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INFLUENCE OF STORAGE CONDITIONS OF PVC ROOFTOP SHEETS ON THE HOT AIR WELDING PROCESS

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ABSTRACT: One of the common welding methods for polymer rooftop sheets is the overlap welding by hot air either done manually for small parts or with a welding machine for long sheets. The weld quality depends on different parameters like the welding speed, the welding temperature or the pressure applied on the joining materials. Due to the field of application of rooftop sheets, there are other environmental influences like the ambient temperature, the air humidity or direct sunshine which can cause a decrease of the welding quality. This work will focus on a pre welding influence, the storage temperature of the rooftop sheets and how it affects the welding quality. Two poly vinyl chloride (PVC) rooftop sheets were chosen and tested separately. The materials were cut into small sheets, stored under different temperature conditions, and were welded afterwards. The welded samples were tested according to the DIN EN 12317-2 to determine the shear resistance of the weld as it is an important mechanical property and a good indicator for the quality of the weld. The results show a minor influence on the welding process but no influence on the quality of the weld itself as all weld lines of all samples managed to stay intact.

KEY WORDS: *Hot air welding, PVC, rooftop sheets, welding conditions, welding quality.*

1. INTRODUCTION

Hot air welding has been proven to be an applicable welding technique for polymer parts, rooftop sheets or even for polymer-metal hybrid structures (Kobayashi et al., 2019). It can be separated in different welding techniques such as the tack welding, the permanent hot gas welding, or the high-speed welding (Rotheiser, 2009). This work will focus on another hot air welding technique, the overlap welding, as it is a common method for welding

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rooftop sheets. For this method a rooftop sheet is placed on top of another sheet with only a certain part overlapping and then a hot air fan, followed by a pressure roll is lead through the overlap (Oba et al., 1994). The surfaces of the sheets are melted and the pressure of the roll bonds them together. This welding method depends on some different parameters to achieve a good welding quality. The main parameters are the welding temperature, the welding speed and the pressure applied to the rooftop sheets. However, as the sheets are used to cover roofs outside, there are a lot of other influences on the weldability of the sheets and the quality of the weld itself, like rainfall during the welding process, direct sunlight, wind, or the humidity of the air (Bucko et al., 2012). Research has shown that the ambient temperature has an influence on the welding of ethylene vinyl acetate (EVA) rooftop sheets and welding parameters must be adapted to ensure a good weld quality (Park et al., 2020). Another influence on which this work focuses, is the effect of the storage temperatures of rooftop sheets. There is no common guideline as to how storing temperatures affect the welding since producers of rooftop sheets usually only recommend a dry storage.

2. METHODOLOGY

To analyze and characterize the effect of storing temperatures, PVC rooftop sheets are stored under different temperatures and welded directly after the temperature treatment. As there is a wide variety of different PVC rooftop sheets, two rooftop sheets were chosen. Material 1 is the Bauder Thermofol U15, a PVC-P rooftop sheet with polyether sulfone (PES) synthetic fibers insert and material 2 is the Wolfin IB a homogenic PVC-P rooftop sheet without fibers (Figure 1).

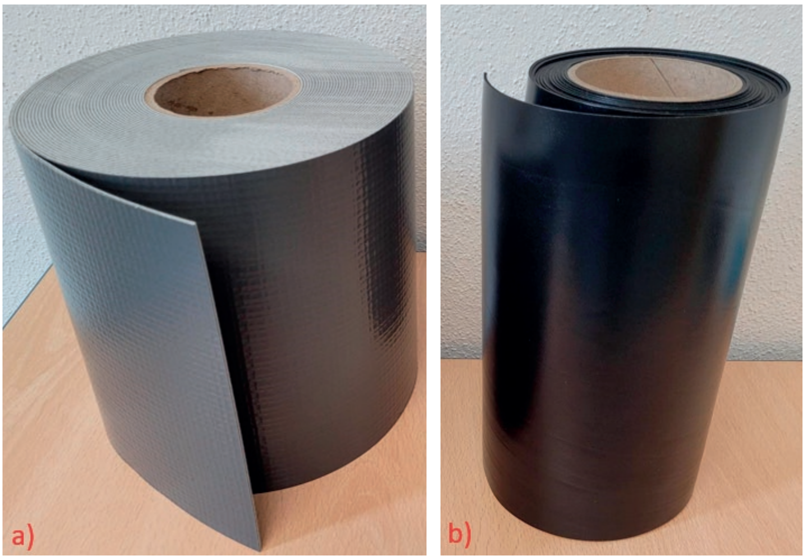

Figure 1. Rooftop sheets Bauder Thermofol U15 (a) and Wolfin IB (b).

