

# Investigation of the weldability of the self-reinforced polypropylene composites

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**Abstract.** In the present work weldability of self-reinforced composite was investigated. As reinforcement a fabric, woven from highly stretched split PP yarns, whereas as matrix materials two kind of random polypropylene copolymer (with ethylene) were used. The composite sheets were produced by film-stacking method and compression molded with different thickness (1 mm, 2 mm) with different contents at different processing temperatures keeping the holding time and pressure constant. The SRPPC sheets were welded by ultrasonic welding machine with different welding parameters. The welds were qualified by mechanical and microscopic tests. The results showed that the thermoplastic reinforcement has not got melted; therefore the reinforcement was kept the strength-increasing effect.

## Introduction

Polypropylene (PP) is the most used thermoplastic material in the automotive industry which has good mechanical properties, cheap prize (~1 Euro/kg) and it can be reprocessed several times without significant loss of properties. PP has to be filled and reinforced in order to compete with engineering plastics. Glass fiber (GF) is commonly used to improve the properties of PP. The disadvantage of the PP-GF structure is that reprocessing complicated and very expensive whereas the matrix and reinforcement need to be separated. In the several decades some environmental regulations were produced, for example End-of-Life Vehicle directive by European Union for automotive recycling [1]. This triggered the development of more environmental-friendly materials which show similar mechanical performance, however, at far better recyclability. Self-reinforced composites represent the right alternative to traditional fiber-reinforced thermoplastic composites, because both reinforcement and matrix are from the same polymer family, thereby the easy recyclability is given. To produce self-reinforced polymer composites three methods are mostly followed: hot compaction, consolidation of coextruded tapes and film-stacking methods.

The hot compaction technique was developed by Ward and coworkers [2-4]. Oriented thermoplastic fiber was used and laid to the metal mold. It was recognized that when these performs were put under pressure and the temperature increased their surface and core showed different melting behaviors. This finding was exploited to bring the outer layer of the fibers and tapes into melt, which after solidification (crystallization) overtook the role of the matrix, whereas their residual part (i.e. core) acted as the reinforcement in the resulting composite. Beside that the product of this technique has very good mechanical properties. The disadvantage of this method is that it requires a highly controlled production due to the narrow processing window (3-5°C). This technique was initially developed for melt-spun polyethylene fiber [5] and later adapted to practically all fiber-forming semicrystalline thermoplastics (e.g. PE [6], PP [7], PET [8], PA66 [9] etc.) from which fibers can be produced. The product of hot compacted PP woven fabric is already commercialized under the trade name Curv<sup>®</sup> [3, 10]. To enlarge the processing window of hot compaction and thereby to improve the consolidation several attempts were made. Peijs et al. [11]

developed a coextrusion-technique. The invention was to “coat” a PP homopolymer tape from both sides by a copolymer through a continuous coextrusion process. Note that a copolymer melts always at lower temperature than the corresponding homopolymer owing to its less regular molecular structure. The coextruded tape was stretched additionally in two-steps. This resulted in high-modulus, high-strength tapes. The primary tapes could be assembled in different ways: as in composite laminates (ply by ply) structure with different tape orientation, such as UD [12-14] or integrated in various textile structures (e.g. woven fabrics) [15-17]. This composite material is also commercially available as Pure<sup>®</sup> [11]. The second method to improve the consolidation was the film-stacking [18-24]. During this technique the reinforcing layers are sandwiched in between the matrix-giving film layers before the whole “package” is subjected to hot pressing. Under heat and pressure the matrix-giving material, having lower melting temperature than the reinforcement, melts and infiltrates the reinforcing structure accordingly. Recall that both matrix and reinforcement are given by the same polymer or polymer family. The advantage of these methods is an enlarged processing window from the viewpoint of the temperature (20...40°C).

Welding of the self-reinforced composites was not developed and published yet. Generally, ultrasonic and laser welding was used for polymeric materials on the automotive industry now. The biggest welding problem of the thermoplastic composites is that the reinforcement structure not overlapped each other. The connection of the reinforcements are not be generated and only the matrix bonding is caused the composite strength. Initial aim of the self-reinforced PP sheets was the reinforcement fibers kept the original reinforcing function. Under ultrasonic welding when the welding parameters are optimal the reinforcements connected to each other [25, 26].

The aim of this study is to investigate the weldability of self-reinforced PP composites with ultrasonic welding machine. The self-reinforced composites plate was produced by hot pressing with using film-stacking method. Static tensile tests, polarization optical microscopy and 3D CT tests were performed on the plates.

