# ONLINE WEAR ANALYSIS OF CARD CLOTHINGS

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## ABSTRACT

The processing of abrasive fibres in the carding process, in particular high-performance fibres such as glass, carbon or aramid fibres, can cause increased wear of the card clothing. In the FutureTex project 'HPF-Garnitur', the wear of card clothing was investigated and an online wear measurement system has been developed. The aim of the project was both, to optimize the clothings to enable gentler processing of the fibres, and to develop a digital monitoring system to observe the degree of wear of the clothings, which offers a new possibility for maintenance prediction and production planning in the sense of Industry 4.0.

## KEYWORDS

Online analysis; Digital monitoring system; Industry 4.0; Wear level; Card clothing; Nonwoven; High performance fibres; Abrasion.

## INTRODUCTION

Interval replacement of card clothings due to wear is well known. The wear is caused by the processing of fibres and results in loss of sharpness of the teeth, which affects the fibre transport during carding and reduces the nonwoven fabric quality up to the inability to work [1]. The clothing exchange is routinely carried out at certain maintenance intervals. Regardless of the wear of the individual clothings, the clothing of the entire nonwoven line is replaced in order to be able to continue production quickly without any further unexpected interruptions. This leads to unnecessarily frequent maintenance intervals.

Within the frame of the futureTex project 'HPF-Garnitur', a project team consisting of two institutes and four industrial partners considered the wear of card clothing due to the processing of high-performance fibres especially glass, carbon or aramid. Aim of the project was to prevent avoidable clothing changes by developing an online wear measurement system and to take a step towards industry 4.0. Before project start there have been approaches to check and evaluate the wear of clothings [1, 2], but an online analysis had not yet been developed.

The online analysis was developed by the project partner Faserinstitut Bremen e.V. — FIBRE, and was implemented on a pilot scale at Centre of Textile Lightweight Engineering at Sächsisches Textilforschungsinstitut e.V. — STFI. Subsequently it was tested at the nonwovens producers of the project consortium ASGLAWO technofibre GmbH, Hilbersdorf, DE, Norafin Industries GmbH, Mildenau, DE and TENOWO GmbH, Hof, DE, for industrial scale-up. The team was supported by the project partner Graf & Cie AG, Rapperswill-Jona, CH which provided technical support in wear evaluation and derived measures to optimize the clothings for processing of high-performance fibres.

To improve the clothing and make it not only more efficient but also more resistant to wear, optimisation of the profile shape [1, 3] or clothing surface [4] have been considered.

## MATERIALS AND METHODS

### Card clothing

Besides the number of carding stations (number of worker-stripper pairs), the geometry of the clothing has a major influence on carding process. [5]. Figure 1 shows the most important clothing dimensions. Clothing can be characterized by its tooth geometry, tip shape and tooth density. The angles shown in Figure 1, i.e. the working angle, the front angle and the back angle, are used to describe the tooth geometry, but also the tooth depth or working depth [6]. The working angle enables the fibres

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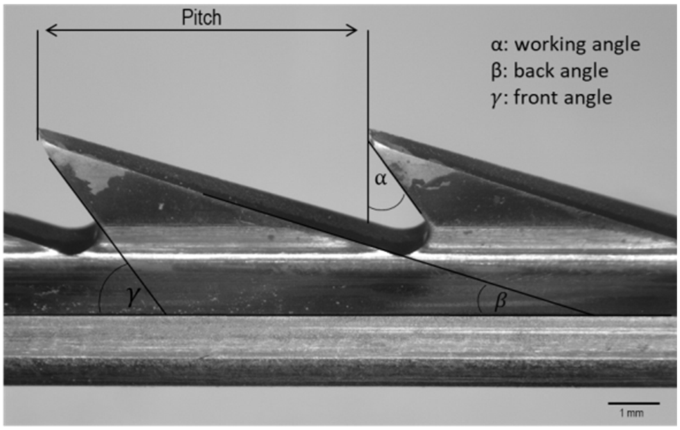


**Figure 1.** Description of card clothing using the example of VD5030-12 of Graf & Cie AG. Naming convention according to [5, 6, 7, 8].

to be picked up as well as held and thus significantly influences the fibre loading of the cylinder [6]. The back angle is responsible for tooth stability and also influences the tooth depth. The tooth depth mentioned is made up of the length of the back angle, the radius of the tooth root and the distance between the tooth root and the base of the clothing. The tooth depth is decisive for the holding capacity of the tooth, i.e. for the fibre loading of the cylinder.

