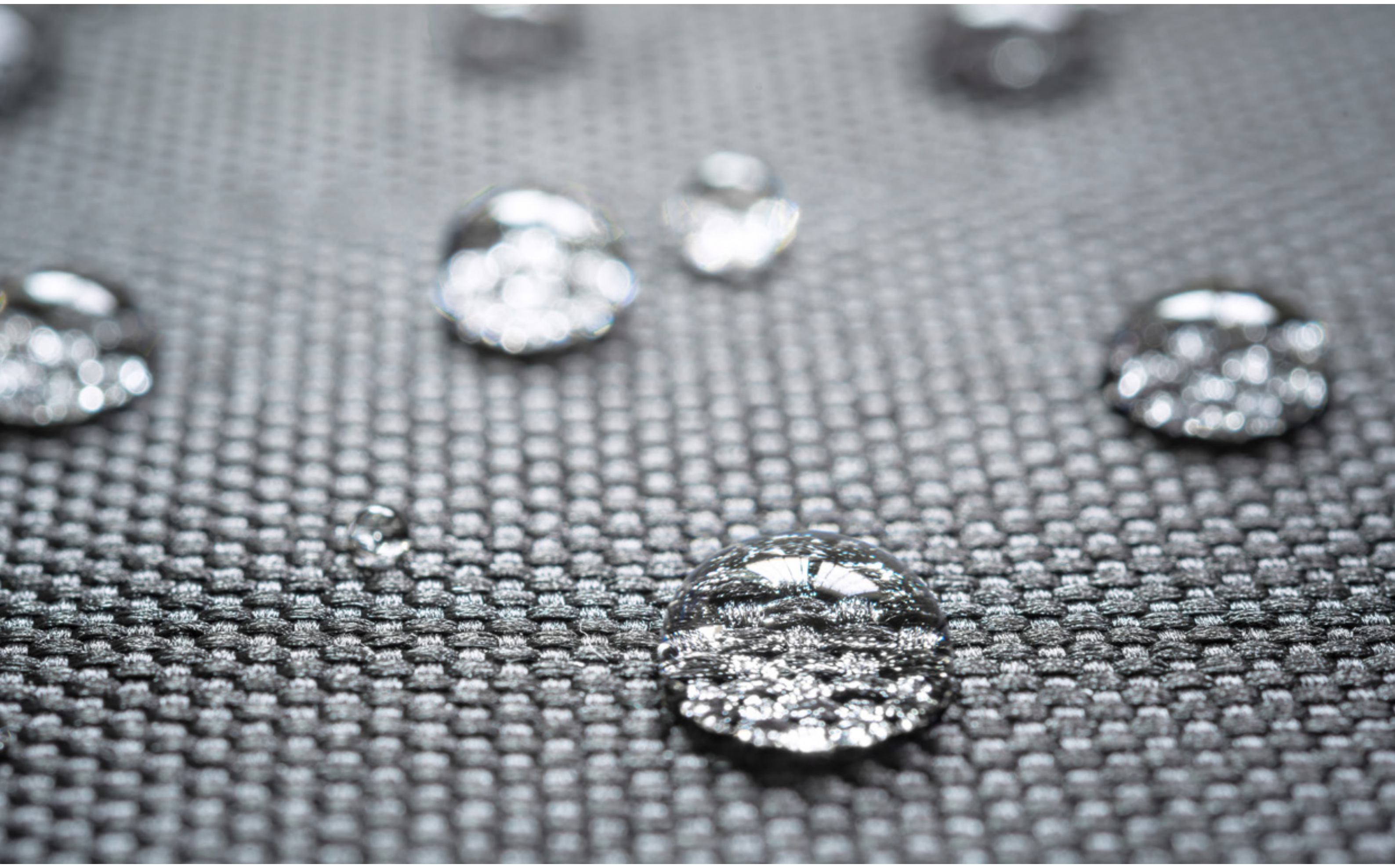
Paper

M-Rays: High-coverage and clean basis-weight measurement of thick nonwovens and coated textiles



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Abstract

The textile industry converts raw materials into semi-finished or finished products. Semi-finished products, among which coated textiles, nonwovens or laminations of either of these two are typically processed as flat materials in roll-to-roll processes in a continuous way. Today these continuous processes are equipped with inline measuring devices to evaluate the material web quality and to achieve lower material consumption and waste. Inline basis-weight measurement using scanners is essential in this regard. Over the last decades, beta gauges, working on the principle of absorption of nuclear radiation have been most successful. Today, solutions using millimeter wave technology, or shorter, M-Ray technology, are on the rise in the market. M-Rays offer advantages in terms of a high measurement stand-off distance (up to 30 centimeters) which makes them extremely suitable for measuring very thick nonwovens at early stages in the nonwoven formation process. Secondly, they enable a high measurement coverage, and finally, they do not cause any harm to persons and the environment. The three topics will be discussed in this paper, with measurement results illustrating the statements. Furthermore, The M-Ray technology will be compared to existing technologies.