## Materials and testing

### Materials and composite preparation

As matrix two kind of PP foil a) random PP copolymer Tipplen R359 (MFI=12 g/10 min) and b) random PP copolymer Tipplen R351 (MFI=8.5 g/10 min) whereas as for reinforcement a woven fabric from highly stretched split PP yarns were used. The reinforcement content of SRPPC was ca. 30 wt% and ca. 40 wt%. Respectively, two different thickness (1 mm and 2 mm) composites were prepared by film-stacking method and compression molded at different consolidation temperatures (152°C and 167°C) keeping the holding time (heating without applying press for 30 s; heating with press for 90 s) and pressure (60 bar) constant in a hot pressure. The cooling rate was 7.5°C /min. The tensile strength of the resulted composite sheets was between 80-90 MPa independently on the used material.

### Specimens and their testing

Ultrasonic welding machine (Herrmann Ultraschalltechnik GmbH PS MPC) and 150x25x2 mm specimens (Fig. 1) was used for join by using a frequency of 20 kHz (as shown on Fig. 2).

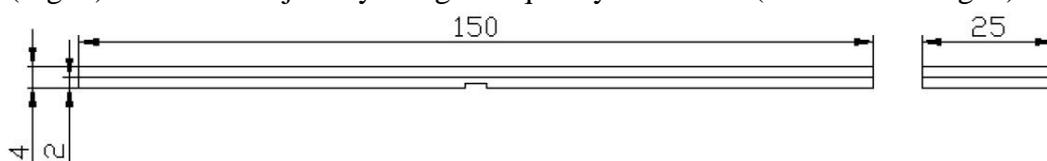


Fig. 1. Welding specimen with total overlap

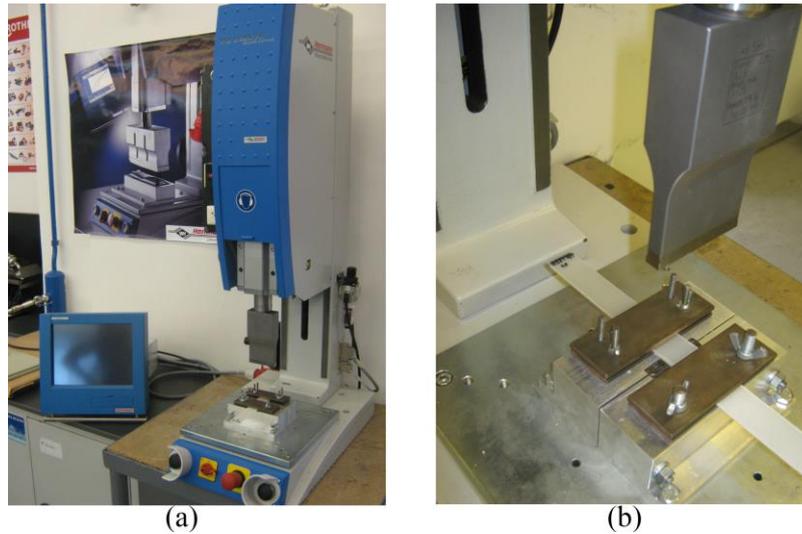


Fig 2. Herrmann Ultraschalltechnik GmbH PS MPC ultrasonic welding machine (a) and the specimen holder (b)

The tensile tests were done on a universal ZWICK Z020 testing machine with a crosshead speed of 5 mm/min at room temperature (RT) according to standard EN ISO 527. The tensile strength was determined from the tests results. The composite structure in the weld line was studied by polarization optical microscopy and 3D CT.

### Results and discussion

The quality of the weld line is influenced by sheet holder, anvil, structure of the sonotrode surface, and the welding control. The strength of the weld was increased by using ragged surface anvil according to the pre-experiments. The time-control was 0.4-0.8 s (sheet thickness was 1 mm) and 1-1.6 s (sheet thickness was 2 mm) and the applied pressure was 6 bar. The vertical amplitude of the sonotrode was 35 (70%) and 40  $\mu\text{m}$  (80%).

#### Static tensile test

Based on the results it can be stated that the longer the welding time was, the lower the tensile strength became (as shown on Fig. 3) that is may be explained by reinforcement failure. All of the composites were failed at the weld line. Using the amplitude of 80% the strength decreased slower than at the amplitude of 70%. The tensile strength was valuable when the welding time was smaller than 1 s. The welding was blocked by the machine at 80% amplitude and 1.6 s welding time.