Besides the tooth geometry, the tip shape is important. It is described by tip width and tip length. Most demanded are pointed tooth shapes that allow targeted penetration into the fibre mass with minimal fibre-metal friction. However, a lacy tip shape also carries the risk that the tooth has lower resistance properties and wears or breaks more quickly [6]. The change of the shape of the tip, e.g. due to wear, can lead to poorer penetration into the fibre flock and therefore also to lower fibre resolution, which massively impairs the working ability of the clothing [6]. This has already been demonstrated in some studies [1, 2], which observed the loss of sharpness of the teeth due to a rounding of the tips.

Based on these investigations, special attention is paid to the tip of the teeth in this study. Another important characteristic of clothing is the tooth density. Depending on the fibre type (especially fibre density) to be processed, different clothings are used. The tooth density can be described with the help of the pitch and base width of the wires. Pitch is defined as the number of tooth tips per inch along the clothing wire. Generally, clothing for fine fibres display high tooth densities [6].

To achieve a good carding result, the tip density increases as the opening of the fibre flock increases. I.e. the number of tips increases in the course of the carding process [5]. Thus, opening cylinders generally have a lower number of points than workers, for example. This leads to different tooth sizes and must be considered for an image analysis.

In the case of clothing for processing glass or (recycled) carbon fibers, clothings with a low tip density are used. I.e. the tip density on the line used at STFI is approx. 48 tips/inch² [9, 10]. On the one hand, this can be explained by the shape of the CFs, which are available as textile waste (e.g. offcuts) and therefore entangled in comparison to staple fibre. On the other hand, lower tooth tips allow gentler processing of the brittle CF.

During the project different clothing geometries have been considered represented by the diverse carding configurations resp. purposes of application of the partners. One of the regarded clothing is the clothing of the MiniCard unit from Autefa Solutions Germany GmbH, Friedberg, DE at STFI, which is primarily used for processing recycled carbon fibres [11, 12]. In the project the clothing of the first and the last worker-stripper pairs (from a total of 3 pairs) were exchanged to investigate the wear of the clothing (VD5030-12, Graf & Cie AG) shown in Figure 1. Flexible Card clothings were not investigated within the project, as they are not common in the field of producing nonwovens based on high-performance fibres.

## Sampling positions

Focus of the project was the wear of card clothing. During the carding process, the fibres are transferred from the cylinder to the worker and via the stripper back to the main cylinder [5, 6]. Particularly the fibre flock disintegration and increasing parallelization between cylinder and worker due to the different cylinder speeds leads to a strong stress on the clothing. The clothings of worker and stripper pairs as well as the main cylinder were examined more intensively, because from experience of the partners the main wear occurs on them. Besides the mentioned cylinders, also opening cylinders, swirling cylinders and transfer cylinders have been investigated in the project.

## Offline analysing methods

Three different approaches of analytical methods have been used: offline analysis, semi-online analysis, and finally online analysis. In offline analysis individual clothing pieces are examined more closely using a light microscope (Digital microscope VHX 1000, Keyence Deutschland GmbH, Neu-Isenburg,