Introduction

The total output of the technical textile market is expected to outreach 40 million metric tons by 2012, moreover at a CAGR of more than 4.68% from 2015 to 2020 [1]. This increase of production volumes will drive textile companies to invest in new production lines during the coming years. However, the steady increase of raw material prices will force textile producers to reduce production scrap and increase the quality of their products, both with the intention to increase product margins. Therefor, inline monitoring and feedback systems are typically applied in production plants. This paper is about inline contactless measurement of basis-weights (or grammages) in the markets of thick (>1 mm) nonwovens and coated or laminated textiles as part of the technical textile market [1]. The paper dicusses a new technique based on M-Rays, enabling new measuring possibilities which previously could not be tackled due to technological limitations of competing technologies.

Technology background

The M-Ray technology's basic compound is a multi-gigahertz electromagnetic wave (scientifically referred to as a 'millimeter wave') which is used in a radar-like wireless system such that it can be applied for basis-weight measuring. KU Leuven previously introduced the technology to the world of textile converting [2], but the company Hammer-IMS optimized it for inline use which is known today as the M-Ray technology [3]. M-Rays thank their existence to the recent evolutions of integrated electronics and the computer chip. Today, chip technology has evolved to a situation where frequencies of multiple tens of Gigahertz's can even be generated at an affordable price. This tendency has also been seen in cell phone technology. Cell phones initially used frequencies of 900 MHz, then 1800 MHz, and finally today we are discussing about deploying 5G networks at frequencies higher than 3 GHz. The frequency is named f_c. Typically, at higher frequencies, e.g. multiple tens of gigahertzes, the bandwidths (BW) are widely available. Consider the following inequality [2].

$$\sigma^2 \geq \frac{c_{air}{}^2 \cdot 3}{4 \cdot \pi^2 \cdot T \cdot SNR \cdot \left[(f_c + BW/2)^3 - (f_c - BW/2)^3 \right]}$$

This inequality states that the uncertainty (σ^2) on a single measurement by means of a radar using frequency fc and bandwidth BW will improve if fc and bandwidth BW will increase. The bottom line shows that radars become more precise when electromagnetic frequencies go up, and so do M-Ray based measurement systems, since their designs are similar to the one of a radar system.

Fig. 1 shows the concept of an M-Ray based basis-weight gauge. A transmit antenna transmits M-Rays that travel through the web material, after which they are received by the receive antenna. The presence of the material will cause the M-Ray wave to slown down. The measurement system itself will measure this time delay and relate this to the grammage of the web material.

There are two intrinsic technology-related advantages of M-Rays. M-Rays are non-radioactive, since their frequencies are below the visible light spectrum. Furthermore, the fact that M-Rays do not get significantly absorbed into the material and are applied in a radar-like concept, makes the concept also work for high stand-off distances and very heavy materials.

Section 2 compares the M-Ray measuring method with traditional methods including beta gauges and x-ray. Section 3 further discusses the high standoff capability of M-Ray based measuring and shows measurement results. Next, section 4 explains why multi-head measuring systems can be beneficial. Section 4 also discusses the different application domains of M-Ray based basis-weight gauges in the markets of technical textiles. Section 5 briefly discusses the first M-Ray-enabled multi-head inline integrated measurement systems, after which conclusions are drawn.

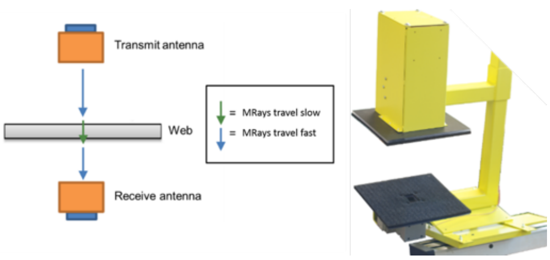

Fig. 1: Left: The concept of an M-Ray-based grammage gauge is similar to the one of a radar system. One antenna transmits a wireless wave, another receives it. The measured delay relates to the weight of the material. Right: an M-Ray-equipped C-frame for basis-weight measuring containing a single transmit-receive pair.

