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Tailings Filtration Using Recessed Plate Filter Presses: Improving Filter Media Selection by Replicating the Abrasive Wear of Filter Media Caused by Falling Filter Cake after Cake Detachment

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Abstract: Currently, the storage of ore processing residues is a major challenge in the mining industry. These tailings are increasingly filtered in advance of disposal using filter presses to make storage safer and to recover water effectively. However, the falling of the detached filter cakes between the individual filtration cycles results in the abrasive wear of the filter cloths at specific points of the chamber geometry and is a main reason for the necessity of a regular replacement. Improved filter media selection through abrasion testing replicating this specific load case increases plant economics by reducing the risk of unplanned downtimes. Therefore, this article explains a test procedure adapted to the direction-specific wear. A brush apparatus is presented, which abrasively loads filter fabrics stretched over an exchangeable edge geometry uniaxially in one direction. The effects of important apparatus setting parameters (sample clamping torque, brush overlap, and brush speed) are shown. Furthermore, the resistances of three different filter media typical for tailings filtration were compared and different edge geometries investigated. Thereby, significant differences were found with regard to filter media type, filter media material, and edge geometry. Depending on the edge geometry used, the polypropylene fabric withstands a load amount by a factor of 3.3 to 8.9 higher than the nonwoven polypropylene, the nylon fabric withstands a load amount by a factor of 3.6 to 5.3 higher than the polypropylene fabric and the nylon cloth withstands a load amount by a factor of 16.1 to 31.8 higher than the nonwoven polypropylene.

Keywords: mineral processing; mine waste; filter press; tailings filtration; filter media; filter cake detachment; abrasive wear

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1. Introduction

The increasing global demand for metals leads to a continuous growth in the extraction of related minerals from ores. Thereby, ore processing residues are a necessary mine waste stream. However, the storage of these tailings is already one of the major challenges in the mining industry. It has been regularly shown that the classical method of storing tailings in tailings ponds secured by dams is problematic due to water evaporation, space requirements and risk of dam failure. The Brumadinho dam breach, recorded on video, quickly gained media attention and led to new industry standards [1] and a demand to make information about such storage facilities available to the general public [2]. In the decade from 2015 to 2024, 18 catastrophic failures are expected [3], of which 13 have already occurred [4]. In terms of process technology, the method of dry stacked tailings has become more common [5]. In this process, the water content of the tailings slurry is first reduced by large thickeners and then dewatered using filter presses to a water content of usually less than 20 mass percent [6]. Then, the resulting filter cake is transported by conveyor belts, stacked and compacted. In addition to a higher geotechnical stability of the deposit, this offers the advantage of an extensive process water recovery which is seen as one of the major potentials of this technology, especially in arid regions [7]. Usually, a large part of the water evaporates in the settling ponds. Effective water management is crucial for economical mineral processing since one ton of ore can require 0.8 m^3 of water [8].

Normally, filtration of tailings in a mine takes place in several large recessed-plate filter presses operated in parallel. These were maximized by the suppliers in terms of size and minimized in terms of cycle time in order to realize the highest possible throughput and to reduce investment and operating costs [9].

Nevertheless, there are several problems in the operation of filter presses, mainly related to the selection of the filter media and its regular replacement. The wear of the filter medium and filter plates represents the main wear problem of filter presses in tailings filtration, causing approximately 80% of the maintenance [10,11]. Three of the main problems are abrasive wear, media blinding and cake sticking.

Abrasive wear is already known as a parameter to be considered in the selection of filter cloths [12], but it is of outstanding importance in applications with abrasive material as tailings filtration. The filter fabric is subjected to mechanical stress at several points in the filtration process [13,14]:

1. Filling the filter, high flow velocities occur in the area around the chamber inlets. Over the years, patches have been sewn into these zones by suppliers to provide additional strength and counteract wear.
2. Increased velocities also occur near the filtrate outlets of the plates at the beginning of filtration before the first cake layer is formed. Particles passing the fabric cause abrasion on the filter medium.
3. Falling filter cake after detachment brushes the filter media at the lower edge of the chamber frame and protruding parts of the chamber.
4. Remaining parts of the filter cake on the sealing surfaces get trapped between two opposing filter plates and filter media for the duration of the next filter cycle. Such repetitive pressing of solid particles causes stress to the fabrics and to the plates.

The permanent adhesion of fine-grained particles, which is referred to as blinding, leads to an increasing hydraulic resistance of the filter medium and, thus, has a negative effect on the filtration performance by prolonging filtration time [15].

The third important problem is an incomplete detachment of the filter cake after filtration. Often, it adheres to the filter fabric, in whole or in part, and reduce the available process space for the next filtration cycle. It is important to note that these problems are often interdependent. Progressive blinding will affect detachment by changing the filter media surface, especially at a very high number of filtration cycles [10]. Furthermore, the limiting problem shifts if one of the points is optimized. If a more abrasion-resistant filter media is used and the achievable number of cycles becomes extended, blinding will play a bigger role. The blinding or the chemical cleaning possibility of the filter cloths and also a detailed description of the detachment behavior and the necessary measurements have been discussed in previous publications [16,17].