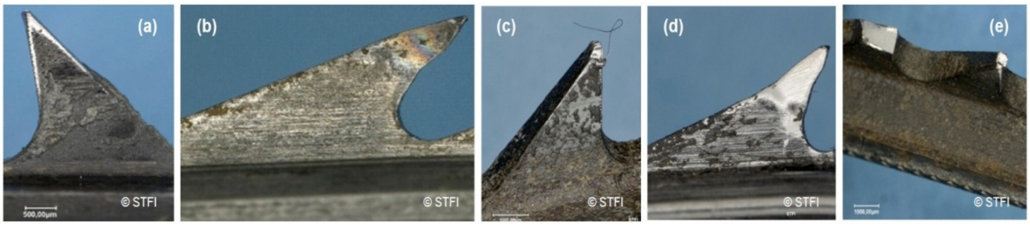

**Figure 2.** Optical microscopy images of various anomalies of clothing at STF and at partners: (a) polluted tooth, (b) discolored tooth tip, (c) split tooth tip, (d) deformed tooth, (e) missing tooth.

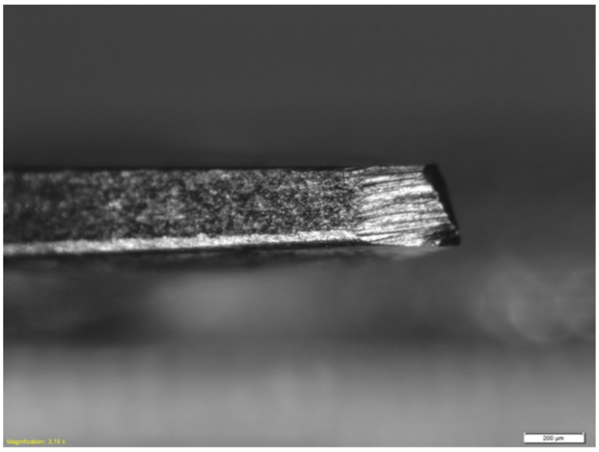

**Figure 3.** Regrinded tooth tip of a clothing, top view.

DE) or SEM (QuantaTM 250 FEG, FEI Company; Hillsboro, Oregon, US). In semi-online analysis by USB-Microscope (USB2-MICRO-200x USB2.0 microscope, Plugable Technologies, Redmond, US) card clothings were evaluated directly on the carding unit, i.e. non-destructively. Semi-online analysis in particular is used in industry and is currently state of the art. Some companies therefore offer corresponding USB microscopes in their product range [8, 13]. However, trained specialists are needed to assess the condition of the clothing using USB microscopes.

## Online analysis

An online analysis was developed at the project partner FIBRE. The aim was to optimize the current semi-online analysis and to take a step towards Industry 4.0. The system was based on a 20 MP industrial camera exo541MGE (SVS Vistek, Seefeld, DE) and MC3-03X lens (Opto Engineering, Mantova, IT) mounted in an IP67 housing to prevent damages by carbon fibre dust. The image area observed is approx 25 x 25 mm² at 4504 x 4504 pixel, corresponding to an edge length of approx 5.5 µm per pixel. This enables the observation of the card clothings in nearly microscopic scale on the one hand, and the observation of slowly moving cylinders on the other hand, if the linear movement is smaller than half of a pixel width per exposure time (i.e. less than 2.75 µm in 500 µs / speed <5.5 mm/s in the configuration reported here). The camera was mounted on a rack constructed from aluminium profiles allowing a positioning over lines up to 3 m working width. The camera holder was movable forward and backward by a stepper motor to enable focusing by remote control. A Justbright JBBL-0506-WT LED illumination unit (MBJ Imaging GmbH, Ahrensburg, DE) with 800 lm luminous flux was directly attached to the camera holder. The camera holder was connected to the rack by a linear guiding (Kamp & Kötter, Dortmund, DE) to enable easy manual position change in parallel to the observed cylinder. The software was self-developed based on the opencv SDK (https://opencv.org/), using the findContours() function. The function uses the algorithm developed by Suzuki and Abe [14]. Additional details of the development are described in section Online wear analysis.

