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# Effect of Workwear Fabric Fluorocarbon Coating on Changes in Tensile Properties of Sewing Threads

*Vpliv fluorokarbonskega premaza delovnih oblačil na spremembe nateznih lastnosti sukancev*

**Original scientific article**/*Izvirni znanstveni članek*
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## Abstract

This paper presents the findings of changes in the tensile behaviour of sewing threads in two-seam configuration on three different workwear fabrics, i.e. drill, duck and rip-stop structures, before and after the coating. For this research, commercially available workwear fabrics were obtained from the domestic industry and the sewing was carried out using a 40 tex core-spun polyester sewing thread. High-speed heavy-duty lockstitch sewing machines were used to construct both the superimposed (SSa) and lapped seams (LSd). The strength of sewing threads sewn in the two-seam configuration were carefully unravelled and compared with the unsewn sewing thread (UST). The effect of coating on the changes in tenacity, breaking elongation and initial modulus of the needle thread was reported. It was found that there was a significant effect of weave structure on the tenacity of the sewing thread.
Keywords: breaking elongation, tenacity, fabric coating, initial modulus, sewing threads

## *Izvleček*

*V članku so predstavljene ugotovitve o spremembah nateznih lastnosti sukancev, izločenih iz dveh različnih tipov šivov, sešitih na tkaninah za delovna oblačila, ki so se razlikovala v vezavi (platno, keper, rips). Za raziskavo so bile uporabljene tržno dostopne tkanine domače proizvodnje, namenjene za izdelavo delovnih oblačil. Za šivanje je bil uporabljen oplaščen poliestrski sukanec finoče 40 tex. Šivanje s ploskim (SSa) in zapognjenim šivom (LSd) je bilo izvedeno na visokohitrostnem šivalnem stroju za težke tkanine s prešivnim vbodom. Igelni šivalni sukanci so bili skrbno izločeni iz sešitih šivov, da bi se primerjale natezne lastnosti sukancev pred obremenjevanjem med šivanjem (UST) in po njem. Proučen je bil vpliv premaza tkanin na spremembe natezne trdnosti, pretržnega raztezka in začetnega modula šivalnega sukanca. Pokazalo se je, da vezava tkanin pomembno vpliva na natezno trdnost šivalnega sukanca in da so abrazivne poškodbe pri tkanini v vezavi rips največje, pri čemer se je po impregniranju začetni modul vseh preskusnih vzorcev bistveno izboljšal.*
*Ključne besede: pretržni raztezek, natezna trdnost, premaz tkanine, začetni modul elastičnosti, šivalni sukanci*

## 1 Introduction

Garment manufacturing is a process of transforming a two-dimensional fabric into three-dimensional apparel by bringing together dissimilar pattern pieces along with the functional and aesthetic styling to enhance the desirable features and to cover up the undesirable features of human beings. Garments' performance fundamentally depends on the fabric and sewing thread characteristics. Sewing threads are special categories of yarn engineered to pass through the sewing machine swiftly without distortion and breaking to deliver the aesthetics and performance of stitches and seams. Various sewing threads are made from cotton and polyesters fibres, e.g. staple spun, multifilament, monofilament, textured, continuous filament or core-spun yarns. Each has distinct properties and is a prime contributor to seam quality [1–2]. The sewing thread, which is about 1% of the mass of the garment, plays a key role in sewing operations. Readymade garment industries widely use either domestic or high-speed industrial sewing machines in sewing operations. During the conversion in cut and sewn garments, seams are introduced to mould, shape and transform the fabric into garments [3]. A seam comprises two or more plies of a material or materials held together by a series of stitches. Seams are used for assembling materials in the manufacture of apparel/garments. In garment construction, seam failure is considered a major problem, their occurrence generally results from poor seam selection, non-compatible sewing thread selection for the given seam type etc. The seam line affects the overall appeal of a garment. Even, straight, neat, smooth seams that are not puckered contribute to aesthetics. According to the British Standard 3870, there are eight types of seams, i.e. Class 1 (superimposed seam), Class 2 (lapped seam), Class 3 (bound seam), Class 4 (flat seam), Class 5 (decorative seam), Class 6 (edge neatening Seam), Class 7 and Class 8 [4].

