Strength of laser welded joints of polypropylene composites

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Abstract. This paper deals with experimental tests of laser welded polypropylene composites. Polymers, such as polypropylene, are often filled with fibres in order to increase their mechanical properties. The welding procedure can also influence material properties nearby weld joints. Therefore the strength of weld joints is lower than strength of primary materials. This effect is proved by realized shear tests. Polymer specimens were filled with 20 % and 40 % of glass fibres and all possible combinations of specimens were welded for experiments. There is also discussed influence of volume fraction of glass fibres in polypropylene on the strength of weld joint.

1. Introduction
Nowadays, laser welding is common method of jointing polymers and its importance is increasing. Generally, welding of plastics is the process of jointing parts through heating in order to melt and fuse the polymer at the interface [1]. Advantages of laser welding to conventional welding methods are localized heat input to the joint interface, reduced welding flash, weld seams of high mechanical strength and quality [2]. Also the settings of welding conditions like speed of welding, laser power and focal distance are easy. So the repeatability of potential measurement is high.

1.1. Motivation
Mechanical properties of polymers compared to metals are worse. The value of material strength, yield point and stiffness is much lower but the enhancement of these properties can be achieved by adding fibres, fabrics or particles. Welding of reinforced composites is more complicated than welding of pure polymers but it is still possible. The effort of researchers is mainly aimed at welding process itself, welding conditions and possibilities of various material jointing [3, 4] whereas area of weld joint strength and material properties is not so inspected. Papers concerning on reinforced polypropylene mostly have to do with carbon fibres [5].

The main purpose of this article is to describe the influence of weld joint on total strength of various jointed materials. Material chosen for shear testing on testing machine was glass fibre reinforced polypropylene with 0, 20 and 40 % amount of fibres.

1.2. Materials properties
Jointing of plastics by laser welding and shear tests as well have certain constraints and specifics. One of the pair of the welded polymer needs to be transparent and one absorbing, usually clear (or natural) and black. Although jointing of two transparent polymers is possible [6, 7], common method (used in this research) is doping the polymer with absorbing additive. These additives, e.g. carbon black, partially change material properties (see Table 1).
The measurement of mechanical properties of both natural and black polymers had to be conducted before the shear tests. Afterwards it was possible to compare the tensile strength of origin basic material and strength of weld joint. The specimens were cut out of an injected plate. Material experiments were performed on testing machine as standard tension tests and only the strength of material was important for following evaluations. The material strength of used glass fibres reinforced polypropylene is in Table 1.

**Table 1.** Materials used for jointing by laser welding and their tensile strength. The letter “N” means natural (clear) material, letter “B” means black absorbing material and number denotes the volume fraction in % of glass fibres.

| Material | Tensile strength [MPa] | Material | Tensile strength [MPa] |
|----------|------------------------|----------|------------------------|
| PP N0    | 33                     | PP B0    | 35.7                   |
| PP N20   | 60.4                   | PP B20   | 58.2                   |
| PP N40   | 60.6                   | PP B40   | 69                     |

**2. Measurement and welding**

The shear test was proposed as a tensile test of two welded overlapped pieces of material. None of European Standard describes this type of experiments so proper methodology was specified. The scheme of welded specimens is in Fig. 1. Dimensions of specimens were 130×20×2 mm and the lap length was 20 mm. The weld joint was continual across the specimen and its width was 1 mm.

The end areas were clapped into grips of testing machine Instron and loaded by increasing force till the rupture. The velocity of crosspiece was 1 mm/min. The main result was the maximal force on the tensile curve, which is the strength of the weld joint. Then the area of joint weld of each specimen was measured by the image processing and all data were statistically processed and evaluated. Nine combinations of materials were welded for the teste, see Table 2.