# CLOTHING DAMAGE AND WEAR DETERMINATION

## Offline analysis of clothing damage

Offline analysis enables a closer look at the card clothing. It allows determination of the cause and evaluation of the intensity of wear or damage. The analyses were carried out using the above-mentioned methods. During the course of the project, it was possible to identify various anomalies of clothing at STFI and at the partners' lines. These are sorted according to their degree of damage and shown in Figure 2. As displayed in Fig. 2, the teeth of different clothing show contaminations (dust and fibre fragments), tooth discoloration, split and deformed teeth and even missing teeth. Polluted teeth mainly occur on opening cylinders and (as in this case, shown Fig. 2(a)) pre-cylinders. This can be explained by the fact that the fibre flocks are first opened by the opening and pre-cylinders, and the fibre-fibre and fibre-metal friction can deposit lubricants

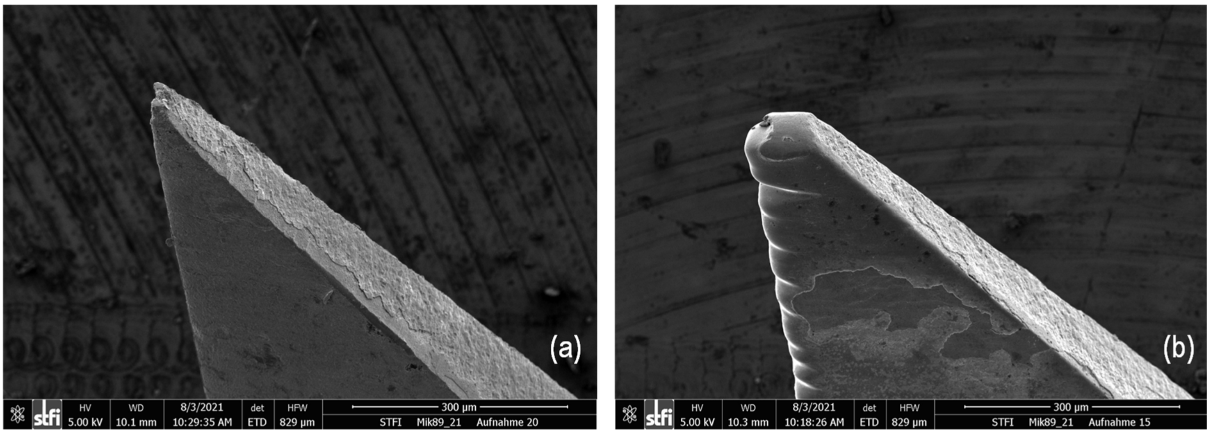


**Figure 4.** SEM images of tambour clothings: (a) new and (b) worn.

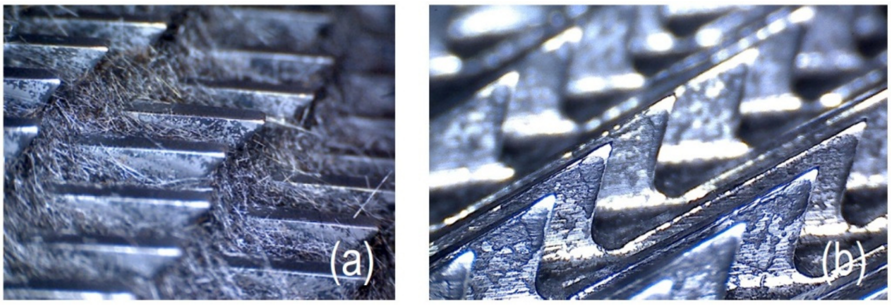


**Figure 5.** USB-Microscope images of: (a) Fiber accumulation on the clothing of a feed cylinder and (b) sediments on the clothing of a pre-cylinder.

or sizing agents on the clothing when they first come into contact with them. The lubricant residues may lead to undesirable stickiness, which causes increased adhesion of fibres and contaminants to the clothing. In extreme cases, this can lead to 'clogging' of the cylinders, which makes cleaning of the cylinders unavoidable and thus leads to unwanted maintenance work and unplanned process stops. For this reason, the condition of the clothing must also be examined with regard to possible contamination.

