

SUSTAINABLE SURFACE ENGINEERING: EFFECTS OF YARN COMPOSITION AND FUNCTIONALITY ON ROUGHNESS

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Abstract: Sustainability is closely tied to material surface roughness because it directly impacts material choice, the functional and aesthetic properties of textiles, and the environmental footprint of textile manufacturing. By optimizing surface roughness through sustainable practices (using recycled yarns, eco-friendly procedures, yarns with improved functionality, etc.) the overall environmental impact of textile production can be significantly reduced. This study investigates the surface roughness of materials, which plays a crucial role in determining both the tactile and functional properties of fabrics. Using the PCE RT-2000 roughness meter, surface roughness measurements were taken for different materials produced of specific yarns different in composition and functionality. Results show that polyamide-based yarns are generally smoother than polyester yarns. Functional treatments applied to polyamide yarns, such as antibacterial or water permeability treatments, tend to reduce roughness, resulting in smoother textures. In contrast, polyester yarns display higher roughness, particularly in the horizontal direction, which may be advantageous for certain textile applications. The impact of elastane component on yarn roughness varies based on material type and the applied treatments, with polyester and specific polyamide treatments showing more pronounced changes.

Key words: surface roughness, sustainability, material, polymer, functional, composition, yarn

1. INTRODUCTION

Roughness refers to the small-scale irregularities or variations on the fabric's surface. Roughness, on a microscopic level, defines the texture, impacting the fabric's look, touch, and suitability for specific applications [1]. In textiles, this characteristic is essential, as it significantly affects both the feel and functionality of fabrics. A textile's roughness can be influenced by fiber composition, yarn structure, fabric construction or finishing process. The fibre composition, along with the fiber's thickness and structure, play important role in roughness. Wool, for example, generally has a rougher texture than cotton, whereas synthetic fibers can be designed with specific textures. As far as the yarn structure is concerned, the number of twists, yarn evenness or diameter are parameters that also influence surface roughness. Fabric construction, together with the type of knit or weave also affect the surface. On average, woven fabrics tend to have a more consistent surface, while knitted fabrics show varied textures. Some finishing processes are conducted in order to change the material appearance, as well as the surface roughness. For example, materials can be treated with processes like brushing, calendering, or sanding to modify surface qualities.

Roughness measurement is essential for quality control and for tailoring textile properties to specific applications. Various methods have been developed to accurately assess textile roughness. These can be broadly categorized into contact and non-contact techniques. In recent years, various advanced methods have been developed to remain at the cutting edge of roughness measurement, especially in textile applications. In their studies [2]-[4], the researchers highlighted different methods, outlining instrumentation, measurement techniques, advantages, and limitations, as well as the types of textile samples analyzed. For instance, the x-ray microscope is a contact-based instrument that enables detailed microscopic analysis without damaging the textile tissue. It also accounts for environmental factors like humidity and temperature, and allows layer-by-layer assessment of textiles, though it is noted for being complex and expensive. The van der Pauw method with electrodes also employs a contact approach and offers basic measurements without requiring costly hardware. This method is versatile, providing information beyond surface roughness and allowing layer-by-layer analysis of both woven and knitted samples. However, similar to the x-ray microscope, it is considered complex and expensive. Non-contact methods also include scanning electron microscopy (SEM) and atomic force microscopy (AFM), each suited to different types of textiles. SEM, utilizing electron beams, produces high-contrast two-dimensional images with good depth of field, but requires a vacuum environment and is typically used with nonwoven textiles.

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Conversely, AFM uses lasers to create three-dimensional images on a nanometric scale, offering higher resolution but slower processing times compared to SEM. AFM also demands more restrictive sample preparation. To conclude, these methods collectively provide a range of roughness measurement solutions tailored to different textiles and experimental needs, with each technique offering a balance between precision, complexity, and cost.

Sustainability is closely tied to material surface roughness because it directly impacts material choice, the functional and aesthetic properties of textiles, and the environmental footprint of textile manufacturing. By optimizing surface roughness through sustainable practicess - such as using recycled fibers, eco-friendly treatments, improved functionality of material and energy-efficient finishing techniques, the overall environmental impact of textile production can be significantly reduced. Our previous studies in the field [5]-[7] were focused at the investigation of subjective methods to determine the material surface characteristics, as well as comparison with the results of instrumental testing. The intention of this study is to observe the effect of yarn parameters on material roughness (composition, structure and functionality) to give an important input in the ongoing mission to make the production and use of textiles sustainable.

2. EXPERIMENT

In this study, a selection of knitted materials designed for sportswear production was tested for surface roughness. The materials were produced using different yarns and maintaining the same knit – single jersey. The yarns differ in fibre raw material (polyamide, polyester), type of yarn (conventional, recycled, functional) and production technique (with or without elastane-plating). The structure of the materials tested is shown in Figure 1, while the details are presented in Table 1.