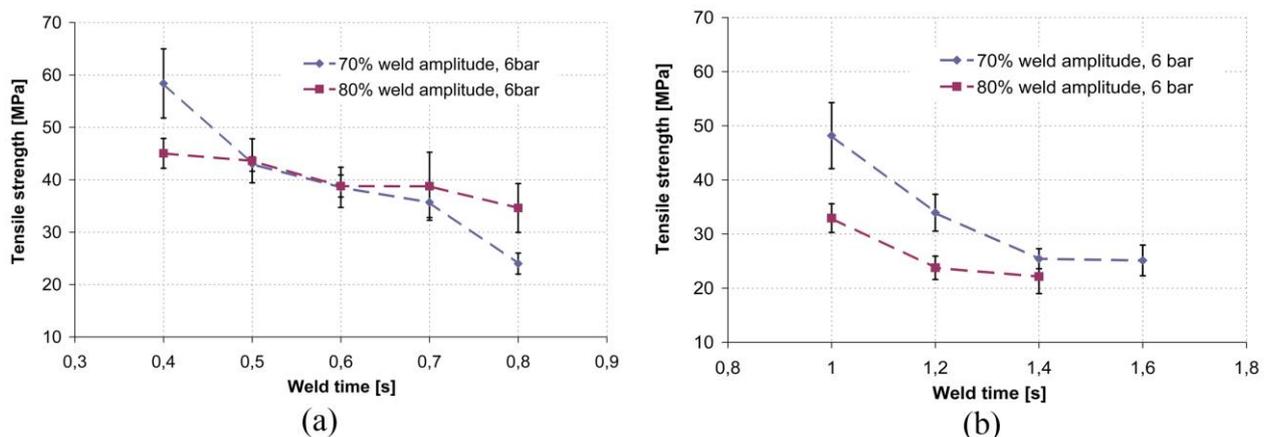


Fig.3 Tensile strength of the 1 mm (a) and 2 mm (b) thick composite sheets

Figure 4 shows the delivered energy as a function of welding time. It can be seen that the delivered energy increased with increasing welding time. More than 100-150 J energy is necessary to weld a 1 mm thick composite plate with 80% amplitude as of 70%. The weld line is strongly fractured and the material molten in between the anvil and sonotrode above 200 J and 0.5-0.6 sec. In case of 2 mm thick plates the delivered energy and the welding time are two-fold than 1 mm thick ones. The curves of the 70% and 80% amplitude are diverging. Increasing the welding time the difference between the curves is increasing. This effect is explained by damping capacity of the polymer. The vibration is absorbed by the material (principle of ultrasonic welding) but the absorption distance of the PP is small. The distance for the total absorption depends on the welding amplitude.

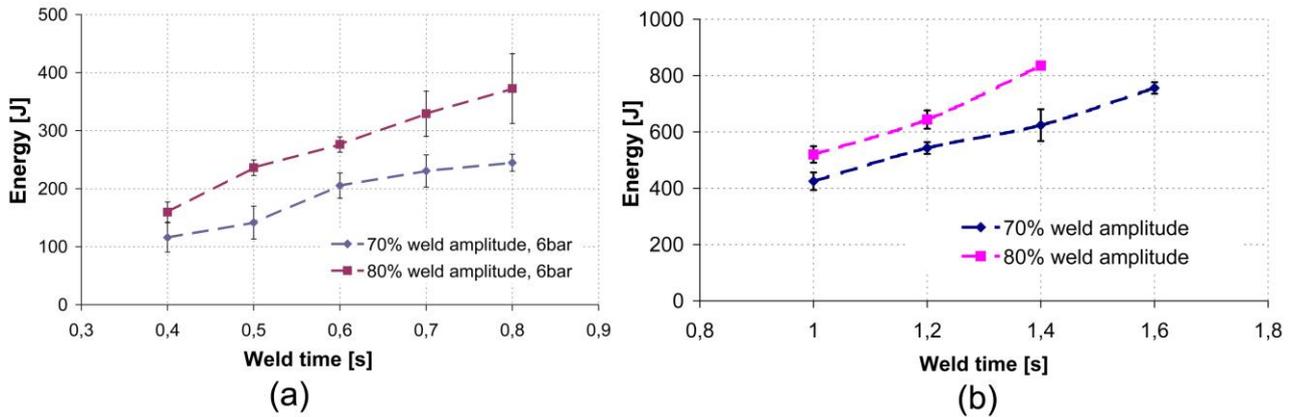


Fig. 4 Demanded/absorbed energy of the 1 mm (a) and 2 mm (b) thick plates

Figure 5 demonstrates the tensile strength and the elongation at break of the samples with different reinforcement contents and consolidation qualities. One can see that at lower processing temperatures the composites are not consolidated perfectly while the tensile strength is decreasing and the scattering increasing. It shows that the strength of the weld line depends on the processing parameters.

