Winding of Extruded Thermoplastic Tapes by Using a Hot Air Heat Source

P. Klein, P. Reinicke, F. Haupert, K. Friedrich

Institute for Composite Materials Ltd. (IVW), University of Kaiserslautern,
PO Box 3049, 67663 Kaiserslautern, Germany
Tel.: +49 631 / 2017 316
Fax: +49 631 / 2017 196

Abstract

The present paper deals with a winding technology which allows to process thermoplastic tapes that can be used for manufacturing of polymer covered metal rollers for the paper making industry. The specific feature of the tape winding process presented in this study is the ability to process extruded tape material whether it is reinforced with short/continuous fibers or not.

Introduction

At various industrial installations polymer covered cylindrical parts having special elastic, impact, fatigue and surface properties are needed to produce textiles, papers or paper boards. They are also necessary for transportation and handling purposes. A new winding process allows to manufacture such thick polymer coatings with high precision and good quality. Especially huge parts which can hardly be produced by injection molding could be manufactured this way. **Fig 1** shows the process parameters which mainly influence the consolidation quality of the winding process.

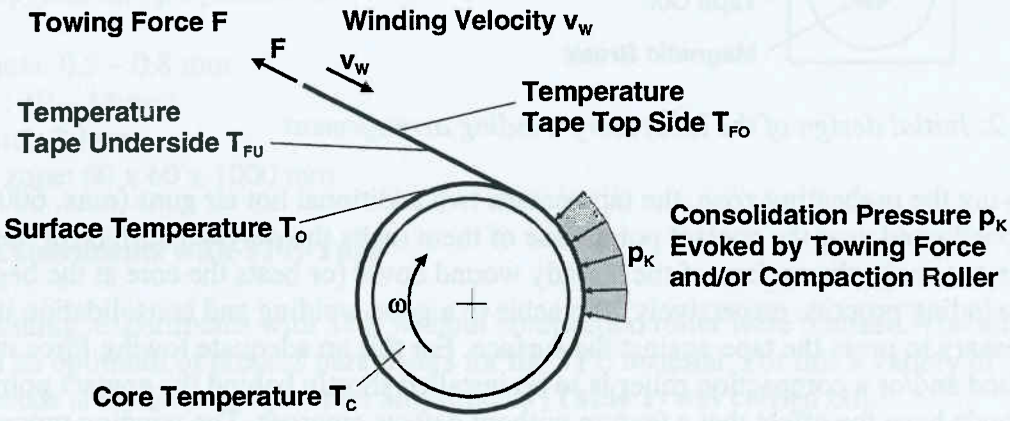

Fig. 1: *Processing parameters during thermoplastic filament winding*

Processing thermoplastic materials by winding technology is principally possible, but in case of discontinuous or unreinforced tape-material two process parameters are critical to the success of the winding operation, the towing force and the temperature of the tape material.

Accurate control of both parameters avoids tape failure prior to winding. Continuous fiber reinforced tapes offer the general advantage that they can convey towing forces even at elevated temperatures. In this study only short fiber reinforced and unreinforced extruded tapes were used for the winding experiments.

The Laboratory Winding Machine

Fig. 2 shows the laboratory winding machine used for the winding experiments in its initial state. A prewarming chamber which includes the tape coil allows to heat the tape up to temperatures below the processing temperature. Heating occurs by electrical radiators. In this way it is possible to preheat the tape coil at a controlled temperature up to 250°C. If necessary, the tape can also be dehumidified in this prewarming chamber. From there, after passing through a towing force measurement, the tape reaches the preheating zone in which its temperature increases to nearly processing temperature. This temperature should be as high as possible but sufficient tape strength has to be secured. The preheating zone consists of a long square tube and is heated by a hot air gun which meets the preheating zone in the middle. This leads to hot air streams in the reverse flow direction to the tape in the first half and in parallel direction to the tape in the second half.

