the first ultrasonic welding parameter optimization. The influence different parameter settings have on the load-carrying capacity is shown. Different joining forces N were applied while ultrasound amplitude A and joining time t remain unchanged. Higher joining force resulted into higher load-carrying capacity. The spikes in the slope of the green line are caused by slip of the clamp during measuring. Experiments with optimized geometry have not been conducted in this

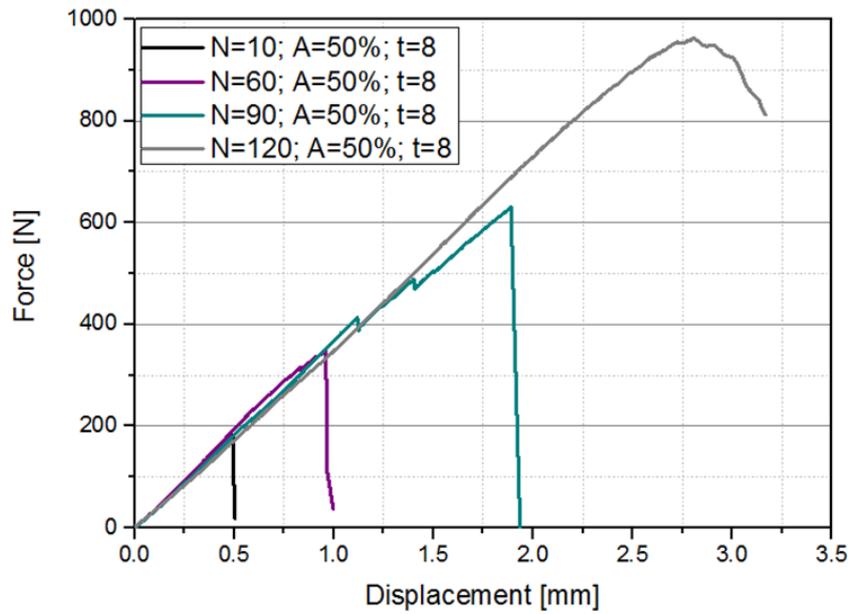


FIGURE 6. Comparison of the load-carrying capacity of specimens bonded with varying ultrasonic parameters.

first experimental series.

4.2. SECOND ULTRASONIC PARAMETER OPTIMIZATION AND FIRST GEOMETRY EXPERIMENTS

In this second experimental series the potential of this joining technique is explored. Figure 7 shows a comparison of specimen created with untreated adhesive, adhesive with ultrasonic treatment and different geometry possibilities without the use of an adhesive between the joining parts. The geometry specimen are bonded by the material melting up during the joining process. This was done to explore how much the geometry can contribute to the total load carrying capacity of a combined sample (ultrasonic treated adhesive, geometry).

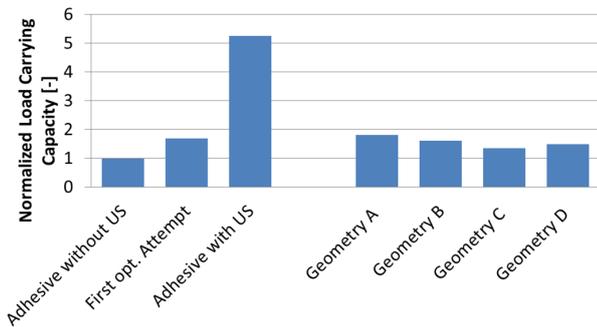


FIGURE 7. Normalized load-carrying capacity improvement comparison.

The column on the left side represents the specimens which have been joined just by the use of an adhesive. Their average load carrying capacity value was used as reference to normalize the values of the other specimen. Comparison shows a significant raise in the load-carrying capacity between the three left

columns. A more detailed optimization of the ultrasonic joining parameters improved the load-carrying capacity by a large amount compared to untreated and specimen belonging to the first optimization attempt. The first geometry specimen created (A-D) did not provide a load-carrying capacity as high as the optimized samples created with ultrasonic treated adhesive did.

Results of latest unfinished experiments showed, geometry also has a high potential to increase the load carrying capacity of the joining parts more than what can be seen in Figure 7. If parametrization of the ultrasonic joining device is done correctly and the geometry matches the application higher load carrying capacities can be achieved.

To further increase the specimen’s load-carrying capacity a combination of ultrasonic assisted adhesion and an application matching geometry joined with the adopted ultrasonic joining parameters will be examined. This combination is assumed to offer even higher load carrying capacity than the specimens tested till now.

5. CONCLUSIONS

Based on a systematic parameter study, the influence of three main factors (geometry, adhesive, ultrasonic-treatment parameters) on the final bonding quality was examined. Moreover, the potential of ultrasonic-assisted bonding was highlighted throughout experimental studies. In Figure 7 the significant improvement of load-carrying capacity can be seen. Comparing the treated specimen of the second optimization with the untreated reference samples load carrying capacity was improved approximately five times.

Basically, the ultrasonic-treatment parameters have the highest impact on the final bonding quality for

both the geometry and ultrasonic treated adhesive. Here, the load-carrying capacity was determined from lap shear measurements and was used as a measure of the bonding quality. As the utilized geometry was not according to the respective lap shear test standard (ASTM D1002-01), the bond strength was not evaluated. The performed mechanical experiments were only for relative comparisons within the here studied specimens. Bond strength has to be determined in future works and compared to data achieved by other bonding technologies.

LIST OF SYMBOLS

A Amplitude
 N Joining force
 t Joining time

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