PLEATING CHARACTERISTICS OF SYNTHETIC FILTER MEDIA: NEW TEST METHOD & PARAMETER TO ASSESS PLEATABILITY USING A PLA/PP BLEND

Dr. Guenter Mueller, Florian Bauer, Dr. David Weidt
Sandler AG, Lamitzmühle 1, 95126 Schwarzenbach / Saale, Germany

ABSTRACT

The market for pleatable filters is dominated by media made of glass fibre paper. Such media offer high efficiency and stiffness, which supports a good processability during pleating. However, this material exhibits certain disadvantages such as hygroscopic behaviour or deleterious fibrous airborne matter caused by fibre shedding. Synthetic filter media compensate these drawbacks, which makes them attractive for pleatable filters. However, the media are more difficult to pleat than glass fibre paper, especially on a rotative pleating process. Though, the use of such synthetic media is indispensable due to the various advantages against glass fibre media and the fact that some markets can only be served by rotative pleated media.

As the impact of products on the environment are shifted towards the centre of public attention, many efforts are made to exchange petrochemical by bio-based materials, such as polylactide. This work addresses the use of biopolymers from the perspective of processability and pleatability. For this, a meltblown PLA/PP blend was produced on a pilot line and its pleatability on rotative pleating machines was characterised using a new testing method. To the author´s knowledge there is no comparable method and parameter that quantify pleatability of filter media. Therefore, a new testing method is proposed, which involves a new parameter, auxiliary device as well as a small-scale pleating device.

The functionality of the testing method was investigated using media that can be classified as well and poorly pleatable. The proposed parameter pleating angle and the testing method were able to distinguish between those two media classes. The obtained angles of the well and poorly pleatable media are 43° and 97°, respectively.

Finally, the parameter folding angle was used to describe and investigate the pleatability of a PLA/PP blend. The mean of the measurements is 43° and equal to the analysed well pleatable media. Therefore, the measured angles indicate a good pleatability of the tested blend.

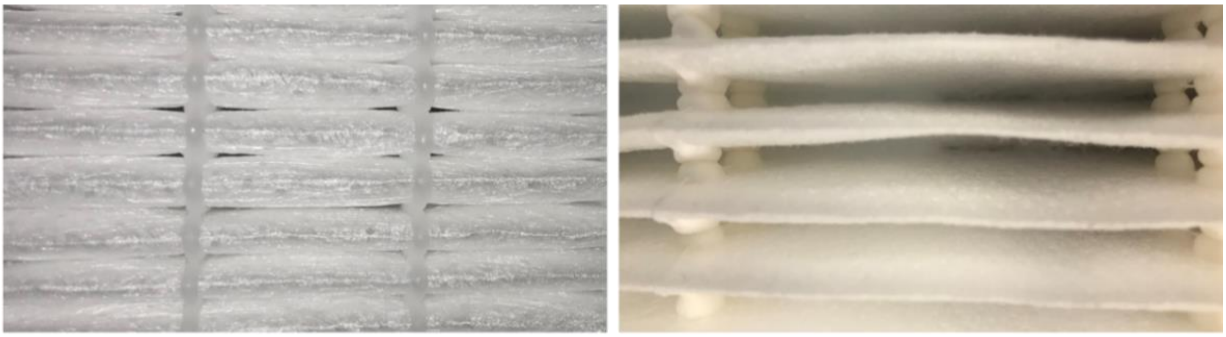
Key Words: PLA, Pleat, Meltblown, Synthetic Filter Media, Filtration, Test Method

Background of work

In automotive filtration and other sectors, such as HVAC (heating, ventilation and air conditioning) filtration, the reduction of installation space is an ongoing trend. At the same time, however, there is a rise of standards regarding filtration performance such as lifetime, efficiency and life-cycle-costs. Thus, there is a growing demand for pleatable filter media, which provide largest possible filtration surface without compromising performance and durability. This is reflected by a CAGR (compound annual growth rate) of ~ 5 % for the global pleated filters market till 2025 [1].

Synthetic filter media are well-established in automotive cabin air filtration. However, for pleatable HVAC filters, especially higher filter classes, the market is still dominated by media made of glass fibre paper, which is usually treated with chemical binders or adhesives. Based on very fine fibres and a very homogeneous fiber distribution throughout the entire medium, such glass fibre papers offer high efficiency, stiffness and therefore good processability in pleating processes. This material, however, exhibits certain risks during production, assembling or use. Even small amounts of water or moisture result in a reduced fold stability that may lead to the final collapse of folds and, thus, of filter performance. Moreover, glass fibre filters may easily get damaged, which causes fibrous airborne matter. Fibber shedding poses health risks to skin, eyes and to the respiratory tract.