One purpose of this work is the development of a test method to characterize a filter medium in terms of abrasive wear by reproducing the load resulting from detaching filter cakes. A schematic visualization of the load occurring during cake falling and its locations is shown in Figure 1. Figure 1A illustrates an adhering cake before detachment. The five elevations in the middle of the plate are necessary from a certain plate size, as they stabilize the plates in the stack against bending. Likewise, the edges protrude, as they seal the plates.

In general, the whole plate is covered with filter media. It is very important to mention, that the surface fibers of filter cloths are orientated in vertical direction to improve cake detachment. The falling cake (Figure 1B) is sliding in the same direction which results in a recurrent direction-specific load.

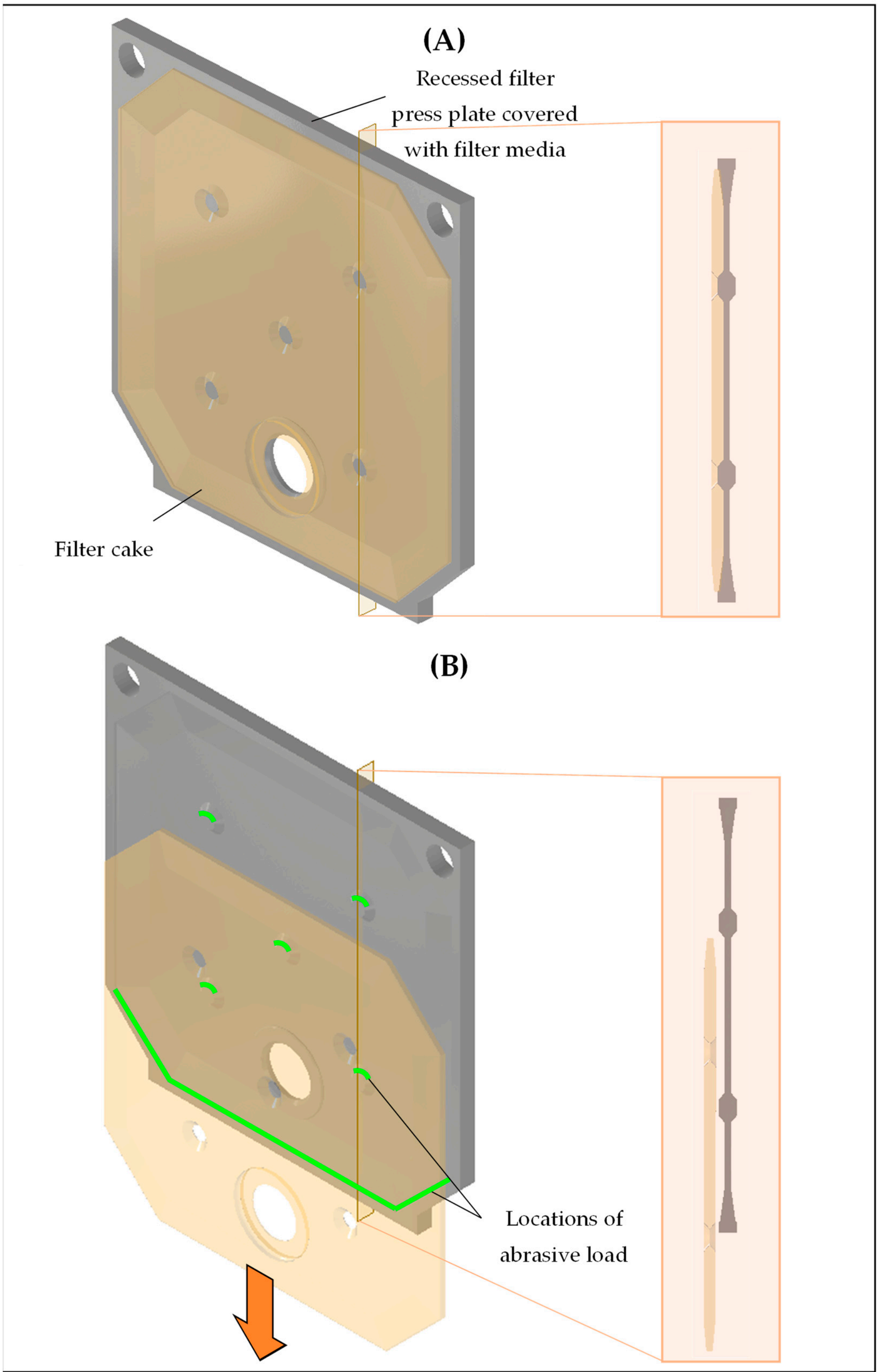


Figure 1. Schematic representation of the locations of abrasive load on the filter media due to protruding parts of the filter plate. (**A**) Filter cake adhering to filter cloth. (**B**) Falling filter cake.

In general, suppliers give a rough wear classification of their filter media based on the materials used. Explicit information in relation to the application they are used for on individual fabrics is usually not provided.