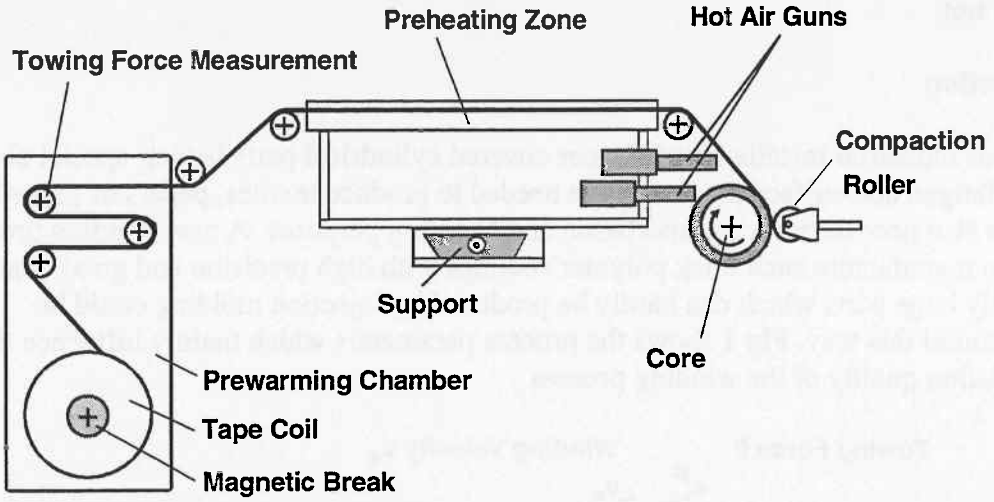

Fig. 2: *Initial design of the laboratory winding arrangement*

Leaving the preheating zone, the tape passes two additional hot air guns (max. 600°C) which are positioned near the contact point. One of them melts the polymer surface of the tape, the other one melts the surface of the already wound cover (or heats the core at the beginning of the winding process, respectively). To achieve a good welding and consolidation it is necessary to press the tape against the surface. For this an adequate towing force must be applied and/or a compaction roller is to be installed shortly behind the contact point. Both methods have the effect that a texture without defects emerges. The winding process also requires a constant towing force to make sure that constant conditions occur at the contact point. Too low forces implicate a poor tape handling during winding so that a precise tape deposition becomes impossible. On the other hand too high forces implicate tape failure. To avoid these problems the signal of the towing force measurement is directed to a control unit, which adjusts the break power of the magnetic break in the center of the tape coil. The towing force could be adjusted in a range between 10 N and 60 N.