Self-supporting synthetic filter media compensate these drawbacks due to their high resilience and mechanical stability. Besides, fibre shedding is not present. However, synthetic filter media are (a) usually based on petrochemical raw materials such as PP (polypropylene) or PET (polyethylene terephthalate) and (b) show difficulties during pleating. The latter is visible in the lack of contour precision and pleat stability and is most dominant for rotative pleating systems. In contrast to blade pleating, rotative pleating usually does not use any thermal fixation of a single pleat. Thus, when compared to glass fibre paper, a higher mechanical stress, impact depth and distance of pleats is usually necessary to create an accurate pleat. Moreover, such pleats tend to relax into a rounded shape. As a result, there are contact areas of adjacent pleats that cause a loss of filtration area and increase pressure drop. The issue of media relaxation and contact of adjacent pleats is visualized in Figure 1.



a) b)

Fig. 1: Synthetic PP based filter panels based on a) rotative- and b) blade pleating.

To compensate theses drawbacks, polymers such as PLA (poly lactic acid) may offer promising means for pleatable filter media due to the availability of low-viscosity meltblown grades, its electrostatic chargeability and sustainability. PLA is produced from renewable biological resources that make it bio-based and biodegradable and, thus, take sustainability considerations into account.

In literature, pleatability of synthetic materials has been sparsely investigated. The main documents that cover this topic are patents, for example [2], [3] and [4]. In contrast, the processability of PLA used in meltblown lines is better described [5-8]. This holds true for the evaluation and characterisation of PLA/PP blends [9, 10].

To the authors' knowledge there is no existing parameter that examines media pleatability – especially on rotary pleating machines. Parameters such as the crease recovery angle (CRA), which is used in textile industry for quantifying the ability of a medium to go back to its original shape [11, 12], have not been applied to describe media pleatability. The loading applied during rotative pleating is rather dynamic than quasistatic. Interpretation of the parameter CRA that is based on a slow deformation is therefore limited. Moreover, it may only be applied to the blade pleating process in which the material experiences much lower strain rates.

Thus, a new parameter is presented. This new parameter requires a specific sample preparation which is described in the following chapter. With the help of the new parameter and testing method, the rotative pleating characteristics of a selected PLA media can be assessed and furthermore, the material can be quantitatively compared to other nonwoven media.

Sample preparation and testing methodology

SAMPLE PREPARATION

A PLA/PP meltblown with 10 weight percent of PP was selected since it could be useful for later processing steps as calendaring with a second PP layer. The blend was produced on a meltblown pilot line to gain basic information concerning processability of the raw materials and the resulting media properties. The meltblown process was chosen as it is a common approach to create synthetic nonwoven with submicron fibres from thermoplastic polymers. A weight percentage of PP up to 15 % could be incorporated into the media without any defects or process aids. Very fine fibres could be realized for PLA/PP (0,3 dtex). The produced blend/meltblown had a basis weight of 123 g/m² and a thickness of 0,58 mm.

Although the blend consists of only one meltblown layer, the two sides of the material show differences in optical appearance. Unlike the other, one side has a noticeable print of the collector (within referred as collector side). The contrary side is referred as die side.

PARAMETER AND TESTING METHOD

Under the assumption of an embossing velocity of 1 m/s up to 3 m/s for rotative pleating machines and a material thickness of 0.5 mm for the medium, the strain rates are in the range of 2000 s^{-1} and 6000 s^{-1}. It is well known that the mechanical behaviour of polymers is sensitive to the applied strain rates, e.g. the yield strength increases with increasing the strain rate [13, 14, 15]. This renders the parameter CRA, which is based on measurements of samples that are folded manually and loaded for a certain time with a mass of 1 kg [11, 12], as inapplicable.

To examine the pleatability of a PLA material, a special device for creating pleats was designed and built. It allows the generation of pleats at higher strain rates.

The device is shown in figure 2. It consists of a pneumatic cylinder, which can be adjusted in its height. The cylinder moves an embossing unit. The air pressure which regulates the embossing force as well as the velocity of the unit can be controlled with a pressure regulator. A quick exhaust valve is necessary to realize a velocity of the embossing unit comparable to a rotary pleating machine. The unit creates a predetermined bending line on the specimen. An embossing pressure of 4 bar was set for the device. It was the highest pressure whereby no damage of the tested material occurred. With 4 bar pressure, an embossing velocity up to 3 m/s was possible. The embossing depth was set to 2 mm. This value was chosen as it is a possible setting for fully synthetic materials on rotary pleating machines.