Regarding the storage temperatures, five different temperatures were chosen: -18 °C, 0 °C, room temperature, 40 °C and 60 °C. These temperatures represent a wide range of possible storage temperatures which can occur depending on the way of storing the material and the given environmental influences. The materials were cut into two sheets, for each chosen temperature, with the dimensions of 200 mm × 200 mm and stored for 24 hours in the freezer, fridge, or oven. After the storing process the samples were taken out of the storing devices and immediately being welded by the hot air welding method. For the hot air welding method, a laboratory hot air welding machine was used (Figure 2).

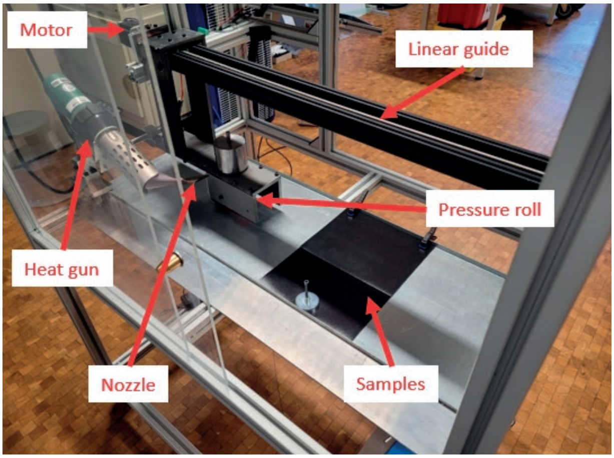

Figure 2. Laboratory hot air welding machine in the workshop of the University of Ansbach.

The device was developed and constructed at the University of Ansbach and is capable of welding small rooftop samples (Michalak, 2022), similar to rooftop welding machines. It is possible to set different parameters like speed, temperature, and pressure directly at the machine to ensure a consistent welding process. The chosen parameters for the welding are 500 °C for the welding temperature and 2.2 m/min for the welding speed. These values were within the recommended welding parameters for both materials according to the installation instructions and material datasheets. The recommended parameters for the welding of the Bauder Thermofol are in the range of 480 °C to 580 °C for the welding temperature and 2 m/min to 4.5 m/min for the welding speed (Bauder, 2020). For the Wolfin IB the recommended welding temperature is around 520 °C and the welding speed around 2.2 m/min (Wolfin, 2023). Regarding the pressure no additional weight was added as first welding tests have already shown a good weldability without added weights. After pre-heating the hot air fan of the device, the cut sheets were put into position and the welding process was started with the selected parameters. The hot air fan is guided through the contact surfaces of the materials, causing them to plasticize while the roll follows and applies the pressure to join them. After the welding process the materials were left cooling and then stored for 24 hours before being cut into 5 samples for each variant (Figure 3).

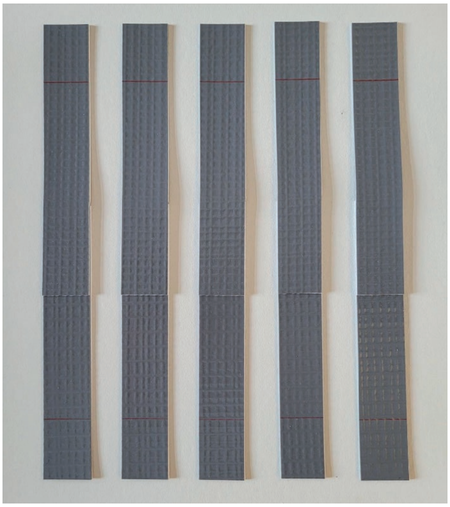

Figure 3. 5 samples for the tensile strength test of the material Bauder Thermofol U15.

The welded samples are tested according to the DIN EN 12317-2 (Deutsches Institut für Normung [DIN], 2010), with a minor change in sample dimensions, to determine the shear resistance of the weld as it is an important mechanical property and a good indicator for the quality of the weld. The samples prepared for the testing have a width of 25 mm instead of 50 mm as stated in DIN EN 12317-2. This change had to be done to ensure a proper fixation in the tensile testing machine as the clamps have a width of 25 mm as well. The tensile testing machine used for the determination of the shear resistance is the Instron 4411 with a 5kN load cell.

3. RESULTS

The results of the tensile strength test show different behaviors of the materials. The samples of the Bauder Thermofol U15 tend to break with two peaks in the tensile strength test (Figure 4).