M-Rays compared to other technologies

The M-Ray technology essentially is a multi-gigahertz electromagnetic wave (millimeter wave) which is used in a radar-like wireless system such that it can be applied for grammage or basis-weight measurement. Tab. 1 shows a comparison of the different state-of-the-art techniques for measuring grammage or basis-weight in the textile industry. M-Rays, the solution proposed by this paper, is totally different compared to other techniques in the sense that its principle is not based on the principles of radioactivity.

The technology with the largest market share is without any doubt the beta gauge, especially when additionally taking into account the plastics and foam extrusion markets. Depending on the basis-weight of the material, Prometium, Krypton or Strontium-based isotopes are used. Prometium isotopes are typically only used in the paper industry. The maximum measurable basis-weight of a beta gauge depends on the source that is applied. The stronger the source, the higher its measuring range, yet resulting in more inaccurate measurements. The beta gauge is believed to be the most precise technology, but the listed numbers take into account the periodic replacement of the nuclear source when it passes its half-life-time. For a Krypton-85 based gauge, that means a replacement every 10 years or even more frequently. For this reason, the beta gauge has a 'No' for 'Long-lasting precision'. The other gauging technologies do not suffer such a degradation.

Recently, due to increased stability of high-voltage supplies, x-ray has become a competitive solution. The licensing related administration and costs is becoming a real issue when measuring material thicknesses exceeding one millimeter. For these rather thick materials the standard sub-5kV x-ray source will not work anymore. In many countries, this means special licenses should be obtained and recurring taxes have to be paid.

The technique of Gamma backscatter offers the advantage that the material can be measured from a single side. Moreover, due to its high-power nature, materials up to multiple tens of kg/m^2 can be measured. A drawback of the technique is that it requires physical contact with the material, potentially introducing markings or leaving traces behind.

As introduced before in this paper, M-Rays offer a high stand-off distance, enabling thick materials to be measured. Thanks to its low-absorbance in typical nonwoven and textile materials, heavy materials can be measured. Experiments have shown that materials could easily exceed 10 kg/m^2. The ability to measure both thick and heavy materials with high stand-off distance is therefor a unique asset of M-Ray weight gauges (Read section 3). M-Ray measuring heads need to be mounted on rigid frames, maximizing the focus between the upper and lower antenna. This is less required for the other techniques. The M-Ray technology is the only technology that offers an economically affordable approach of combining multiple measuring heads in a single scanner (Read section 4). This is possible because the cost of an M-Ray weight gauge relates more to the processing electronics rather than to the heads itself. The processing electronics can be shared between multiple measuring heads, making multi-head weight gauging an economically viable product. For comparison reasons: multiplying a beta gauge head would also multiply all administration and nuclear waste management costs. That added up to the cost of the nuclear source itself makes this an expensive solution.

	M-Rays	Gamma backscatter	x-ray	Beta gauge
Stand-off	Up to 30 cm	Requires contact	Unlicensed: < 1 cm. Licensed: unlimited	Few cm
Maximum-measurable basis-weight	Up to 10000 gsm validated	Up to 25000 gsm	Not-limited: but licenses needed	< 5 kg (with Sr-90)
Precision (standard deviation)	1 gsm	0.1 gsm	0.05 % of full range. (e.g. for 10000 gsm this is 5 gsm)	0.05 gsm (with Kr-85)
0.25 gsm (with Sr-90)				
Long-lasting precision	Yes	Yes	Yes	No
Multi-head scalable	Yes	No	No	No
Absorption based measurement	No	Yes	Yes	Yes
Rigid frame design necessary	Yes	No	No	No
Radioactive technique	No	Yes	Yes	Yes

Tab. 1: Comparison of various weight gauge technologies.

High stand-off: thick and heavy materials

This section illustrates the capability of M-Ray based gauges to deal with very thick and heavy materials. A straightforward measurement case has been setup. A pile of various-colored synthetic nonwovens has been placed in between the upper and lower head of an M-Ray enabled weight gauge. For the experiment, a Hammer-IMS Marveloc 602-CURTAIN-C has been used. The total thickness of the pile is 47 mm. Its basis-weight is 9.6 kg/m2. Fig. 2 shows the setup.