Another anomaly identified was the discoloration of individual teeth, shown in Fig. 2 b; on a tooth of a worker clothing at STFI. Due to a regrinding process, some tooth tips experienced partial overheating, which caused an extreme heat exposure on individual tooth tips and leads to discoloration of the metal. The regrinding process can also be confirmed by Fig. 3, which shows one of the reground teeth and thus clearly the traces of grinding due to the changed tooth tip. All teeth are evenly ground at the tip.

Furthermore, damage to the tooth tips and teeth could be determined. This includes split tooth tips (Fig. 2 c) as well as deformed teeth (Fig. 2 d) and even missing teeth (Fig. 2 e). These damages can be traced back to foreign bodies (metal parts) in the process. Not every conspicuous feature must necessarily lead to a change of clothing. In particular, pollution like dust or fibres can be easily removed by cleaning, so that maintenance is necessary, but there is no need for a replacement of the clothing.

Furthermore, the offline analysis made it possible to investigate where the most wear occurs on the tooth. As in literature discussed and already mentioned above, the wear of clothing was especially seen on tooth tips and front angles due to the mechanism of the carding process [1, 4]. For this reason, SEM images of new clothing, i.e. clothing before their use in the carding process, and old clothing, which already had to be replaced due to their wear, were to be compared with each other.

SEM images showed both, the extreme case of a rounding of the tooth tips, already described in the literature [1, 4] and deep indentations caused by fibres working into the metal of the teeth occurring before the rounding of the tooth tip. The investigations confirmed that especially the tip of the tooth but also the front angle are affected by abrasion, shown in Figure 4 using the example of a tooth of a clothing of a main cylinder. Due to the role of the main cylinder during the carding process, the abrasion effects were clearly visible. The tip is already completely rounded and clear scoring is visible on the breast angle.

## Semi-online analysis of clothing damage

A semi-online analysis using an USB-microscope is a non-destructive method for determining wear. This analysis offers the possibility to evaluate abnormalities, which can only be seen inline. These include, for example, contamination of high fibre accumulation (see Fig. 5), the degree of which must be assessed on the system in order to schedule maintenance rep. cleaning in production.

Such information also makes it possible to assess the interaction between fibre and clothing, i.e. the

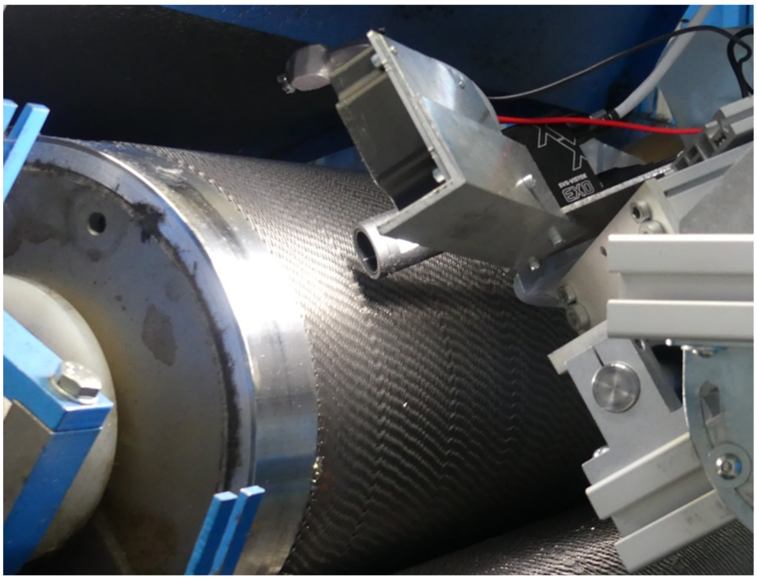


**Figure 6.** Experimental setup used for online measurement at the carbon fibre pilot plant of STFI.

processability of the fibres used. This for example can lead to fibre changes due to their sizing, as this adheres particularly strongly to the clothing. Furthermore, the number of wear anomalies is decisive. Single damaged teeth do not significantly influence processing, but may indicate further damage or undesirable metal parts in the process, underlining the necessity of considering the entire clothing. The analysis of the card clothing using an USB-Microscope is neither exact, nor it is comprehensive. Main restrictions are the exposure at different angles, which can lead to distortions of the teeth and thus to a false assessment, as well as the varying illumination, preventing a reproducible statement about the condition of the teeth. In addition, it is not possible to observe the complete surface of a cylinder reproducibly.