Another aspect of developing an application-specific abrasion test methodology is the development and investigation of composite filter media, e.g., with microporous zeolite in the future [18–21]. These are used in wastewater treatment, because of their ability to immobilize heavy metals [22]. Heavy metals are also an important issue in mineral and tailings processing. A modification of the filter media or the introduction of zeolite layers in tailings ponds offers the possibility to prevent heavy metals from entering the groundwater [23]. In addition, there are studies on the successful prevention of acid mine drainage [24]. An interesting fact is that zeolites themselves represent a reuse of, for example, bauxite and iron ore mine tailings [25,26].

Standard wear tests also do not provide a recurrent direction-specific load, for example, use of a Taber Abraser. This test procedure is mentioned in various standards (ISO 9352 [27], ASTM D1044 [28], ISO 3537 [29], ISO 15082 [30]). Two friction rollers generate an abrasive load. These are pressed onto a rotating test sample with a specified force. Evaluation after the test is usually carried out by differential weighing, in which the abraded portion of the specimen is determined. Alternatively, measuring roughness or wear depth is conceivable [31]. The Taber Abraser is used to test a wide range of materials such as plastics, laminates, natural materials, and safety glazing [32]. Another common and standardized abrasion method is a pin-on-desk apparatus (ASTM G99 [33]) [34–36]. This test also results in an isotropic load. An uniaxial test used (e.g., for nonwovens) is the sliding block method using sandpaper according to ASTM D4886 standard [37,38]. However, the abrasive stress is caused by a forward and backward movement and, therefore, represents a significant difference to the stress caused by a falling filter cake.

Summarizing, using one of the mentioned standards for replicating the problem under investigation would not be specific enough, since abrasion in filter press by cake detachment has a characteristic stress direction and cyclic behavior in one direction. Therefore, a brush apparatus causing such load has been developed.

2. Materials and Methods

The abrasion apparatus is based on a chain brush system (Mink Kett-System®, August Mink GmbH & Co., KG, Göppingen, Germany) alternately equipped with stainless steel brushes (120 mm width and 25 mm height) and spacers. The device is driven by an electric motor. Its height can be adjusted by four feet, and a pneumatic lifting device allows the placing of a sample holder frame under the brushes. Figure 2 shows the structure of the lifted apparatus with a placed sample underneath.

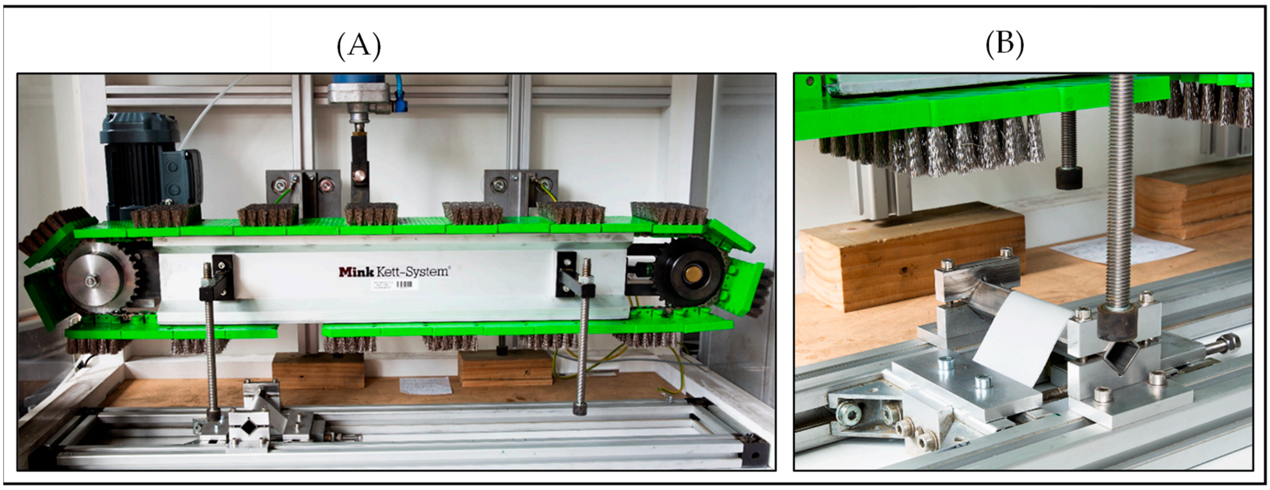


Figure 2. (**A**) Abrasion apparatus. (**B**) Clamped filter media sample.

Three stainless steel devices of different geometry were manufactured, over which filter media samples of 60 mm width can be clamped using a movable carriage and a threaded rod. These are of a square, a circular, and a hexagonal shape, whereby the highest point of each geometry is at an identical distance from the frame. The respective devices are shown in Figure 3. Using a sensor counting the revolutions of the driving shaft and including the number of brushes, it is possible to evaluate the number of abrasions until rupture of a filter media sample.