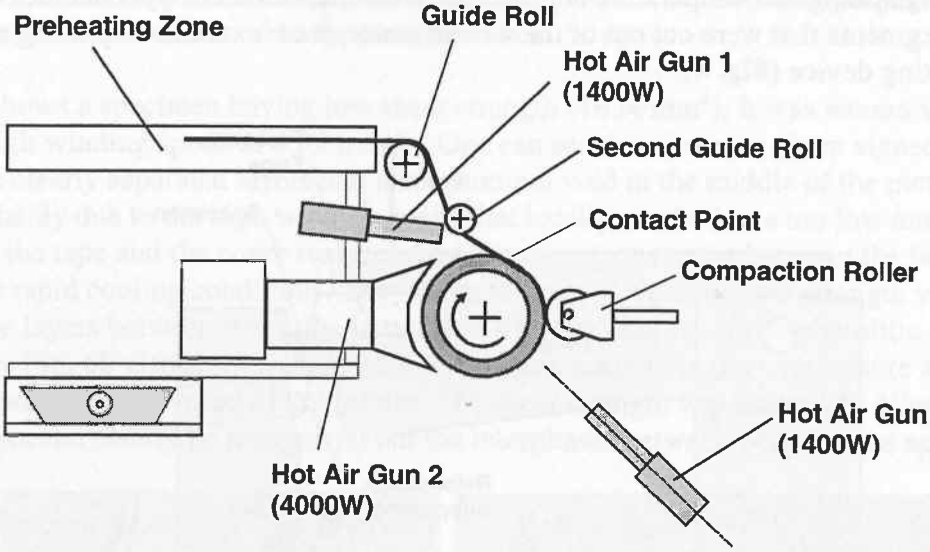

Fig. 3: *Modified design of the laboratory winding arrangement*

First winding experiments showed that the previous arrangement had to be modified as shown in **Fig. 3**. The main differences to the first arrangement is the shorter distance between the contact point and the leading (second) guide roll. This modification allows a more precise tape deposition. The other modifications concern the heating. A more powerful hot air gun no.2 and a hot air gun in order to preheat the core were installed.

Materials and Dimensions

In the following part of this paper, only winding experiments with a thermoplastic elastomer (TPE) are reported. However, further materials which were also processed with this technique are polypropylene and polyamide 66.

tape thickness: 0.5 – 0.8 mm
tape width : 10 – 14 mm
core diameter: 80 mm
preheating zone: 60 x 60 x 1000 mm

Winding Experiments with TPE-Tape

At the beginning, experiments with TPE without compaction roller were realized. The aim was to find an optimum of process parameters for the TPE material. For this a variety of winding speeds at different temperature adjustments (**Table 1**) was carried out.

Table 1

	Preheating Zone	Hot Air Gun 1	Hot Air Gun 2	Hot Air Gun 3
Adjustment 1	120°C	------	480°C	Level 5, 15 min Preheating
Adjustment 2	150°C	200°C	480°C	Level 5, 15 min Preheating

To investigate the consolidation quality of the wound covers, their shear strengths in relation to winding speeds and temperature adjustments were measured /1/. Specimens, consisting of curved segments that were cut out of the wound cover, were examined by using a special shear testing device (**Fig. 4**).

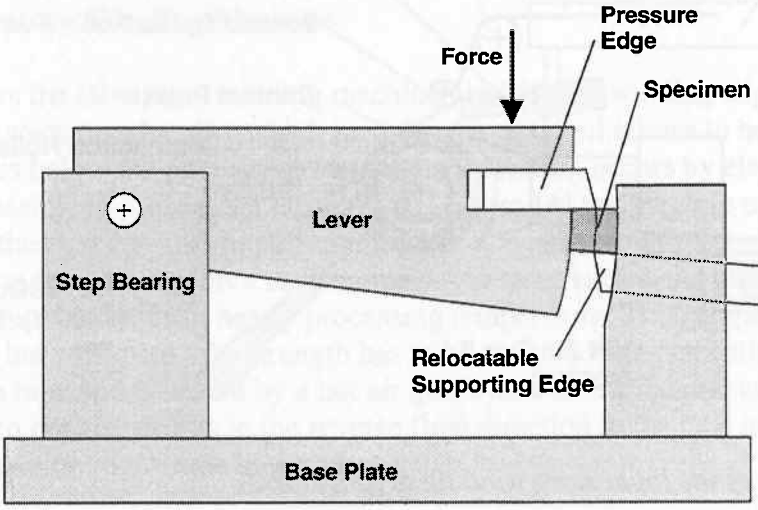

Fig. 4: *Shear testing device used*

This test method should allow to characterize the consolidation quality. The results of these shear tests are shown in the charts below (**Fig. 5a,b**). Each point in the charts represents an average of at least five measurements. The different measurement points resulted from different samples wound under the same parameters. Towards higher winding speeds the shear strength decreases slightly for the temperature adjustment 1 (**Fig.5a**). This effect is due to a decrease in both the tape temperature and the wound surface temperature, because of their shorter time being in contact with the hot air. At winding speeds of more than 4 m/min defects appeared (see also **Fig. 6a**) because of a rather poor consolidation.

Fig. 5b shows the results of winding experiments at the temperature adjustment 2. Good consolidation qualities were even reached at higher winding speeds of more than 4.5 m/min. Winding speeds below 3.5 m/min were, on the other hand, not possible to realize because of tape failure due to the longer exposure to higher temperatures.