At the moment, only trained specialists are able to view and evaluate clothing conspicuities appropriately on the basis of many years of experience. Data collection and documentation are done manually and therefore cannot be integrated in the sense of Industry 4.0. Preliminary tests at STFI using an USB-Microscope highlighted the requirements for an online wear measurement:

- preventing distortions by using a constant recording angle,
- development of a suitable illumination concept to prevent unwanted reflections,
- focusing multiple teeth to evaluate larger areas.

## ONLINE WEAR ANALYSIS

An online analysis was developed at the project partner FIBRE. The analysis system is essentially based on a digital industrial camera with a suitable lens and a lighting arrangement designed for this purpose (see Figure 6).

The system is mounted on a frame and thus enables the reproducible approach of measuring positions. The camera position is approx. 2 mm above the tooth tips. This distance is sufficient to prevent damages on camera or clothings during operation. Image acquisition is done using a laptop connected to the camera via Gigabit ethernet. The evaluation of the recorded images is carried out by means of analysis software developed at FIBRE. From the original image, the teeth of the clothing in the focus area are marked and evaluated by means of edge detection. For a correct evaluation it is essential that at least three rows of teeth over three teeth are in the focus area. If the cylinder diameter, tooth distance (pitch) and height are known, the front and working angles can be calculated from the image, and edge breakouts or damaged tips can be detected. The side surfaces of the teeth do not have to be completely visible in the image, but the edges must all be recognisable. The lighting is placed to illuminate mainly tip and upside of the teeth, and to a certain extent the side opposite to the camera. The camera is mounted in a 45 degree angle with view to the non-illuminated side of the teeth. Consequently, the side surface of each tooth appears dark, whereas the tips and edges are strongly illuminated and appear in a high contrast to the dark side surface. The optimum image position depends on the cylinder diameter and tooth angles, is therefore cylinder-specific and can only be determined on site on the device if necessary. First orienting experiments to validate the system have been conducted at the lab-scale line (30 cm working width) at FIBRE.

### First scale up at STFI

The first step of scale up was done by switching to the dust-proof pilot plant with 1 m working width at the Centre of Textile Lightweight Engineering at STFI, Chemnitz, DE, described in section Card clothing. In Figure 7 the scheme of image analysis used in the

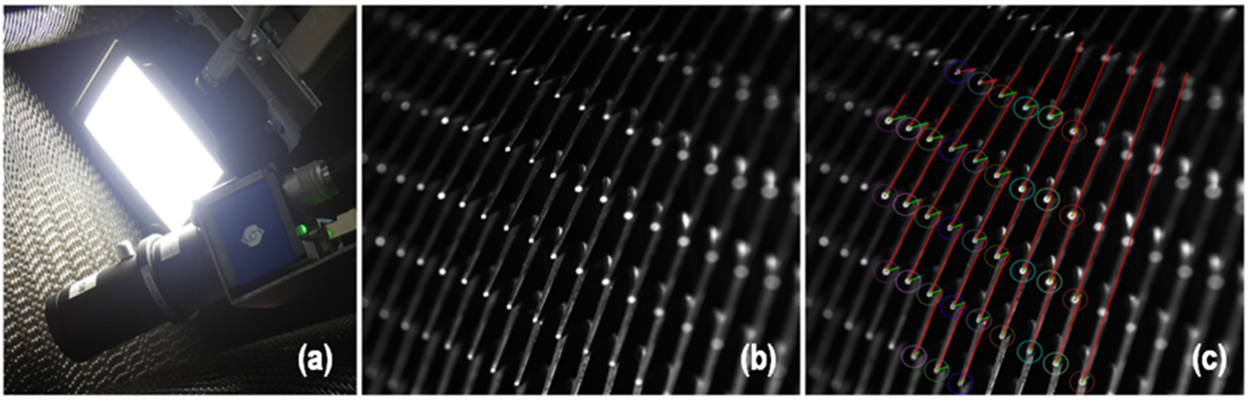


**Figure 7.** image analysis system with camera & illumination unit (a), original image of worker #3 (b) and clothing with edges marked in focus area after edge detection (c).