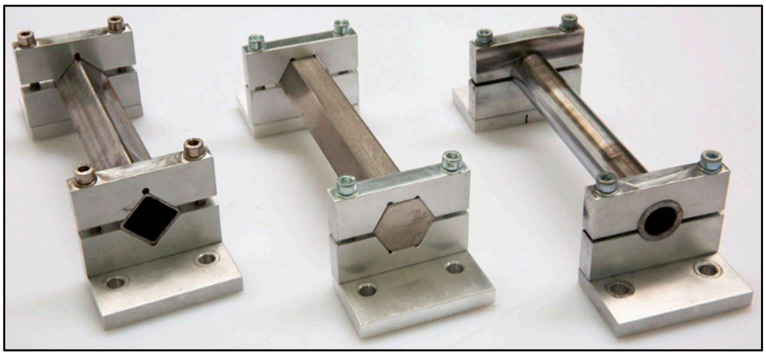


Figure 3. Square, hexagonal and circular geometry variation for sample clamping.

The investigations are divided into two parts, illustrated in Figure 4. In the first series of tests, the investigation of the apparatus settings of clamping torque of the fabrics, overlap of the brushes and speed of the brushes were carried out with a thin nylon (NY) fabric. Three clamping torques (0.5, 0.75 and 1 Nm) were investigated, each in the elastic range of the sample. Furthermore, three overlaps (2, 4 and 6 mm) and three speeds resulting from three different rotational speeds of the motor (20/0.74, 40/1.47 and 60 rpm/2.21 ms^{-1}) were evaluated. The limiting factor of the speed is the possibility of visual rupture observation by an operator (only possible when one of the spacer is directly over the sample). Furthermore, tests were carried out to characterize typical tailings filtration filter media provided by FLSmidth for all three edge geometries. All tests were performed six times.

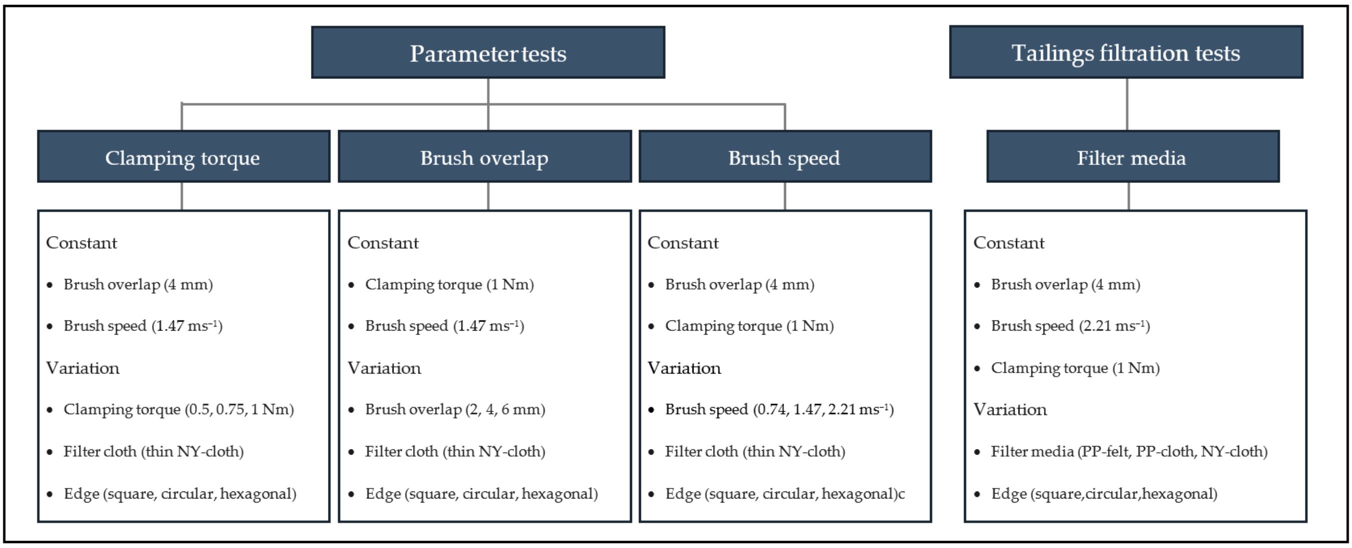


Figure 4. Overview of abrasion test for apparatus parameter evaluation and tailings filter media investigation.

A laser scanning microscopy (LSM) image and details of the filter media used for apparatus parameter evaluation are listed in Table 1. Therefore, a thin plain-weave nylon cloth was used. A pressurized filter cell according to VDI Guideline 2762 was used to determine filter media flow resistance using water [39].

Table 1. Properties of apparatus parameter tests filter cloth.