During a time-frame of 40 seconds, a piece of regular copy paper has been inserted and re-inserted multiple times. During this operation, the pile of nonwovens has remained permanently in place. The figure below shows the response of the sensor. It can be seen that the sensor stays responsive, even at this high stand-off distance and while measuring through a pile of various-colored nonwovens of almost 10000 gsm. Moreover, the copy paper's grammage is displayed without any distortion effects.

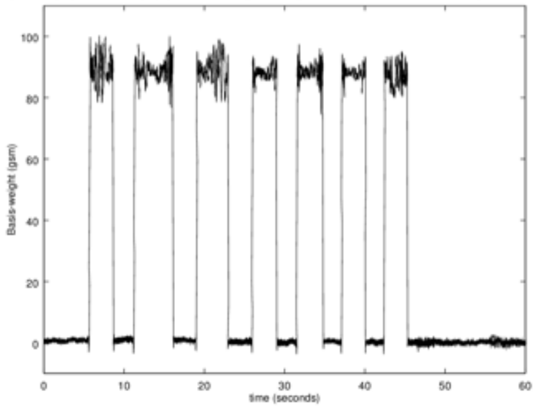

Fig.3: Graph showing the effect of repeatedly adding and removing a piece of copy paper in the measurement gap while continuously measuring a thick and heavy stack of various-colored synthetic nonwovens (thickness: 47 mm, basis-weight: 9.6 kg/m^2). Note that the sensor is zeroed before introducing the piece of paper.

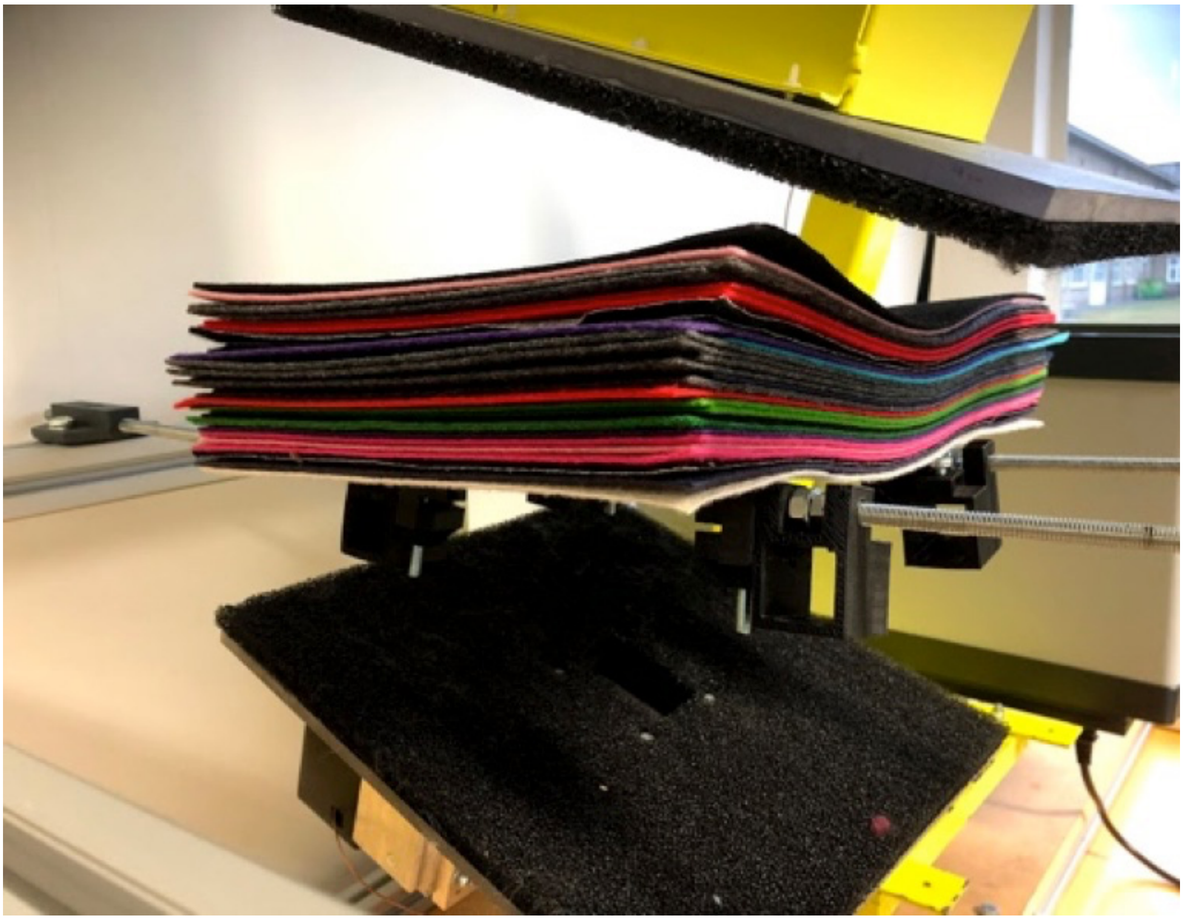

Fig. 2: Picture of an M-Ray weight measurement of a 47 mm thick, 9.6 kg/m^2 stack of various-colored synthetic nonwoven products, placed between the transmit and receive antennas.