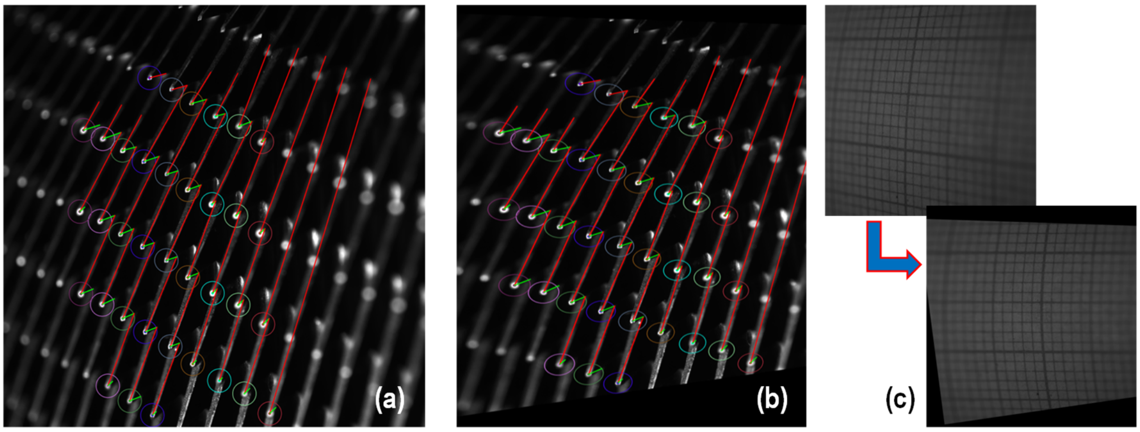


**Figure 8** original image after edge detection (a), after perspective correction (b), and assisting grid to visualise the effect of perspective correction (c).

project is displayed with the camera system positioned in the card (a), consisting of industrial digital camera and a LED illumination unit. In (b) an original image recorded on worker #3 is displayed. First step of analysis is to determine the clothing lines within the focus area. For this purpose, the tooth tips are determined by the algorithm using binarisation. This is possible, since the tips appear as spots characterised by the largest gray scale values in the image, typically values exceeding the average by more than 100 (8-bit gray scale, allowing values 0 – 255). Subsequently, the teeth are grouped by wire, as displayed in Fig. 7(c). In the next step a region of interest is defined per tooth and the tooth edges are searched in this region. For all teeth with two edges detected (i.e. back and front edge), the tip is marked by a green circle as valid tooth. The result is shown in Figure 7(c).

Finally, additional information is necessary (i.e. cylinder diameter, clothing teeth distance and tooth height) in order to calculate correct angles from the visible edges in the image. Using this input, a perspective correction can be conducted on the images to bring all visible teeth within the focus area to identical size and geometry. In Figure 8 are displayed: the original image after edge detection (a), the converted image after perspective correction (b) and an assisting grid to visualise the effect of perspective correction (c). In Figure 8 (b) the tip angles are displayed distortion-free and can thus be used for further evaluation.

