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Time-Dependence of Stop Marks in Warp-Knitted Fabrics
Časovna odvisnost stopoznak snutkovnih pletiv

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Abstract
Stop marks are one of the most frequently occurring errors in warp-knitted fabrics. They become visible in a fabric each time a warp-knitting machine stops and restarts. Nevertheless, investigations of such stop marks are rarely found in scientific literature. Here, we report on time-dependent investigations of stop marks in warp-knitted fabrics. Microscopic examination of stop marks after stopping times ranging between 1 s and 7 weeks revealed a superposition of the common stop mark due to imperfectly matching rotational speeds of the warp beam and main shaft, and an additional effect due to relaxation in the machine.
Keywords: stop marks, warp knitting, microscopy, image evaluation.

Izvleček
Stopoznake so ene najpogostejših napak snutkovnih pletiv. V pletivu postanejo vidne vsakič, ko se snutkovni pletilnik ustavi in znova zažene. Raziskave o teh napakah kljub njihovi pogostnosti le redko najdemo v znanstveni literaturi. Članek obravnava časovno odvisnost napak v snutkovnem pletivu zaradi zaustavitev stroja. Mikroskopski pregled napak po določenem času od zaustavitve stroja, v obdobju od ene sekunde do sedmih tednov, je pokazal, da prevladujeta najbolj razširjena stopoznaka zaradi nepopolnega ujemanja vrtilnih hitrosti osnovnega valja in glavne gredi in dodatni učinek zaradi relaksacije pletiva na stroju.
Ključne besede: stopoznake, pletenje osnove, mikroskopija, vrednotenje slike

1 Introduction
Detecting and, if possible, avoiding defects in textile fabrics is an important task in order to improve the quality of fabrics. Various methods have thus been reported by different research groups, mostly based on optical inspection. Hanbay *et al.* give a comprehensive overview of different cameras, lenses, and light on the hardware side, and diverse automatic fault detection approaches with their respective mathematical background on the software side [1]. More reviews on fabric defect detection were published by other groups [2–4].

One of the fabric defects that is of high importance due to its large dimension is the stop mark, also named stop line or start mark. This defect occurs in different textile fabrication methods upon stopping and restarting a machine. Most often, it is investigated in cases of woven fabrics. Wimalaweera and Tang discussed the influence of machine stopping time, warp yarn tension, weave pattern, etc. on the severity of stop lines [5]. Karasan and Erdogan mention the importance of correct keel settings to avoid stop marks in woven fabrics [6]. Patil *et al.* report on stop marks occurring in the form of increased or decreased pick spacing, i.e. thin or thick places. They mention the importance of correct cloth fell position to reduce or even avoid such stop marks [7]. Other authors reported on the effect of shed geometry [8] or concentrated on optical investigation methods to detect and classify stop marks [9–11].

Similar investigations regarding stop marks in warp and weft knitted fabrics, however, are scarce. Au mentioned stop marks in circularly knitted fabrics and described them as straight horizontal streaks, occurring due to different yarn tensions [12]. Wijesingha and Jayasekara mention stop-lines as one of eight defect types in warp-knitted fabrics and discuss their possible detection by self-organizing maps, finding nearly an 80% detection rate [13]. Earlier, Orchard and Barker discussed high-speed photography as a possibility to detect stop lines in circularly and warp-knitted fabrics [14].

A more detailed examination of the reasons for stop marks in warp knitted fabrics was reported by the ITA of RWTH Aachen University [15, 16]. They described the stop marks as being the actual stop line plus additional lines before and after the row of machine stopping and identified these additional lines as stopping (larger stitches) and starting (smaller stitches) lines, which they attributed to a difference in the time-dependent rotational speeds of the warp beam and main shaft. The small number of scientific publications, however, is in contrast to the importance of solving this problem for warp-knitting machines.

Here, we report on a superposition of common stop marks and a time-dependent effect which became evident due to longer stopping periods of a warp-knitting machine due to Covid-19 restrictions in our university.

2 Materials and methods

Experiments were performed on a warp knitting machine HKS 3-M-EL, 42'' with gauge E28 (Karl Mayer Textilmaschinenfabrik GmbH, Obertshausen, Germany). The simple warp knitted structure reverse locknit (1-2 / 1-0 // 1-0 / 2-3//) was selected to enable a relatively simple investigation of the pore sizes between the yarns (cf. Figure 1).