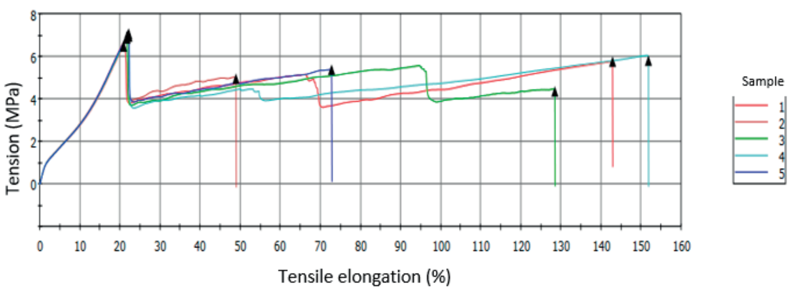

Figure 4. Results of the samples 1 till 5 of the Bauder Thermofol stored at room temperature.

The first peak shows the breakage of the fibers and the second peak the breakage of the PVC material. All the samples had similar first peaks, but the second ones were very dissimilar. This was caused by the preparation of the samples, as they were cut and the number of fibers can vary depending on the location of the cut, and by the influence of the tensile strength test when the fibers broke. In Figure 5 it is clearly visible in which parts the fiber and the material of the samples broke.

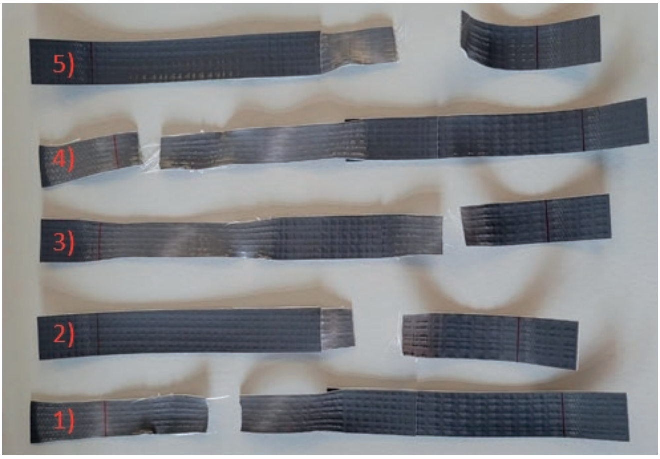

Figure 5. Samples of the Bauder Thermofol stored at room temperature after breakage.

However, the welded connection of all tested samples of every variant stayed intact, and every breakage took place above or below the welding. The force at the first peak causing the breakage of the fibers corresponds to the maximum force which was applied to the welding itself and the comparison of all five variants showed similar results (Figure 6).

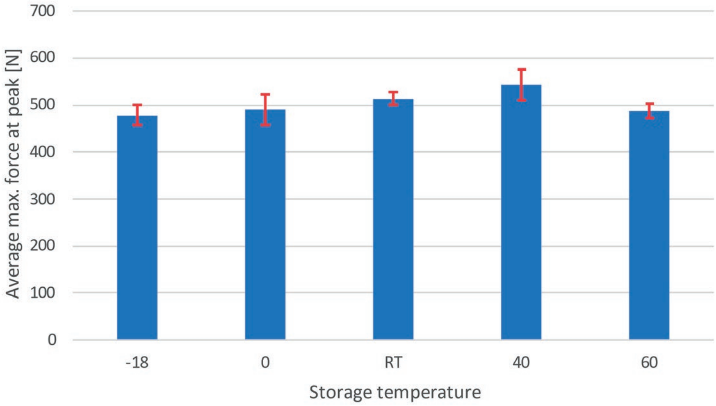

Figure 6. Maximum force at peak on all Bauder Thermofol samples of all variants.

The Wolfin IB material managed to not break in total and to use the maximum way for elongation of the tensile testing machine. The maximum force on the welding is the peak tensile strength at the maximum elongation of the tensile testing machine (Figure 7).

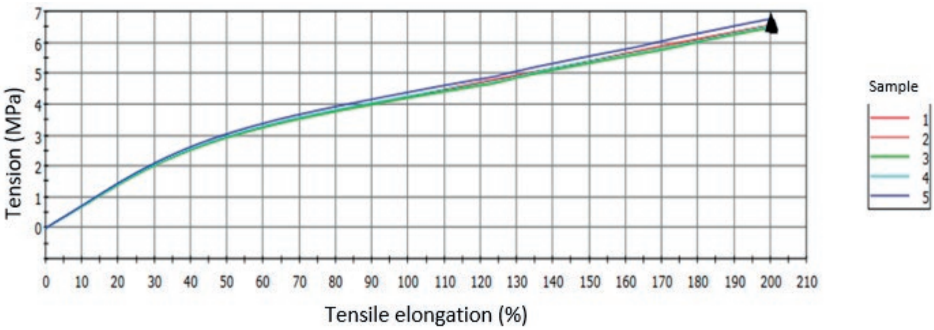

Figure 7. Results of the samples 1 till 5 of the Wolfin IB stored at room temperature.