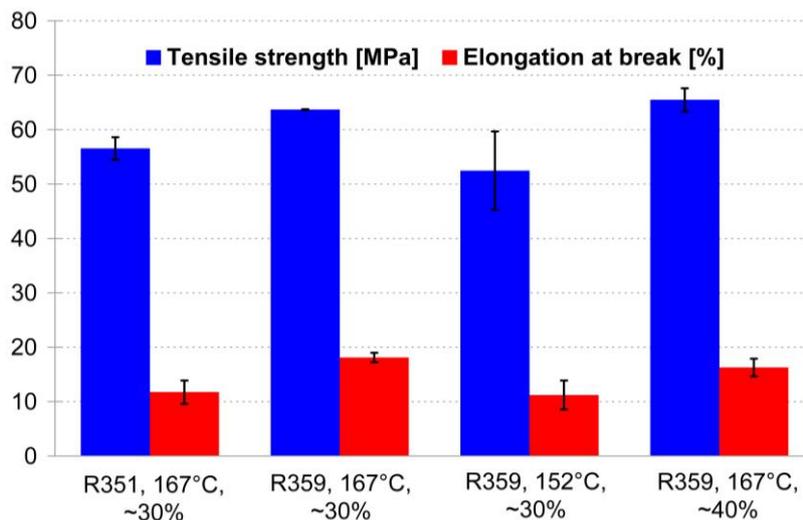


Fig 5. Tensile strength and elongation at break of the different reinforcement contents with consolidation

## Microscopy

Typical failure behavior was studied by light microscopy. Specimens were cut from the cross-section and analyzed by polarization light microscopy and 3D CT. The weld line was made by flatness anvil in order to avoid the negative effect of the ragged anvil. Figure 6 demonstrate the reinforcement and matrix layers. The pictures show that the reinforcement continuity was disappeared and it was molten by the high temperature and pressure. Under the fibers recrystallization of the local orientation was observed. It is caused by the flow direction under pressing (as show on Fig 6b.). One can see further by the indentation of the sonotrode the molten material was press to the side from the weld seam and barb was formed.

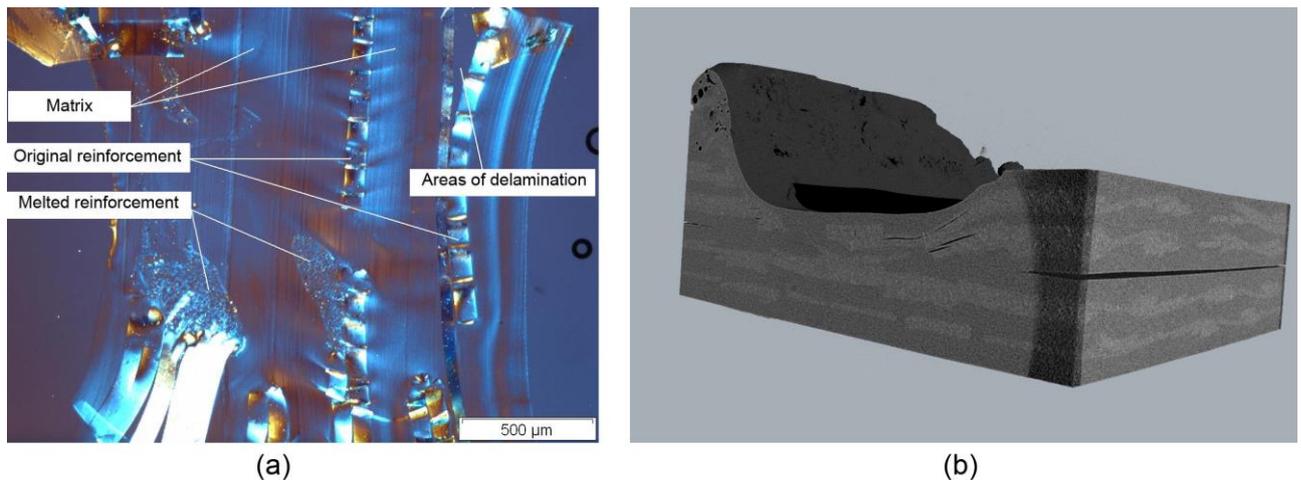


Fig. 6 Cross-section of the weld line by polarization light microscopy (a) and 3D CT picture of the weld line (b)

## Conclusion

The aim of this paper was to investigate the weldability of the self reinforced polypropylene composites with different thicknesses, materials, consolidation qualities and welding parameters. Results show that the ultrasonic welding is available to weld these materials. The tensile strength of the sheets approached the original strength of the material. The aim of the welding is to keep the reinforcement in fiber form. The sheets were investigated by static tensile test. Light polarization micrographs and 3D CT pictures of the cross section were taken. Based on the results it can be concluded that the reinforcement was strongly destructed but the residual content did not lose its strength-increasing effect. Increasing the absorbed energy and welding time the strength was decreasing therefore the quality of the weld line is sensitive to the change of the welding parameters.

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