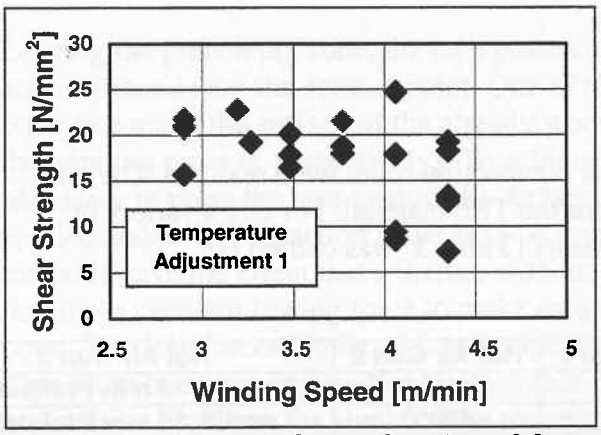

Fig. 5a: *Shear strength as a function of the winding speed (temp. adj. 1)*

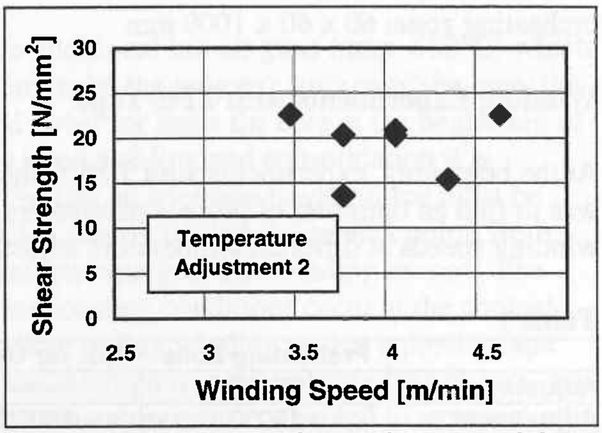

Fig. 5b: *Shear strength as a function of the winding speed (temp. adj. 2)*

By using a microtome, thin slices were cut of the wound specimens in order to investigate their layer texture in subjection to the processing parameters. The following pictures show the texture in a cross section vertical to the circumference.

Figure 6a shows a specimen having low shear strength (16 N/mm^2). It was wound with a relatively high winding speed of 4.35 m/min. One can see that there are sharp signed lines between the clearly separated layers and a longitudinal void in the middle of the picture. The latter is probably due to the high winding speed that locally resulted in a too low temperature for welding the tape and the cover surface. Amorphous regions occur between the layers as an effect of the rapid cooling conditions. They seem to possess clearly lower strength values than the bulk tape layers between them; the latter have a semicrystalline, fine spherulitic morphology. **Fig. 6b** also shows a specimen which was made with the temperature adjustment 1 but at a lower winding speed of 2.9 m/min. The shear strength was around 22 N/mm^2. Here, also the layers can clearly be recognized but the interphases between become less apparent.