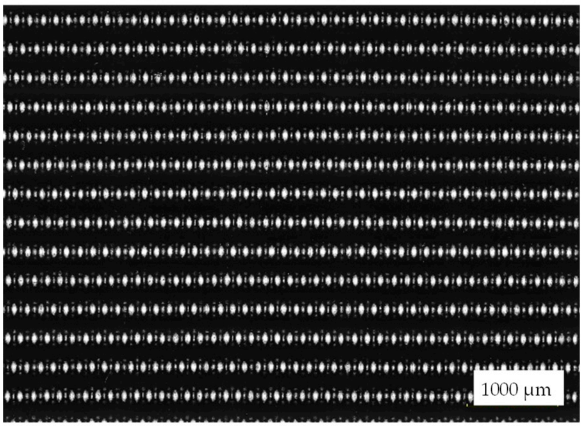
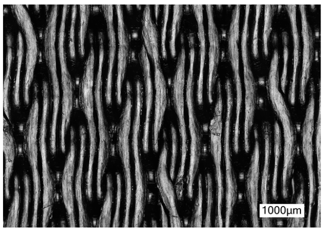
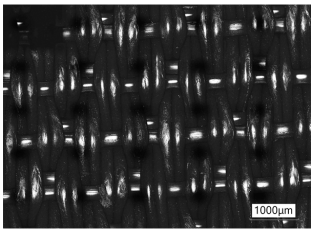
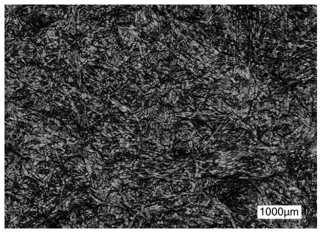
	Thin NY-Cloth
LSM image	
Weave-type	Plain
Fiber type	Mono/mono
Fiber diameter (warp/weft)	85 ± 4/95 ± 16 µm
Flow resistance	$1.1 \pm 0.1 \times 10^8$ m^{-1}
Thickness	0.16 ± 0.01 mm

Table 2 lists LSM images and data of the tailings' filtration filter media (polypropylene (PP) cloth, nylon cloth and felt media out of PP). The two cloths differ in weave type, with filter media flow resistances and thickness in the same range. The resistance of the felt media is slightly higher and its thickness is about twice that of the cloths. These media were already part of investigations of filter cake adhesion after filtration [17].

Table 2. Properties of tailings filtration filter media [17].

	PP-Cloth	**NY-Cloth**	**PP-Felt**
LSM image			
Weave-type	Twill	Plain	-
Fiber type	Mono/mono	Mono/mono	-
Fiber diameter (warp/weft)	180 ± 10/330 ± 30 µm	280 ± 20/310 ± 20 µm	-
Flow resistance	$2.6 \pm 0.6 \times 10^8$ m^{-1}	$1.8 \pm 0.1 \times 10^8$ m^{-1}	$7.4 \pm 0.9 \times 10^8$ m^{-1}
Thickness	1.1 ± 0.1 mm	1.0 ± 0.1 mm	2.2 ± 0.2 mm

The manufacturer's specifications for the filter medium material were verified by wide-angle X-ray scattering (WAXS) measurements (Xeuss 2.0 Q-Xoom, Xenocs SA, Grenoble, France).

As soon as the operator detects a rupture of 50% ± 5 mm of the sample width (30 mm), he stops the apparatus and notes the turn counter of the motor. This, multiplied by the number of brushes (14), is noted as the number of abrasions until rupture. It has been observed that once a rupture has been started, it leads to a complete one within a few cycles. Figure 5 shows an example of a rupture for a test using the thin nylon fabric over a circular edge geometry.

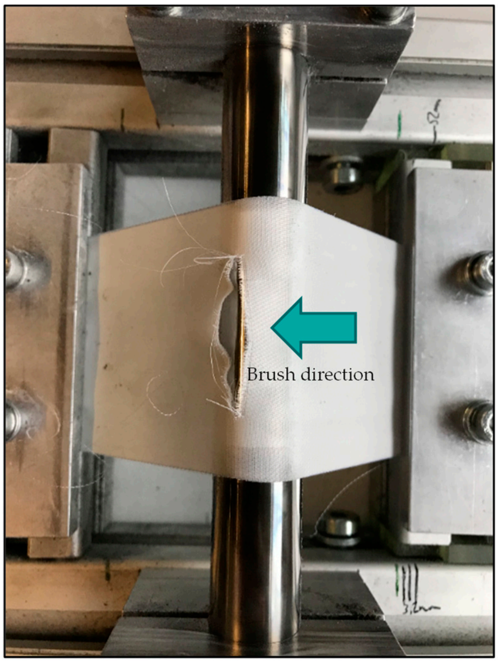


Figure 5. Point of rupture for the thin nylon cloth clamped over a circular edge geometry.

3. Results

The results section is divided in WAXS measurements of the filter media, tests concerning apparatus parameters, and investigations on tailings filtration filter media wear behavior.

3.1. Filter Media Material Characterization

The spectra of the thin polyamide fabric and the polyamide fabric used for tailings filtration are shown in Figure 6. They show two main peaks close to 20° and close to 23° and therefore agree with usual polyamide spectra [40–43].