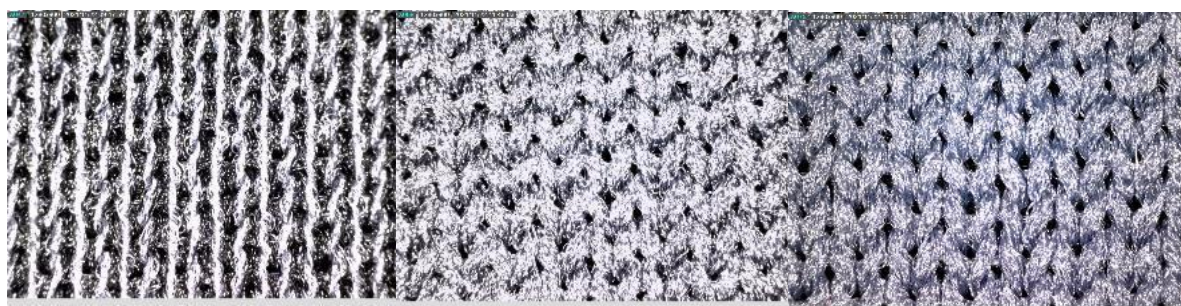


Figure 1 –Typical material structure

Table 1 –Material description

Material ID	Yarn description	Yarn count
Y1	100% polyamide, conventional yarn	18 tex
Y2	100% polyester, standard	18 tex
Y3	100% polyamide, recycled yarn	18 tex
Y4	100% polyamide, functional yarn - antibacterial treatment	18 tex
Y5	100% polyamide, functional yarn - water permeability	15 tex
Y6	100% polyamide, functional yarn - heat transfer	17 tex
Y7	100% polyester, functional yarn - hollow fiber	19 tex
Y1 + EA	100% polyamide, conventional yarn + 100% EA	18 tex + 44 dtex
Y2 + EA	100% polyester, standard + 100% EA	18 tex + 44 dtex
Y3 + EA	100% polyamide, recycled yarn + 100% EA	18 tex + 44 dtex
Y4 + EA	100% polyamide, functional yarn - antibacterial treatment + 100% EA	18 tex + 44 dtex
Y5 + EA	100% polyamide, functional yarn - water permeability + 100% EA	15 tex + 44 dtex

Y6 + EA	100% polyamide, functional yarn - heat transfer + 100%	17 tex + 44 dtex
Y7 + EA	100% polyester, functional yarn - hollow fiber + 100%	19 tex + 44 dtex

The PCE RT-2000 roughness meter was used to measure various parameters of textile samples.

Before measuring, it was essential to identify the front and back of each sample and determine the vertical and horizontal directions of the construction loops. This is done by analyzing each sample under a microscope. The roughness meter generates a graph where the x-axis represents the length of the sample in millimeters, and the y-axis shows the peaks and valleys in micrometers. A reference mean line, often positioned to balance the areas above and below it, is used to derive the measurements. This device calculates different parameters:

- Maximum Profile Peak Height (Rp)
- Maximum Profile Valley Depth (Rv)
- Maximum Height of Profile (Rz)
- Mean Height of Profile Elements (Rc)
- Arithmetical Mean Deviation of Assessed Profile (Ra)
- Root Mean Square Deviation of the Assessed Profile (Rq)
- Total roughness depth (Rt) and
- Asymmetry parameter (Rsk).

Arithmetical Mean Deviation of Assessed Profile (Ra) is the parameter that is most helpful and frequently used to analyze the surface structure. The absolute values of the profile variations Z1, Z2, ... Zn from the mean line in the evaluation length are averaged mathematically to produce this number. Ra is the widely accepted and applied roughness parameter and is generally used to assess surface roughness. Therefore, the focus within this paper was placed on this parameter.

3. RESULTS AND DISCUSSION

The results of the roughness measurement for the materials produced of yarns Y1-Y7, without addition of elastane (EA) are shown in Figure 2.