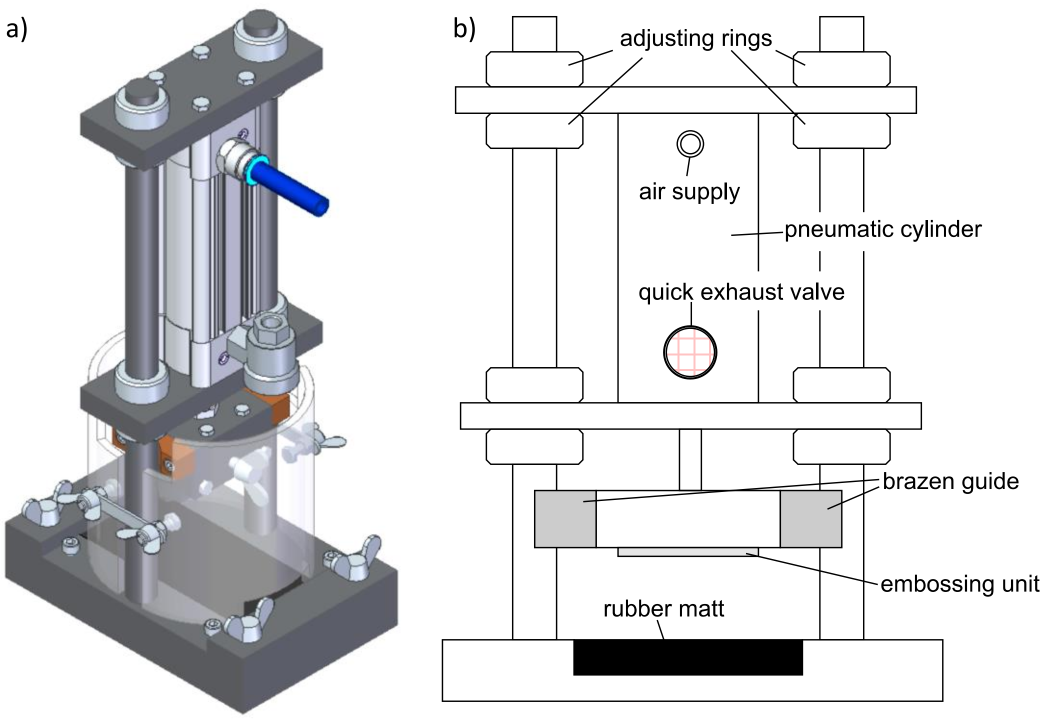


Fig. 2: Pleating device; a) 3D depiction, b) schematic figure

The specimen had a width of 20 mm and a length of 200 mm. The width was in alignment with the specimen size described in the DIN 53890 [11] and DIN EN ISO 2313 [12]. When folded, the length of 100 mm shall represent a typical pleat height. The samples were cut out in machine direction (MD) and embossed in cross direction (CD) in the specimen middle over the entire width.

To examine the pleatability of the sample, a new parameter – the pleating angle – was introduced. The pleating angle is formed by putting the sample in an auxiliary device between two moveable sleds and pushing them together. This angle was photographed and analysed (cf. figure 3 a)).

The functionality of the testing method was investigated using media that can be classified as well and poorly pleatable. Two standard market media were selected: Medium 1 (well pleatable) PET/PP bicomponent spunbond and meltblown layer; medium 2 (poorly pleatable) PET/PP bicomponent spunlaid and meltblown layer.

Results and discussion

In the following, the results are separated into two chapters. Firstly, the investigation of the functionality of the testing method. Secondly, the application of the method on PLA/PP (90/10) samples.

FUNCTIONALITY OF TESTING METHOD

To examine the functionality of the testing method, first, the samples of medium 1 and medium 2 were pleated using the small-scale pleating device. Then, the pleating angles of those samples were analysed and compared to their qualitative results after processing on a rotative pleating line.