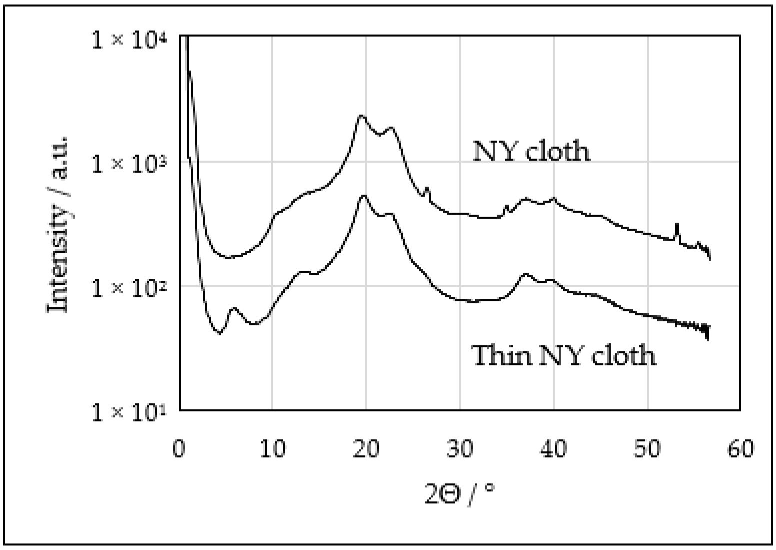


Figure 6. WAXS spectrum of thin NY-cloth and NY-cloth typical for tailings filtration.

Figure 7 shows the spectra of the PP-felt and the PP-cloth used in the abrasion tests. There are four main peaks close to 13°, 16°, 18° and 21°. This confirms that the material used is polypropylene [44].

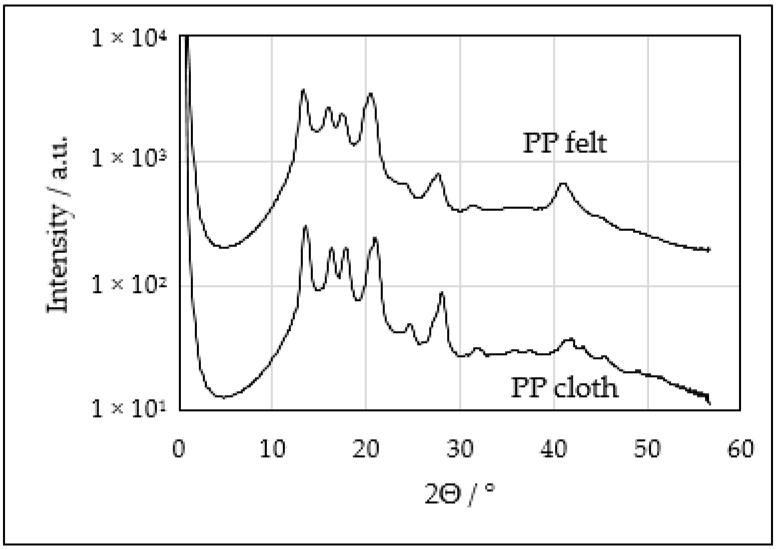


Figure 7. WAXS spectrum of PP-felt and PP-cloth typical for tailings filtration.

3.2. Brush Apparatus Parameter

The influences of the parameters that can be adjusted on the apparatus (clamping torque, brush to filter cloth overlap and speed of the brushes) are assessed using a thin nylon fabric. Figure 8 shows the number of abrasions until rupture for increasing clamping torque using the three different edge geometries including standard errors of the mean. For each geometry abrasions to rupture decrease with increasing clamping torque. Furthermore, it can be stated that a circular edge geometry results in the lowest number of abrasions, followed by the square geometry. The hexagonal edge has the highest abrasion values and highest uncertainties.

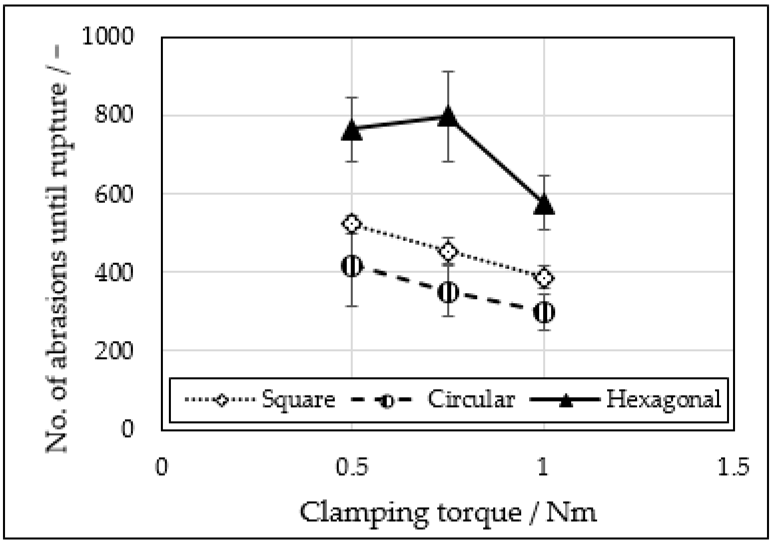


Figure 8. Number of abrasions until rupture of the thin nylon cloth for 0.5, 0.75, and 1.0 Nm for a square, a circular and a hexagonal edge geometry.