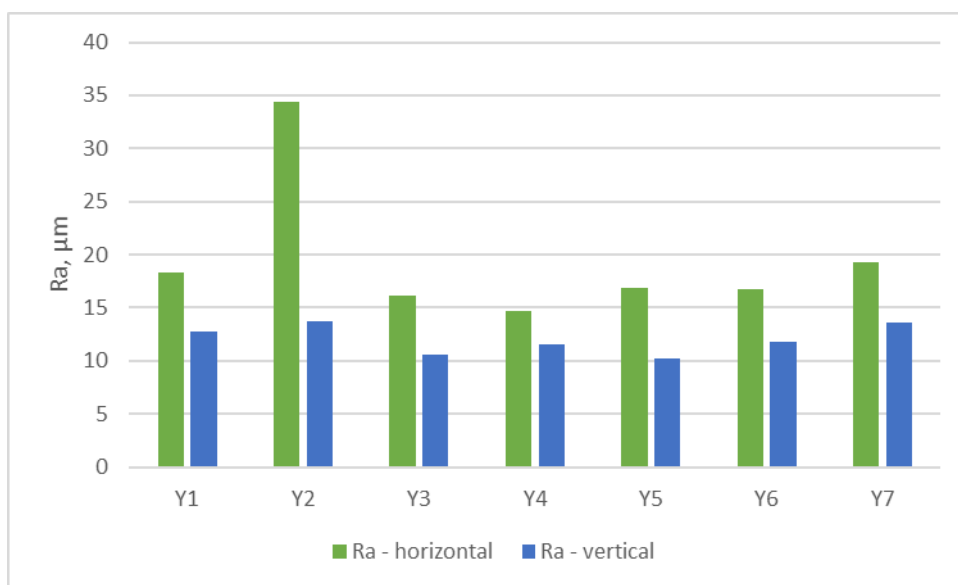


Figure 2 –Ra values for materials without EA measured in both directions

As seen from Figure 2, polyamide-based yarns typically display moderate roughness, with horizontal roughness being greater than vertical roughness. The differences between horizontal and vertical roughness might be due to the alignment of the yarn filaments during production. For instance, Y1, a conventional 100% polyamide yarn, has a horizontal roughness of 18.35 μm and a vertical roughness of 12.79 μm . In comparison, Y3, made from recycled 100% polyamide, shows lower roughness, with 16.14 μm horizontally and 10.54 μm vertically. Y4, a functional polyamide yarn treated for antibacterial properties, has a horizontal roughness of 14.64 μm and a vertical roughness of 11.54 μm , indicating it is smoother than conventional polyamide. Y5 and Y6, functional polyamide yarns designed for water permeability and heat transfer, display similar roughness values of 16.90 μm and 16.70 μm horizontally, respectively. These polyamide yarns generally have moderate roughness, maintaining a balanced surface structure that could be advantageous for applications like textiles and functional treatments. Regarding polyester-based yarns, Y2, made from 100% standard polyester, exhibits the highest horizontal roughness at 34.44 μm and a vertical roughness of 13.71 μm . This indicates that Y2 has a significantly rougher surface, especially in the horizontal direction, compared to polyamide-based yarns. The different filament structure of polyester may contribute to more prominent surface texture during manufacturing. Y7, a 100% polyester yarn with a hollow fiber functional treatment, has a moderate roughness of 19.31 μm horizontally and 13.60 μm vertically, making it rougher than the polyamide-based yarns.

When examining the impact of functional yarn treatments, different behaviors are observed. Y4, the antibacterial-treated polyamide yarn, has relatively low roughness values, with 14.64 μm horizontally and 11.54 μm vertically, suggesting that the treatment smooths the surface compared to conventional polyamide yarns. Y5, designed for water permeability, has a smooth texture with a horizontal roughness of 16.90 μm and a slightly smoother vertical roughness of 10.21 μm , likely designed for better fluid transport. Y6, which is engineered for heat transfer, shows similar roughness to Y5, with 16.70 μm horizontally and 11.84 μm vertically. Its texture remains consistent, likely optimized to enhance thermal properties without significant changes to surface roughness. In terms of measurement direction, polyamide-based yarns tend to show a larger difference between horizontal and vertical roughness (e.g., Y1, Y2, Y7), with horizontal roughness being noticeably higher than vertical roughness. This may be due to filament alignment or the manufacturing process, which could cause more texture to develop in the horizontal direction, especially during yarn production. However, Y3 (recycled polyamide) and Y5 (water permeability) show a smaller difference in roughness between the two directions, indicating a more uniform surface texture.

When elastane yarn (EA) is plated into the material structure, there is a decrease in roughness for some yarns, Fig. 3. Specifically, yarn Y3 (recycled yarn), yarn Y5 (functional yarn for improved water permeability), and yarn Y2 (conventional yarn) all exhibit a reduction in surface roughness. This suggests that elastane component may act as a smoothing agent, particularly for polyamide-based yarns with functional treatments and for polyester standard yarn.