Stop lines were produced for different nonoperation periods between t = 1 second and t = 7 weeks. Microscopic images were taken in the middle of each stop mark as well as on the left and right side of the fabric, approximately 10 cm from the outer borders, by a digital microscope Camcolms2 (Velleman, Gavere, Belgium).

These images were evaluated by ImageJ 1.53e (National Institutes of Health, USA) in the following way: Firstly, the scale was defined, enabling the conversion of pixels to lengths. Next, a threshold filter was applied in the histograms of the images to differentiate between yarns and "holes" between them, i.e. all pixels brighter than the threshold were defined as yarn, while all pixels darker than the threshold were defined as pores (cf. Figure 1). In this way, the images were converted into black-and-white images where all black areas showed yarn, and all white areas showed pores. Next, the function "analyze particles" was applied to measure the open areas between the yarns. In this way, all pore sizes were separately measured, usually more than 300 pores per image. These quantitative evaluations were performed on the microscopic images taken in the middle of each stop line, while the images taken near the borders will be discussed qualitatively.

3 Results and discussion

A first impression of the stop marks after short and long nonoperation periods is given in Figure 1. Here the stop line is clearly visible after 49 days (7 weeks) without working on the machine (Figure 1b). Even slight color changes are visible, which can be attributed to a light rust film having developed on the needles, caused by the unplanned duration in which working on the machine was not possible. While such long nonoperation periods are uncommon in the textile industry, investigating them is nevertheless important since here effects become more clearly visible, which may already occur after much shorter periods of nonoperation, albeit to a smaller extent.

For a very short stop, by switching the machine off and directly on again, the stop line is much harder to detect (Figure 1a). Indeed, the microscopic images do not fully reveal the impression to the human eye, which makes quantitative examinations more complicated than in cases involving woven fabrics.

For the quantitative evaluation of the structure, it must be mentioned that unit cells of warp knitted patterns normally contain min. 2x2 stitches [17–19]. This is also partly visible in Figure 1, where alter-

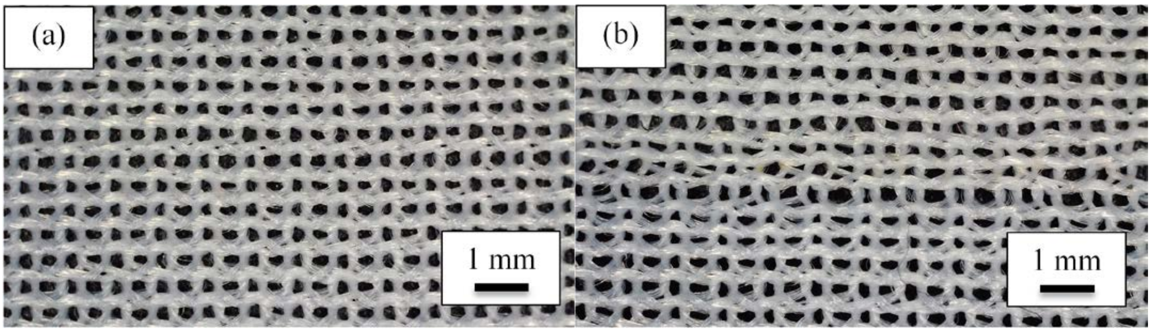
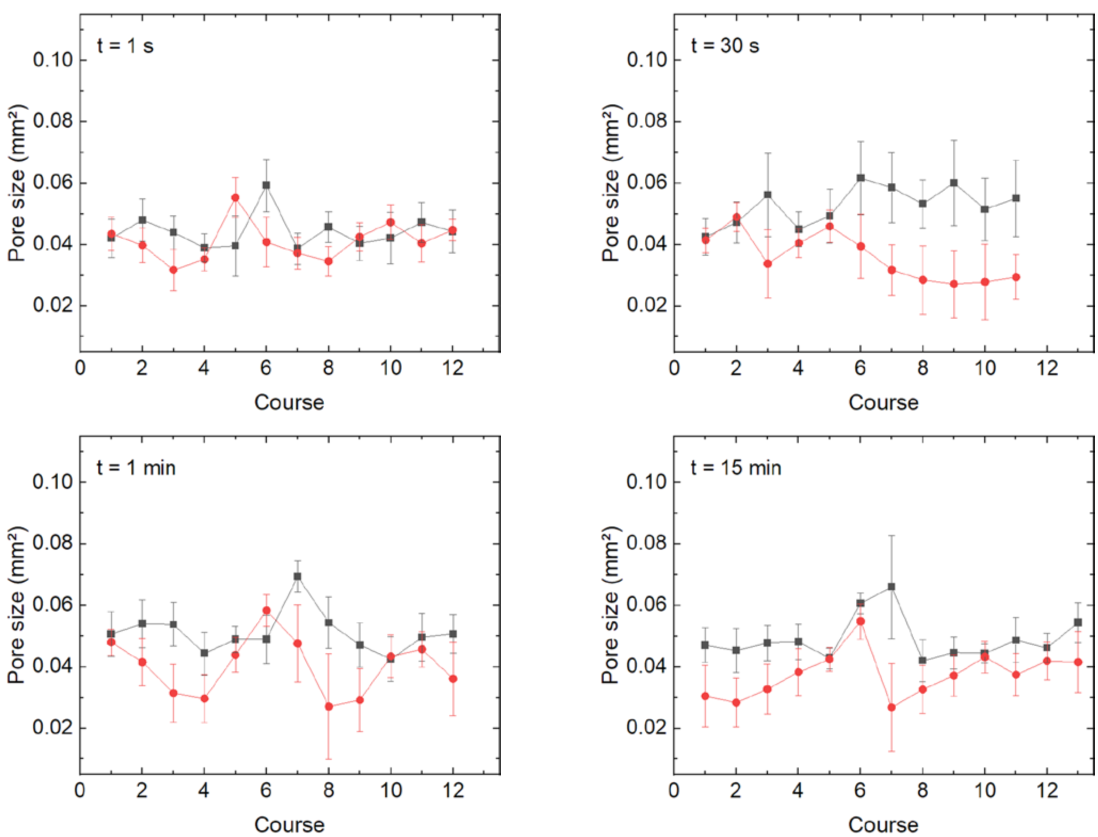