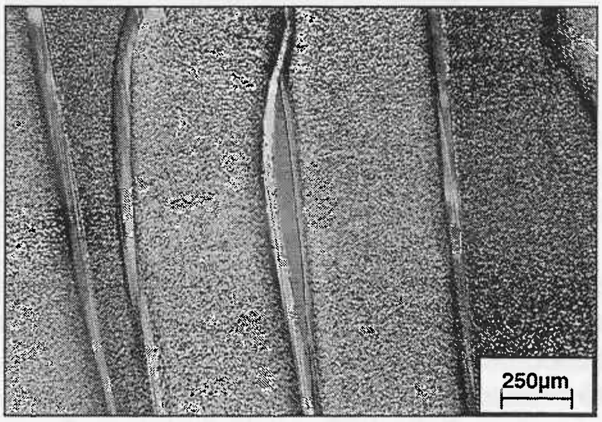

Fig. 6a: *Sample: 4.35 m/min, temp. adj. 1*

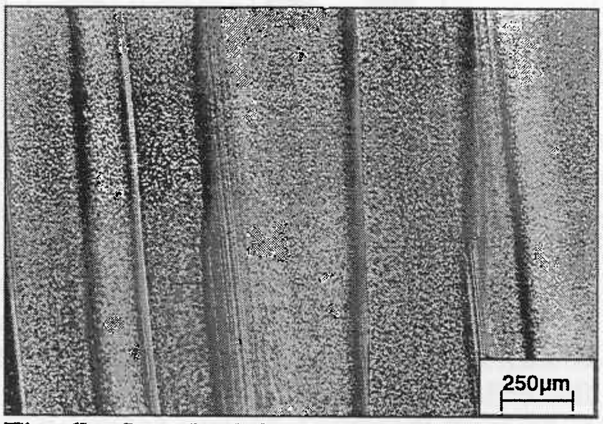

Fig. 6b: *Sample: 2.9 m/min, temp. adj. 1*

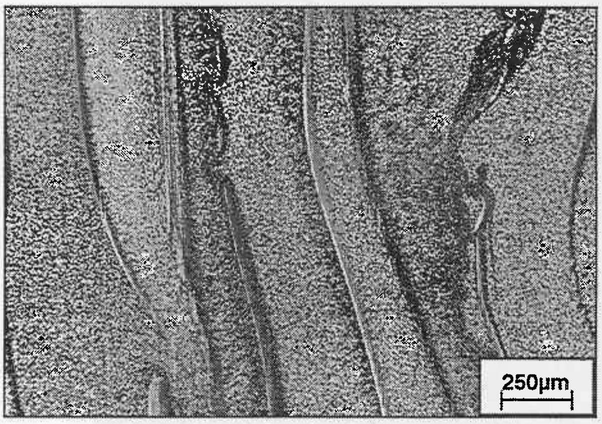

Fig. 7a: *Sample: 4.6 m/min, temp. adj. 2*

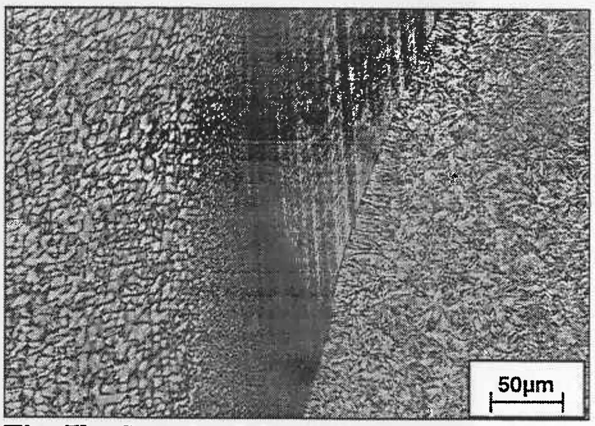

Fig. 7b: *Sample: 2.9 m/min, temp. adj. 1*

In **Fig. 7a** (4,6 m/min, 22N/mm^2) the tape appears to be better consolidated. As seen in the image the interphases between the tapes are discontinuous. The interphase between two layers can be observed at a higher magnification in **Fig. 7b**. In the middle of two spherulitic regions one can see a non-structured, probably amorphous region. The shear strength of this sample (2.9 m/min, temperature adjustment 1) was around 22 N/mm^2.

Some further experiments were realized with an additional compaction roller in order to achieve a better consolidation and deflectors to reduce heat loss. These modifications allowed to increase the winding speed and also the consolidation quality could be improved considerably. Shear tests of these samples showed high values (**Fig. 9**). The texture of one of these samples (No. 47) is shown in **Fig. 10**. The original tape layers could not be recognized any more.