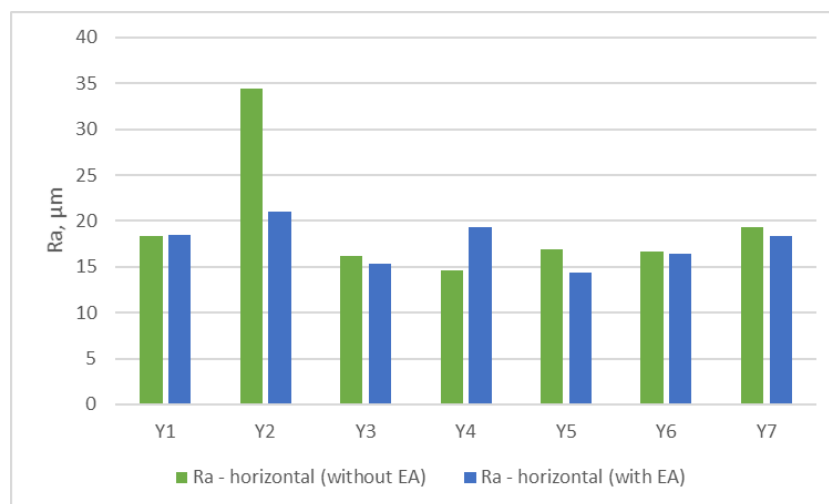


Figure 3 –Ra values for materials with and without EA measured in the horizontal direction

On the other hand, yarn Y4 (functional antibacterial yarn) shows a notable increase in roughness when elastane is applied. This indicates that the antibacterial treatment might interact differently with EA, potentially leading to a more textured or rougher surface. For the yarn Y1 (conventional polyamide yarn), yarn Y6 (functional with improved heat transfer), and yarn Y7 (hollow fiber yarn), there is minimal change in roughness with the application of EA. This suggests that addition of EA has a lesser effect on these yarns or that their surface characteristics are less sensitive to the addition. For the results of measurement in the vertical direction (Fig. 4), when EA is applied, increase in roughness is observed for all tested yarns. The smallest increase is observed for the standard polyester yarn.

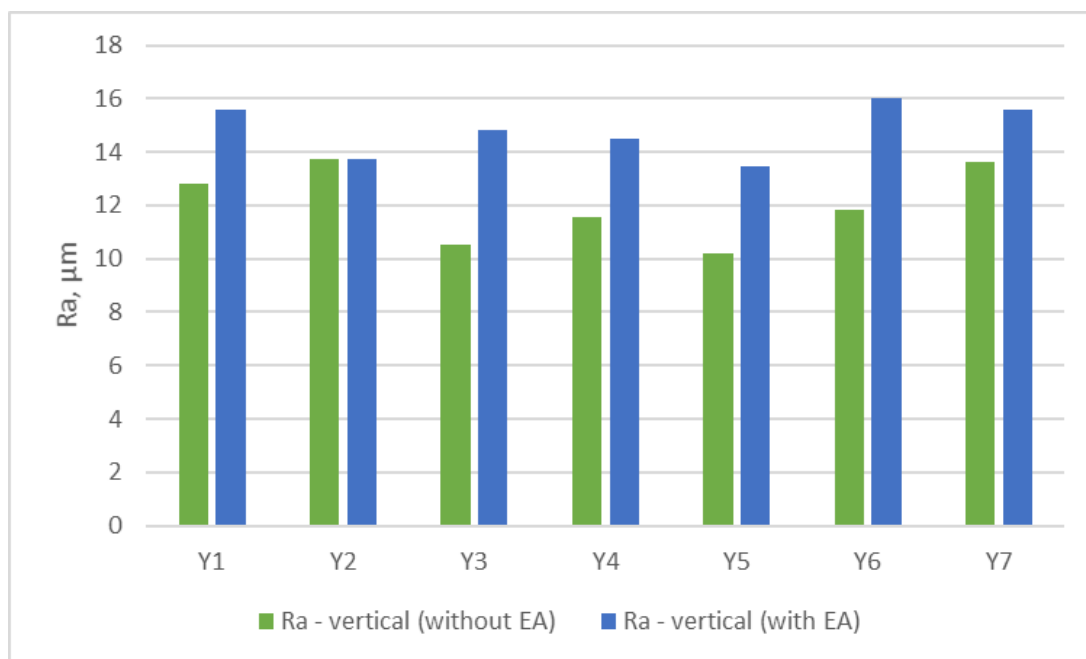


Figure 4 –Ra values for materials with and without EA measured in the vertical direction

4. CONCLUSION

The surface roughness measurements indicate clear differences between yarn materials and their treatments. Polyamide-based yarns are generally smoother than polyester yarns, and the functional treatments applied to polyamide yarns (e.g., antibacterial, water permeability) tend to reduce surface roughness, resulting in more uniform and smoother textures. The higher roughness in polyester yarns, especially in the horizontal direction, suggests different textural properties that may be beneficial for specific textile or functional applications. Overall, the results indicate that the impact of EA on yarn roughness is dependent on both the material type and the functional treatment applied to the yarn, with polyester and certain polyamide treatments showing more pronounced changes than others.

ACKNOWLEDGMENT



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