Figure 1: Microscopic images of stop marks, taken after nonoperation periods of the machine of (a) 1 s; (b) 49 d

natingly smaller and larger pores are visible coursewise. A deeper look reveals also alternating shapes of the pores walewise.
On the one hand, this means that evaluations must take into account the alternating pore sizes by averaging them separately. On the other hand, it cannot be excluded that the visibility of a stop mark depends on whether it occurs in the first or the second line of the pattern used here, and that this effect becomes much more pronounced for more sophisticated patterns. To avoid leveling out any important effects due to overly averaging, Figure 2 shows the raw data (averaged over alternating wales) of all image evaluations. Black and red lines indicate alternating pores in the coursewise direction (i.e. alternating parallel to the stop marks, or in other words, alternating horizontally). It must be mentioned that the areas of the microscopic images were chosen "by eye", trying to position the stop mark in the middle of the image, i.e. at course 7 of 13 visible courses. The marks occurring after very short stopping durations are especially hard to see under the microscope (cf. Figure 1a) as that there are only small deviations of this positioning, so the main deviations from the average pore size are visible in the graphs around courses 6–8.



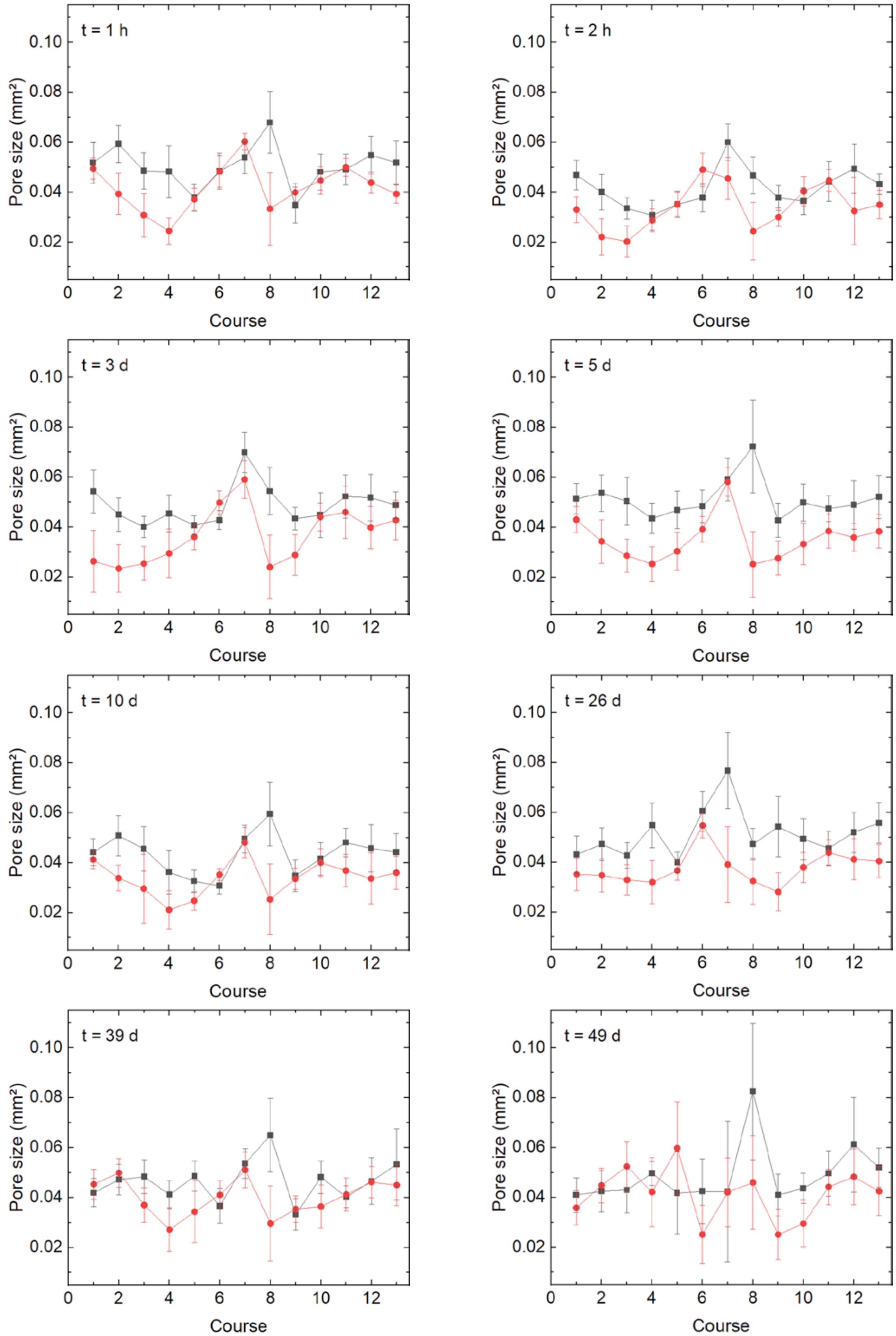


Figure 2: Pore sizes averaged for alternating wales (black and red dots), depending on the courses around a stop mark. The stop marks are located around columns 6-8 in the microscopic images

Comparing these results from a broad range of nonoperation periods, the following statements can be made:

- A maximum pore size can, in most cases, be found roughly in the middle of the image, i.e. at the position where the stop mark was located with the human eye. In most cases, the maxima of the red and the black lines, indicating alternating wales, differ by one course. This finding underlines that not all pores in one course should be averaged.
- Oppositely, no evidence can be found that the severity of the stop line is influenced by the course in which it occurred – if the alternating courses had an effect, there should be two different slopes or maximum heights or the like visible in some of the graphs.
- A tendency towards higher maxima and also slightly larger pore sizes far away from the main stop line is visible for the "black" line. Due to the large error bars, however, this finding cannot be regarded as significant.
- For long nonoperation periods, the error bars of the values near the stop line are increased, and the slopes of the curves vary strongly, corresponding to the quite chaotic impression of Figure 1b.
- Even the relatively small effect after stopping the machine for 1 s, hardly visible in Figure 1a, can be quantified and shows maxima in the red and the black line.
- In many cases, the maxima in the curves seem to be accompanied by small neighboring minima, before, several courses apart from the maxima, the base value is reached again. This is not perfectly identical with the findings reported in [15, 16].