Figure 3 shows the auxiliary device equipped with the samples of medium 1 and medium 2. One can see the sample obtaining its pleating angle from the two sleds of the auxiliary device that are pushed together. The resulting pleating angles were photographed and analysed with a picture processing software (see figure 3c)). Figure 3a) and 3b) show the pleating angles of the two different layers of medium 1. The sample in figure 3a) is embossed on the spunbond side. All samples were folded in the embossed direction. In figure 3b), the sample is embossed on the meltblown side. Figure 3c) shows medium 2 embossed on the spunlaid side and figure 3d) shows medium 2 embossed on the meltblown side. For both media, the pleating angle on the meltblown side is larger than the pleating angle on the carrier side.

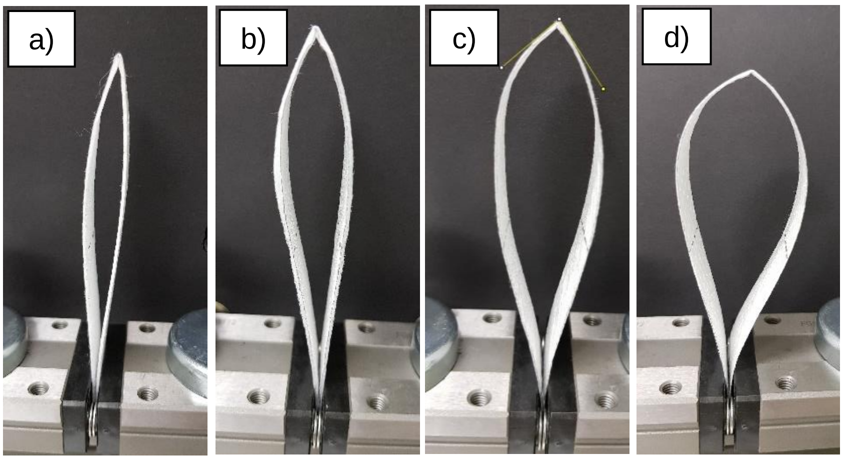


Fig. 3: Pleating angle of media 1 a) spunbond side, b) meltblown side; pleating angle of media 2 c) spunlaid side (yellow lines for analyzing the angle), d) meltblown side

The results of the pleating angles of medium 1 and medium 2 are shown in figure 4. For media 1, a pleating angle of 31° was measured for the carrier side and a pleating angle of 55° was measured for the meltblown side. The pleating angles of medium 2 were 81° for the carrier side and 112° for the meltblown side. The pleating angles of medium 2 were significantly higher, around 50°, when compared to the pleating angles of medium 1. Another significant difference was obtained for the pleating side of the media. When the media were pleated at the carrier side, the pleating angle was around 27° smaller when compared to pleating at the meltblown side.

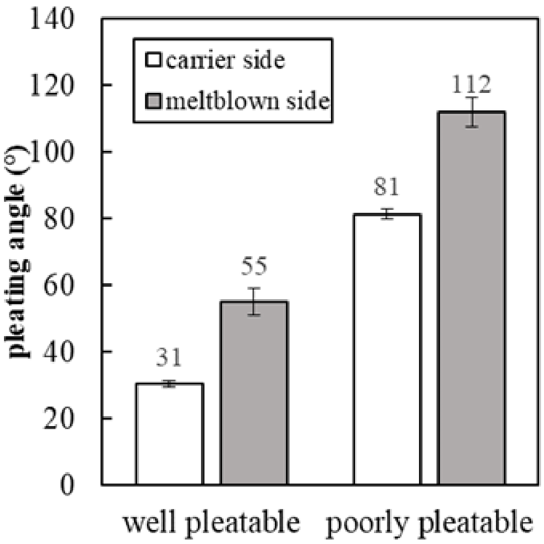


Fig. 4: Pleating angle of the well and poorly pleatable market samples, carrier side & meltblown side; n=12; Error bars show the standard error of the mean $SEM = \frac{s}{\sqrt{n}}$

Those results are in agreement with the qualitative results obtained from the processed media on an industrial rotative pleating line. As seen in figure 5, the pleats of medium 1 are sharp-ended and less bulky than the pleats of medium 2. Moreover, one can see the tendency of the pleats of poorly pleatable medium to contact each other.