**Table 2.** Combinations of welded materials for shear tests. The letter “N” means natural material, letter “B” means black material and number denotes the volume fraction in % of glass fibres.

| Material | Material | Material |
|----------|----------|----------|
| PP N0-B0 | PP N20-B0 | PP N40-B0 |
| PP N0-B20 | PP N20-B20 | PP N40-B20 |
| PP N0-B40 | PP N20-B40 | PP N40-B40 |

Specimens for shear tests were welded on laser station LM05/05P.W. Settings of welding parameters were quite demanding because the weld joints needed to be thin. The presence of glass fibres also complicated the welding process as the laser beam was dispersed by the fibres. Dimensions of the
weld joints weren’t optimal (they were small) but larger area of the joints would cause fracture in the origin material during the test, not in the weld joint. On the Fig. 2 there is both welded parts pressed to the base by a tool. This tool contains of four pneumatic cylinders ensuring adequate contact pressure on specimens. In the middle of the tool there is longitudinal hole for laser beam welding the specimen. Welding parameters were unique for each combination of welded materials to achieve good weld joint. The higher volume fraction of fibres in polypropylene, the higher welding velocity had to be used.

![Figure 2. Work desk of laser station LM05/05P.W during the preparation on welding.](image)

![Figure 3. Separated parts of welded specimens PP N0-B0 (left) and N20-B40 (right) after the test under the microscope.](image)

3. Measurement evaluation
Some specimens cracked too soon and the measured maximal force was very low. It was probably caused by lacking welding, awkward manipulation or other mistake. These specimens were taken out of the statistical processing, there were less than 10 specimens total. The measurement evaluation is in following Table 3 and photographs of broken specimens on the Figure 3.

|                  | Maximal force [N] | Weld area [mm²] | Maximal stress [MPa] |
|------------------|-------------------|-----------------|----------------------|
| PP N0-B0         | 246 ± 16          | 14.6 ± 1.5      | 16.9 ± 1.1           |
| PP N0-B20        | 254 ± 11          | 14.5 ± 1.0      | 17.6 ± 1.2           |
| PP N0-B40        | 290 ± 8           | 19.8 ± 0.8      | 14.7 ± 0.5           |
| PP N20-B0        | 319 ± 22          | 18.6 ± 1.4      | 17.2 ± 1.0           |
| PP N20-B20       | 314 ± 39          | 17.9 ± 1.6      | 17.6 ± 1.4           |
| PP N20-B40       | 504 ± 56          | 24.6 ± 1.4      | 20.4 ± 1.9           |
| PP N40-B0        | 277 ± 50          | 18.6 ± 2.6      | 14.9 ± 1.5           |
| PP N40-B20       | 476 ± 57          | 24.2 ± 2.5      | 19.6 ± 0.7           |
| PP N40-B40       | 702 ± 28          | 36 ± 2.0        | 19.5 ± 1.2           |
For each combination of welded materials the mean value of measured maximal force and evaluated weld area and maximal stress are listed. The stress is a fraction of force and weld area. The mean value is appended with the value of 95% confidence interval. Already quick view to the Table 3 indicates that presence of glass fibres in polypropylene doesn’t increase the strength of weld joints, decisively not proportionally to the strength of welded materials. According to the results (values of maximal stress), the dependence of weld joint strength on volume fraction of fibres can’t be done. The stress values form the Table 3 are shown in Fig. 4 for better understanding.

![Figure 4](image)

**Figure 4.** Mean value and 95% confidence interval of evaluated maximal stress of welded PP composites.

The measured force and evaluated stress corresponds to the shear stress. Shear strength is usually approximately half compared to a material tensile strength. So the weld joints strength of non-filled polypropylene match the expectations, see the Fig. 5. The strength of reinforced PP was much higher but the weld joint strength still remains very similar. It seems the weld joint strength depends mainly on material strength of the basic non-filled material. The reason why the fibres don’t increase the weld joint strength similarly to material strength is meanwhile unknown.

![Figure 5](image)

**Figure 5.** Comparison of weld joint strength (disk) and material strength (square – natural PP, rhomb – black PP).
4. Conclusion
The weld joint strength was not surprisingly lower than strength of welded materials. This was proved by shear tests on testing machine. Quite unexpected result was little influence of glass fibres on weld joint strength. The weld joint strength remains about the same value for all welded material combinations. The weld joint strength of non-filled materials was approximately half in comparison with strength of origin material.

5. References
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