It must be mentioned, however, that some observations do not fit into this idealized description. The following deviations can be found:

- For t = 30 s, the black curve does not show a clear maximum, and both curves differ more strongly for higher course numbers than in the other cases.
- For t = 3 d, both maximum pore sizes occur in the same course.
- And finally, for t = 49 d, the fabric is already damaged so severely that the error bars become quite large, as previously mentioned.

The first two problems may be attributed to the manual handling of the fabrics during image acquisition under the microscope. It cannot be excluded that while trying not to pull the fabric into any direction, it has nevertheless been slightly elongated or sheared erroneously. Such undesired manipulations of the fabric can possibly be counteracted by fixing the fabric on a frame before taking images. Alternatively, stretching the fabric by a defined small ratio may be a good alternative to increase the reliability of the microscopic images.

It must be underlined that in normal use, a warp knitting machine's downtime is normally quite short, so that the case depicted in Figure 1b will usually not occur. However, this artificially produced error is instructive to get an idea of the possible error due to stopping the machine for some hours or even days. In addition, while Figure 1a – taken after the shortest stopping duration of only 1 s – shows nearly no disturbance of the fabric in the microscopic image, the stop mark is, even for this shortest possible stopping time, well visible in reality, if the fabric can be moved, and its shine can be recognized by eye. In this way, there is no "negligible" stopping time as the stop marks become visible at once. The same effect was found in preliminary tests with other patterns produced on the same machine.

This effect is even stronger if the sides of the fabric are taken into account. Figure 3 exemplarily depicts two images taken on the left side, on the fabrics with minimum and maximum nonoperation periods.

For the image taken after stopping the machine for 1 s (Figure 3a), only a small deviation from the desired 90° angle between course and wale orientation is visible. For the longest nonoperation period, however, a strong angle between the wale direction in the "new" part of the fabric (i.e. above the stop mark) and the wale orientation in the "older" part (below the stop mark) is visible. This clearly shows the effect of dry relaxation in the machine, which apparently not only influences the stitches in the stop mark (cf. Figure 1b), but also the residual fabric.

Previous investigations suggested tailoring the time-dependent rotational speeds of the warp beam and main shaft [15, 16]. The aim of the recent study, however, was to define a quantitative description of the stop marks to enable further investigations of possible solutions of this problem.

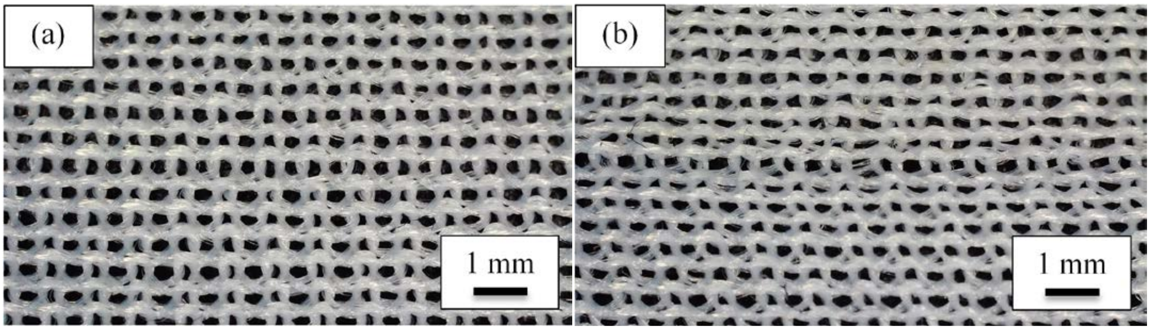


Figure 3: Microscopic images of stop marks near the left borders of the warp knitted fabrics, taken after nonoperation periods of the machine of (a) 1 s; (b) 49 d

4 Conclusion

Stop marks in a warp-knitted fabric were evaluated by taking microscopic images and measuring the pore sizes around the stop lines. By evaluating alternating wales separately, maximum pore sizes were found in two adjacent courses near the optically visible stop mark. In most cases, these maxima were surrounded by smaller minima. Deviations from this systematic description can most probably be attributed to inaccurate handling of the stretchable and shearable fabrics during microscopy.

For the next steps, more reliable handling is thus necessary, as well as taking more measurements on different warp-knitted structures in order to develop a general description of the stop marks and neighboring courses, and finally an approach to reduce the intensity of these fabric defects for different nonoperation periods. The recent study serves as a base for the quantitative evaluation of different approaches to reduce these stop marks.

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