Figure 9 shows the number of abrasions until rupture for the thin nylon cloth for the three different edge geometries and a variation of the brush overlap from 2 mm to 6 mm. Analogous to the clamping torque an increasing overlap results in decreasing abrasion values for each geometry. Again, the circular edge has the lowest and the hexagonal edge the highest number of abrasions to rupture. Furthermore, the uncertainties are higher if more abrasions are needed.

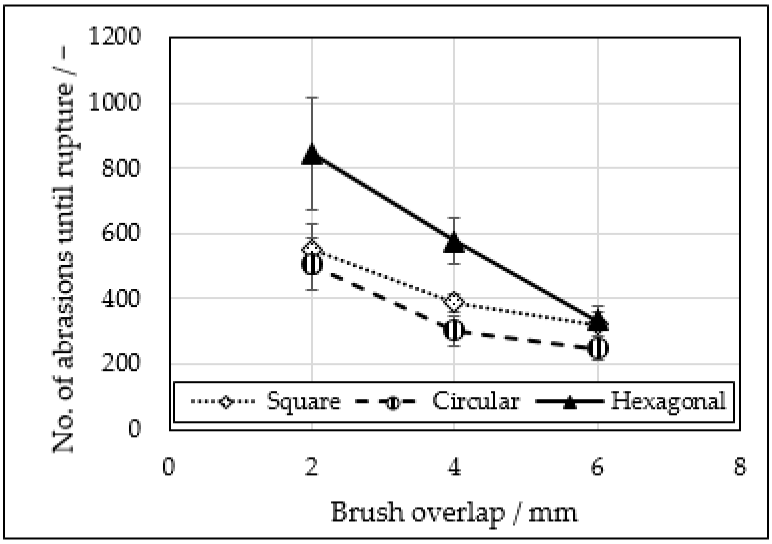


Figure 9. Number of abrasions until rupture of the thin nylon cloth for 2, 4 and 6 mm for a square, a circular and a hexagonal edge geometry.

Figure 10 shows resulting abrasions values for a variation of brush speed (0.74, 1.47 and 2.21 ms^{-1}) resulting from a variation of motor speed (20, 40 and 60 rpm) for the thin nylon cloth for the three edge geometries. The ranking of edge geometries is consistent. The circular geometry results in the lowest abrasion values and the hexagonal one in the highest. However, the tendency caused by the variation of brush speed is not analogous to clamping torque and brush overlap, respectively. A brush speed increase seems to slightly increase the number of abrasions until rupture. Concerning the uncertainties which are once again increased for higher abrasion values, an influence of the brush speed is negligibly small in the speed range considered.

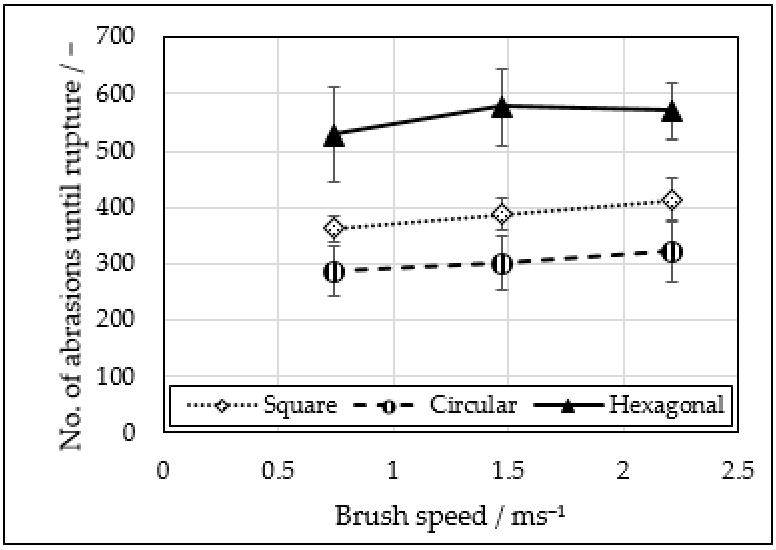


Figure 10. Number of abrasions until rupture of the thin nylon cloth for 0.74, 1.47 and 2.21 ms^{-1} for a square, a circular and a hexagonal edge geometry, respectively.

3.3. Tailings Filtration Filter Media

In addition to apparatus parameter tests, investigations were carried out on industrially used tailing filtration filter media. These concern the main aspect of this article: as the apparatus replicates the load, tailings filter media are subjected to it in the specific operation, thus providing a tool to improve filter media selection for tailings filtration.

Figure 11 shows the resulting number of abrasions until rupture for the PP-felt, the PP-cloth and the NY-cloth for the square, circular and hexagonal edge geometry. Due to the higher thickness of the filter media compared to the thin nylon cloth used in the apparatus parameter study, the abrasions to rupture are much higher. The PP-felt media has the lowest abrasion values. Number of abrasions to rupture is slightly higher for the PP-cloth in comparison to nonwoven fibers due to higher diameter of the single fibers. The highest abrasion resistance can be stated for the NY-cloth independent of the used geometry of the edge. Concerning the edge geometry, it can be seen as analogous to the parameter test that the hexagonal edge has higher number of abrasions until rupture for each filter media. Furthermore, the uncertainty increases with increasing number of abrasions.