Multi-head measuring stands for economically affordable high-coverage measuring

As introduced before, the cost of a M-Ray based measuring system does not multiply when multiple heads are used within this system. The reason for that is that the processing device, which is shared between multiple heads, is the main cost driver and not the cost of the individual heads. This enables the creation of multi-head M-Ray based measuring devices. One of these devices, the Marveloc 602-CURTAIN-O, is shown below. The blue dashed lines indicate the places where the M-Ray heads are located. Such a solution enables a higher material coverage.

[5] discusses the setup of an experiment for using a similar, yet smaller, 4-headed CURTAIN system together with a conveyor belt system to obtain a 100 percent scan of a nonwoven. Such a multi-head system can be used in lab-facilities to validate the quality of a nonwoven in an offline setting. The four heads clearly have an advantage here since they obtain a 2D view of the nonwoven in 1/4th of the time a single-headed system would take.

Application areas

Multi-head M-Ray based measurement systems can be applied in the market of technical textiles at various sites in the production process. Fig. 6 show three interesting application domains: in a lamination line, in a coating line right after the coating knife and, last but not least, in or after the formation stage of a non-woven production line. In this last application domain, the benefits of high stand-off are clearly an advantage, enabling producers to have an early visual on the uniformity of the formation process even when the web is still uncompressed. Installations of the aforementioned applications are typically connected to a panel pc to give the operator an intuitive visual. Fig. 7 shows a screenshot taken from a Marveloc 602-CURTAIN-O in a nonwoven production line.

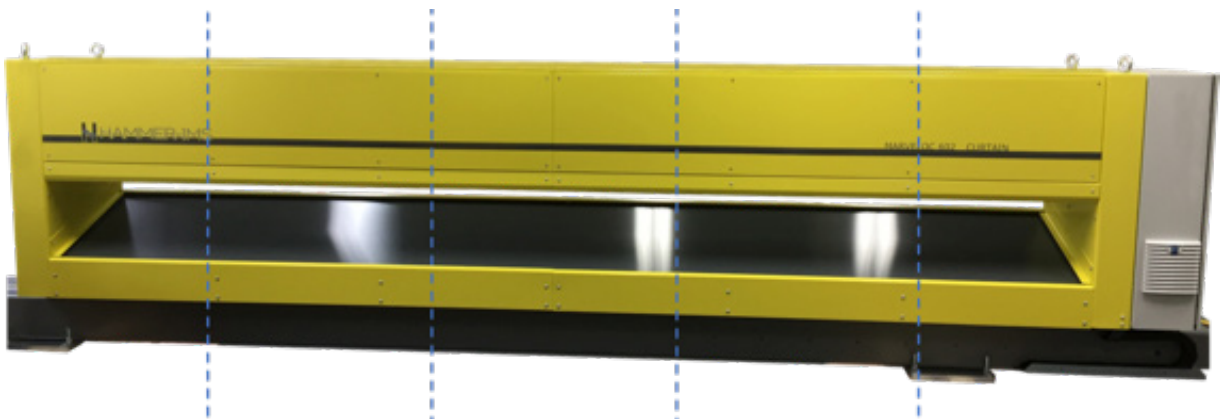

Fig.4: Industrial version of the Marveloc 602-CURTAIN-O basis-weight gauge. The 'CURTAIN' contains four measuring heads, as indicated by the blue dashed lines. This CURTAIN is more than 4.5 meters wide.

Fig.5: Experiments with a four-headed M-Ray system and belt drive, enables a full 2D view of a sample material [5]. Top: setup. Bottom: scan results.