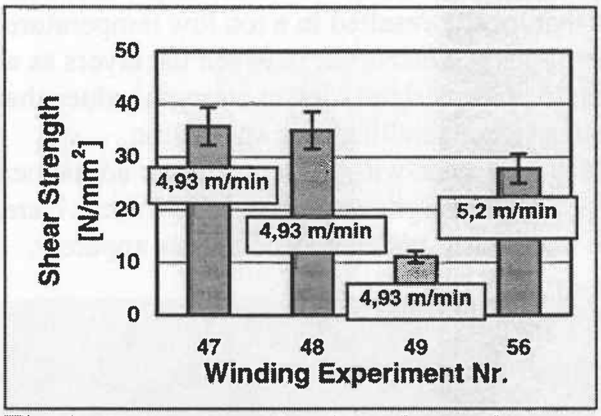

Fig. 9: *Shear strength values detected*

Fig. 10: *Cross section of sample No. 47*

Annotations

A large number of parameters, which had to be controlled manually, influenced the success of a winding experiment. Due to this reason, considerable fluctuations of the process parameters could not be prevented. Taking these circumstances into consideration, the fairly high fluctuation of the shear strength values seems to be acceptable.

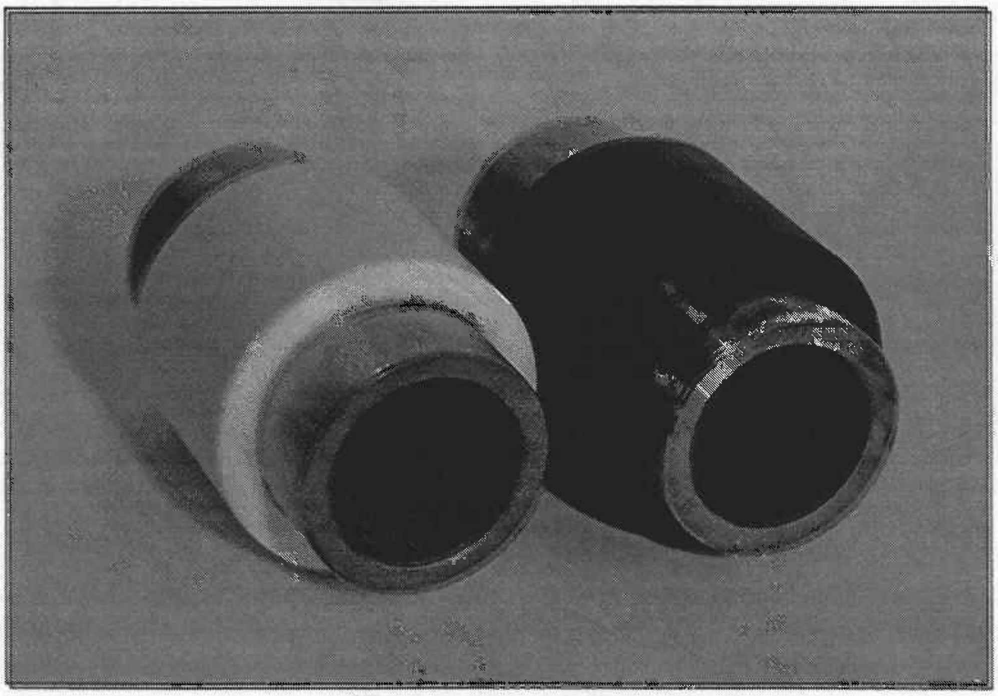

Fig. 11: *Wound covers (TPE, PP)*

Summary

In this study a new winding technology for unreinforced or discontinuous fiber reinforced tapes is presented and proved to work. **Fig. 11** shows two examples of the wound covers on metal cores which were adapted after winding by a lath. In order to find good process parameters, a variation of winding speeds at different temperature adjustments was performed. The consolidation quality of the wound samples was investigated by a shear test. These shear strength values allowed to compare between good and bad consolidation qualities. The texture of the wound covers was investigated by transmitted light microscopy.

Perspectives

To carry forward the application to an industrial scale the operating efficiency has to be improved. For this the winding speed has to be increased. To manage a better reproducibility the winding machine has to be automated.

Acknowledgements

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