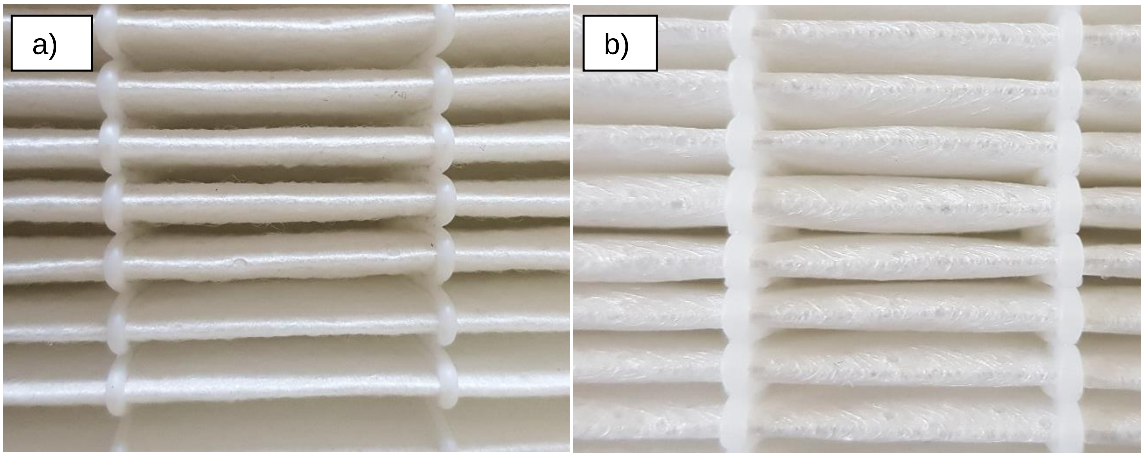


Fig. 5: View on the pleated filter element of a) medium 1 and b) medium 2

The comparison of the industrial scale pleating results with the small-scale pleating device suggests that the pleating angle is a suitable parameter to describe pleatability of media. It was shown that small pleating angles correlate with a good pleatability of a material – based on qualitative observations. On rotative pleating machines, the media will be pleated from both sides. Hence, the mean of the measured angles from both sides may be used to describe the overall pleatability of a medium. Further investigations may be necessary to investigate the transitional pleating angle that separates well and poorly pleatable media.

EFFECT OF PLA ON PLEATABILITY

The PLA/PP medium was analysed in terms of pleatability, using the new testing method, and compared to the standard market samples. Device settings and specimen dimensions were equal to the previous measurements on the market samples. The results of the measurements are shown in figure 6.

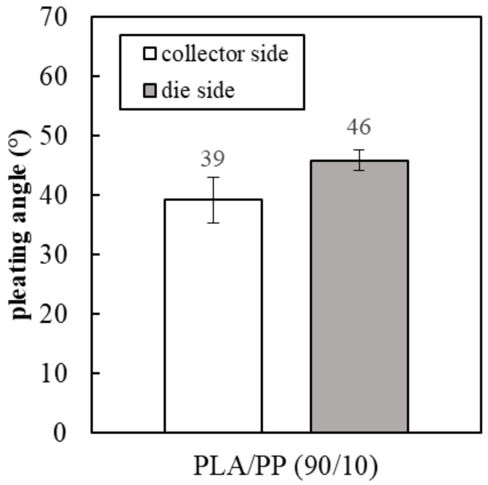


Fig. 6: Pleating angle of the PLA/PP blend, collector side & die side; n=12; Error bars show the SEM

The pleating angles are 39° for the collector side and 46° for the die side. Although the medium is just a one-layered meltblown material, there is a deviation between the samples with different embossing direction. This difference possibly originates from the morphology gradient in the material from die to collector side. The overall mean of the pleating angle measurements is 43°, which is equal to the overall pleating angle achieved for the well pleatable medium. Thus, one can consider the PLA/PP blend as well pleatable.

CONCLUSION AND OUTLOOK

A new testing methodology was suggested to quantify the pleatability of filtration media on rotative pleating lines. The testing methodology involves a new pleating parameter, measuring method and the use of a small-scale pleating device that takes the high strain rates during rotative pleating into account. Qualitative results obtained on industrial rotative pleating lines for well and poorly pleatable media were compared against measurements based on this testing methodology. The measurement values for the new parameter pleating angle were found to be in agreement with qualitative observations for the rotative pleated media. The new testing methodology was used to quantify the pleatability of a PLA/PP meltblown blend. A relatively small pleating angle of 43° was achieved, which suggests a good pleatability of media made of PLA.

Future studies may involve the determination of the bad to good transition angle for different combinations of pleat heights and pleat distances. Furthermore, investigations of the effect of applied strain rate or embossing depth may give hints for the parameter setting of rotative pleating lines. To determine the effect of PLA on its pleating characteristics in more detail, further studies may focus on the comparison of nonwovens with similar appearance and properties made of different polymers.

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