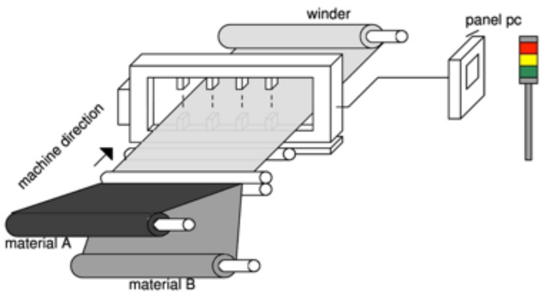

Fig. 6.a: An application case of M-Ray-based basis-weight measuring on a laminated product.

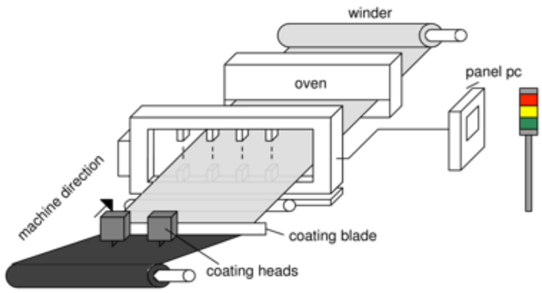

Fig. 6.b: An application case of M-Ray-based basis-weight measuring in a coating line.

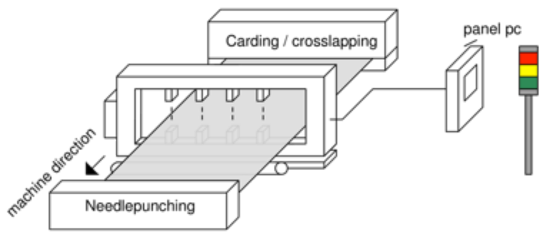

Fig. 6.c: An application case of M-Ray-based basis-weight measuring near the formation stage but before bonding. Thanks to the high stand-off distance of the technology, the gauge can also be positioned in the line where the web is still uncompressed, e.g. in between carding stages or cross-lapping stages.

Fig. 7: Screenshot taken from the panel PC during normal working conditions in a nonwoven production line.

Measurement of coating layer basis-weight

A measurement case is now explained to give a view on the reproducibility of an M-Ray based measuring system. Fig. 8 shows a partially coated cotton sheet of 150 gsm. The coating layer is an acrylic paint of which a single layer is applied by means of a cotton roller. Next, the sample is suspended in a Marveloc 602-CURTAIN-C weight gauge. The gauge scans back and forth multiple times over the sheet (along the scan line as shown in Fig. 8), yielding the scan data as shown in Fig. 9. The upper graph represents the mean weight over a total of 36 scans. The lower graph represents the standard deviations obtained during these 36 scans. The reproducibility of the measurement is therefore between 1 gsm (uncoated area) and 2 gsm (coated area).

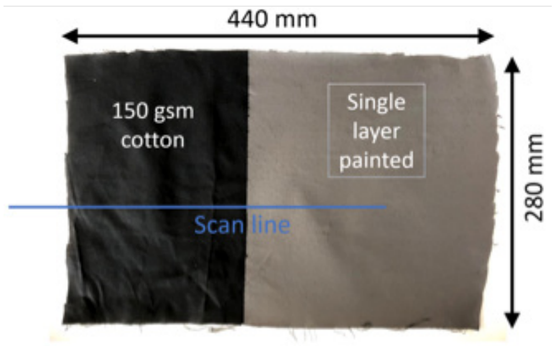

Fig. 8: Picture of the coated cotton sample which is used in the measurement results of Fig. 9. The blue line denotes the path the scanner has taken.

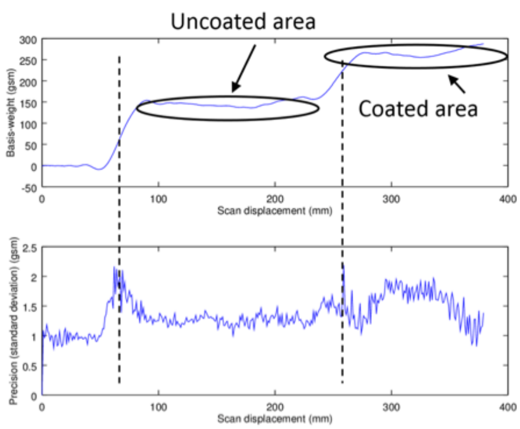

Fig. 9

Conclusion

The M-Ray technology and its implementations such as the Marveloc 602-CURTAIN, enables new applications in the nonwoven and textile converting industries. The technology enables the measurement of very thick nonwovens at early stages in the nonwoven formation process but also responds to the demands for cleaner and safer solutions for coating and lamination.

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