The samples show an elastic behavior and shrink slowly back nearing their dimensions before the tensile strength test. A small deformation is visible in the area around the welding but there is no real damage to it (Figure 8).

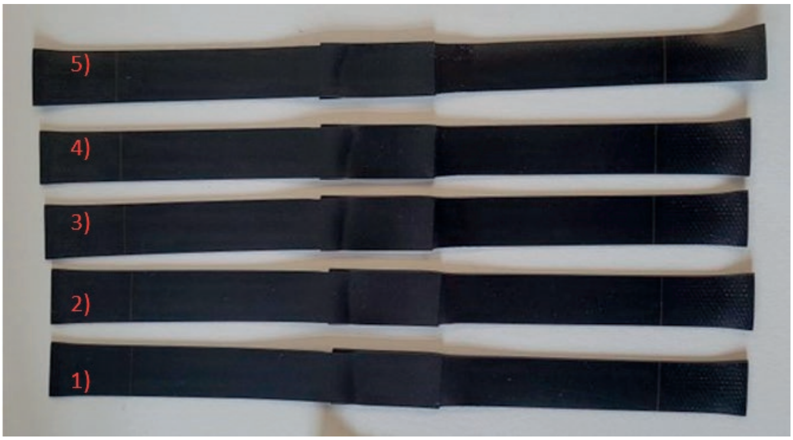

Figure 8. Samples of the Bauder Thermofol stored at room temperature after the tensile strength test.

The comparison of the maximum force on the welding of all the samples shows that they all are in a similar range (Figure 9) and have less deviation than the Bauder Thermofol samples, as it is just one material influencing the whole tensile strength test.

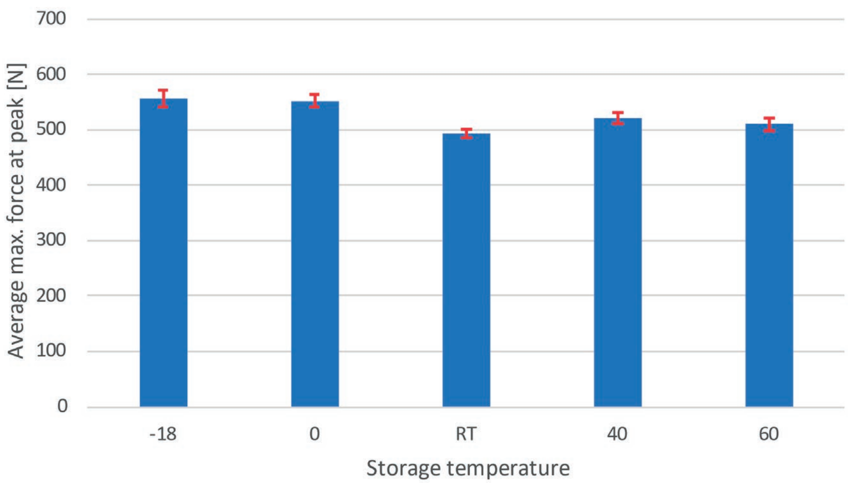

Figure 9. Maximum force at peak on all Wolfin IB samples of all variants.

4. CONCLUSION

Out of all 50 tested samples not a single weld line broke, which demonstrates a good weld quality of the samples no matter which way they had been stored before. The results of the tensile strength tests did not clearly indicate any influence of the storage temperature at all. If room temperature is considered to be the usual storing condition, there were no big deviations to the other variants. All weld lines of both materials managed to resist maximum forces of around 500 N. However, there were some influences on the whole welding process caused by the storage conditions of the materials due to changes in the stiffness of the material. This caused the material to be stiffer when stored in cold temperatures, or softer when stored in warm temperatures. While the stiffer material did not cause any trouble during the welding of the softer material was more difficult to be welded as the material was easily pushed away by the hot air fan running through the welding surfaces resulting in uneven weld lines. The material had to be separately fixed to avoid this failure pattern to appear. All in all, the influence of the storage temperatures between -18 °C and 60 °C on the welding process is so small, that it can be neglected. However, this can vary considering different materials and should be tested material specifically in further research of the influences of the hot air welding process.

CONFLICT OF INTERESTS

There is no conflict of interests.

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