## Final scale-up to industrial scale

The same measurements have been conducted on the lines of three industrial partners covering processing of aramid, glass and carbon fibres. Corresponding to the variety of the processed materials, each of the lines has a different configuration concerning number of stripper-worker pairs, pre- and post-groups, cylinder geometries and of course in clothing geometries. Thus, each of the systems must be assessed individually in terms of wear level detection. In other words: the database acquired here is too small to derive a general approach for wear level detection of all clothing types. But the results acquired here give a good insight into several wear mechanisms and can be used as base for future developments. As example the wear of a tambour clothing is displayed in Figure 9. The images were recorded before and after exchange of the clothing during a scheduled maintenance to visualise the maximal detectable difference. In Figure 9 (a) the ‘old’ worn clothing is displayed, compared to the new clothing directly after installation (b). Both parts of Figure 9 comprise a general view on the clothing plus an enlarged section to visualise the details of one of the teeth. In (b) the complete tip with sharp edges

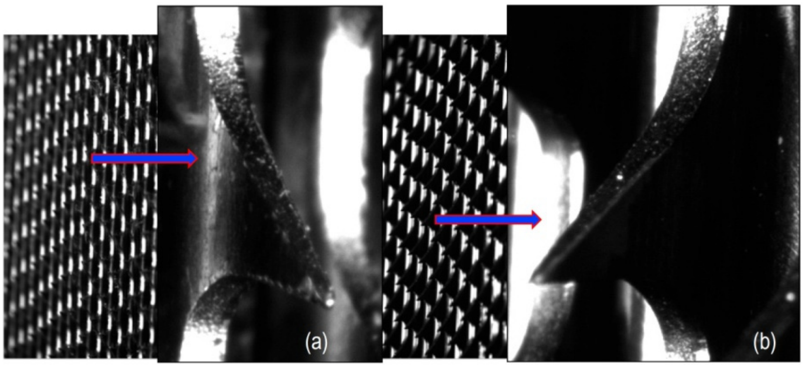


**Figure 9.** tambour clothing (a) worn, after exchange and (b) new, directly after installation.

over the full tooth is visible, whereas in (a) the worn tip displays the typical signs of wear. It is easy to observe that the worn tool tip is rounded, and several corrugations have been grinded into the front edges by contact with the processed fibres. The intensity of the corrugations increases in direction to the tip. The next step of this wear mechanism would be cutting off the tip completely, i.e. reducing tooth height and tip geometry / tip angle. From this point of wear the product quality would be influenced remarkably.

A microscopic off-line assessment of the old clothing would lead to the result, that the clothing is still usable, but should be exchanged in the near future.

This result is in concordance with the off-line analysis by SEM displayed in Figure 4. The detected wear signs obtained from different lines are identical. This gives evidence, that the resolution of the image analysis system with industrial camera used here is high enough to detect the wear patterns occurring on industrial roller cards. Furthermore, it opens as well the way to analyse and quantify the detected wear.

## CONCLUSIONS

Summed up the developed image analysis system is suitable to analyse the wear of card clothings:

- The teeth of card clothings are well-detectable by image analysis.
- BUT: the optimal camera position depends on cylinder diameter and tooth geometry / tooth angles. I.e. the camera positioning is cylinder-specific. Thus, generally it must be determined at the machine.
- Back-, front- and working angle as well as damaged edges and tips are detectable.
- Starting at tip positions, the edge detection in combination with perspective correction (cf. Fig. 7 & 8) enables a reproducible analysis.

The described method of image analysis had been integrated into the pilot plant line at STFI and was tested several times on the lines of three partner companies. Now, at the end of the project it has reached the state of 'proof of concept'. Detailed results of the project have been published in German as final report [15].

Actually, the system described here is a proof of concept. It must be positioned over an existing line while the maintenance doors are opened to enable viewing the card clothings. This makes the analysis possible only during the scheduled maintenance intervals, i.e. approx. each two weeks, which is sufficient to observe the increase of wear. This has the general advantage, that the line is cleaned during the maintenance, thus preventing erroneous measurements caused by remaining fibres on the clothings. For future industrial use, further development of the system will be necessary. This must include building up a database for at least the cylinder geometries and card clothing types to be observed, comprising data about typical wear patterns and limits of clothing usability. This must be combined with data for optimal camera positioning for each occurring combination of cylinder geometry and clothing used on it. Then it will be possible to bring the system to industrial usability.

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