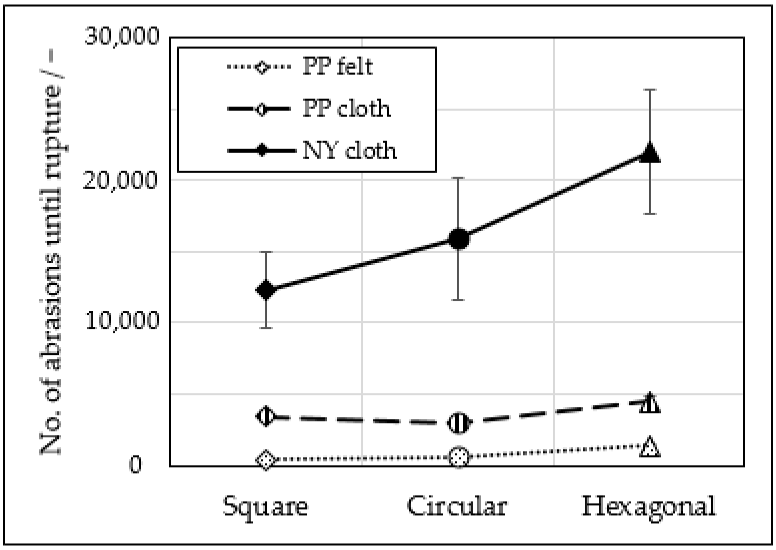


Figure 11. Number of abrasions until rupture of PP felt, PP cloth and NY cloth for the square, circular and hexagonal edge geometry.

Table 3 shows the differences in fabric resistances for uniaxial loading with repetition in one direction achieved with the brush apparatus. The increase of abrasions to rupture for each different edge geometry is listed in each combination. The largest increase results between the NY-cloth and the PP-felt for the round deflection with an increased service life of factor 31.8.

Table 3. Increase of abrasions to rupture of the filter media typical for tailings filtration in comparison with each other for the different edge geometries.

	Square	**Circular**	**Hexagonal**
NY-cloth to PP-cloth	3.6	5.3	4.9
NY-cloth to PP-felt	31.8	25.0	16.1
PP-cloth to PP-felt	8.9	4.7	3.3

4. Discussion

The presented brush apparatus which causing a direction-specific load simulating filter media abrasion in tailings filtration by detaching cakes, represents a reproducible comparison possibility between different filter media.

Important setting parameters of the apparatus were investigated using a thin nylon cloth and their influence on the number of abrasions until rupture was shown. It also allows comparison between media typical of tailings filtration. However, there is a simplification in defining the time of rupture with the time of a 50% rupture of the sample. This serves to improve detectability for the operator who determines the time of rupture. The influence of different operators must also be considered.

In general, it is important to know that a very large number of different filter media types is available. This can be seen in the number of exhibitors of filter media manufacturers at filtration and separation trade shows, such as Filtech or the World Filtration Congress. For this reason, it is important to compare three very different filter media in this article, all of which would be suitable for the same application.

By varying different clamping geometries, a potential area for optimization was demonstrated, which is of particular interest to filter plate manufacturers. However, it must be kept in mind that the process engineering tasks of the edge geometry, e.g., sealing of the process chamber, must be considered in a superordinate manner.

In conclusion, it can be stated that a coarse comparison of filter media for tailings filtration is already possible with currently standardized tests, but the presented methodology is closer to the specific loading case of detaching filter cakes in recessed plate filter presses.

5. Conclusions

One objective of this article is to present and prove the concept of a methodology to improve the selection of filter fabrics for tailings filtration by simulating the specific abrasion process occurring at the protruding edges of the filter plates better than standardized abrasion tests. Another objective is to additionally compare the abrasion resistance of three different filter media that could be used for this filtration application.

The former objective results in the presentation of a brush apparatus that causes a repetitive uniaxial abrasion load in one direction. This apparatus allows the number of abrasions up to a rupture of a fabric sample clamped over an interchangeable edge geometry to be determined. This load is closer to the abrasion caused by falling filter cakes than currently standardized wear test methods.

The proof of concept is carried out by means of a parameter study on important setting variables of the presented brush apparatus. These are sample clamping torque, brush to sample overlap and brush speed. It turned out that an increased clamping torque reduces the number of abrasions, as does an increasing overlap of the brushes. The influence of brush speed in the range of a visual observable velocity by an operator is negligible.

Furthermore, the investigated square edge geometry results in the lowest number of abrasions until rupture, followed by the spherical one, whereas the hexagonal edge causes the highest abrasion values for the same filter media.

In addition, the investigations on possible filter media for filtration of tailings showed significant differences in abrasion resistance. The PP-felt media is ruptured by the lowest number of abrasions, followed by the PP-cloth. A significant increase in the number of abrasions until rupture can be seen for the investigated NY-cloth.

Variations and tendencies by parameter adjustments (clamping torque, brush overlap, and brush speed) play a subordinate role in comparison to edge geometry, media type, thickness and material.

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