A sewing thread is a smooth, strong, elastic, evenly spun ply or cabled yarn with a special finish to reduce friction and resist abrasion as it passes through the needle eye and the material in the stitching and seaming process [5]. A stitch is the formation of the interlacing of the sewing thread in a precise repeated unit. The term *stitches* denote both the thread interlocking (lock-stitch) or interlooping (chain-stitch) used to make joints between two pieces of a fabric that are sewn together. Seam parameters – seam allowance and stitch density together are known to affect the bending length and flexural rigidity of seams [6]. It is understood that during the sewing, generally two series of sewing threads are used, i.e. the needle thread and the bobbin thread. The needle thread passes through several guides, pre-tensioners, take-up lever, tension regulator, tension spring, needle eye etc. before being stitched into a seam [7]. Throughout the passageway, the needle thread is subjected to needle heating, wearing, repeated tensile stresses, torsional forces and pressure [8]. The sewing thread is repeatedly abraded against the material being sewn and the metal surfaces of the take-up lever, guides and needle eye roughly 50–80 times [9]. The degree of influence gets further enhanced with bobbin thread interlacement, fabric weight, number of plies in the seam configuration, and the surface characteristics of a sewing needle and sewing thread. Several investigators have detected that there could be around 30% to 40% strength loss in the needle sewing thread once sewn [10–11]. Moreover, with heavyweight, bulky fabrics with a higher cover factor, the damage could be even more severe. The extent of the sewing thread strength reduction is related to the magnitude of stresses acting and their ability to endure without degradation. Regarding the stitch type, lockstitch is widely used and more secure [12–15].

Poor sewing threads can seriously increase production costs by causing numerous stoppages of sewing machines, in addition to rendering the garment unusable. To accomplish good sewing performance, a sewing thread that possesses requisite physical and mechanical characteristics must be selected according to fabric characteristics and its end-use application. A core-spun sewing thread is the most preferred sewing thread, which is due to its higher strength and abrasion resistance used for sewing workwear fabrics. Among different varieties of core-spun sewing threads commercially available, a polyester-cotton core-spun sewing thread shows better performance as the polyester core gives the required strength, abrasion resistance and cotton fibres on the surface give them good heat resistance. Workwear apparel is a specialised category of clothes that serve as lifesavers and is used in applications such as military wear, hospital drapes, survival suits, firefighter clothing, chemical protective clothing etc. The workwear clothing combines a fabric of higher mass per unit area woven in a specific construction, e.g. duck, drill, rib-stop, sateen etc., followed by one or more functional finishes such as UV protection, waterproofness, air permeability, flame retardancy etc. to enhance their performance and wear comfort [16]. The widely used waterproof breathable finish given to fabrics is fluorocarbon coating [17].

Naeem et al. [18] stated in their work on the effect of the sewing speed on seam strength that seam strength decreases at different rates in superimposed and lapped seams. Furthermore, the lightweight fabric category showed maximum destruction due to the sewing speed. Akter et al. [19] reported in their investigation that sewing threads with the polyester filament core show better seam efficiency and seam strength. Rengasamy et al. [20] established in their study on dynamic sewing tension that the needle thread undergoes four major tension peaks during one sewing cycle, i.e. bobbin thread withdrawal, needle piercing the fabric, tightening of the needle thread around the shuttle and stitch tightening. They also reported that spun polyester threads and polyester filament displayed the lowest and the highest tightening tension. Rudolf [21] considered the properties of 100% PES core-spun sewing threads at different stitching speeds and reported that the loading in the sewing process causes structural changes in thread-twisted fibres. Nayak [22] investigated the effect of Lycra percentage, type of sewing thread and silicon finish on denim fabric sewability, and reported that with an increase in Lycra percentage, the seam efficiency improves as well, whereas the needle damage and seam pucker are affected by fabric weight. Rudolf et al. [23] observed in their study that the tensile and frictional loading of the sewing threads increased with increasing sewing machine stitching speed. It was further reported that the sewing threads with a lower twist intensity show better mechanical properties. In another work, Rudolf [24] investigated and reported that the structural changes in the sewing threads are a result of the deformation of built-in fibres across the cross-section, which in turn influences breaking tenacity, breaking extension, sewing thread fineness and the initial modulus of fibres.

A good quality sewing thread with high breaking tenacity, initial modulus and good breaking elongation must be selected to achieve high efficiency from the sewing threads during the sewing operation. From the literature, it can be observed that quite a few researchers have carried out studies on sewing thread strength loss after the sewing; however, the effect of fabric physical characteristics and finishing remains unfamiliar. Since workwear fabrics are functionally finished, a requirement before being made into a garment, this research assumes the significance of finishing. As such, in this study, the effect of different weight workwear fabrics structure on the change in the tensile properties of sewing threads concerning functional finishing in superimposed seam (SSa) and lapped seam (LSd) were studied.

## 2 Experimental

### 2.1 Materials

The fabrics used in this study were 100% cotton undyed workwear fabrics, namely drill, rip-stop and duck, varying in weave structure and weight, were taken into consideration. The workwear fabrics were obtained from three different mills in India, i.e. Loyal textile mills Ltd., M/s Vaibhav Textile Mills and Balavigna Pvt. Ltd. Commercially available polyester-cotton core-spun sewing threads of 40 tex linear density were purchased from Vardhman Threads Pvt. Ltd. The sewing thread was made up of two single yarns plied together with about 40 twists/inch in Z-direction. In the study, the sewing thread was used without any modification for both the needle and bobbin thread. A Juki industrial lockstitch sewing machine – DDL 8300N model, was used for producing a balanced seam with 10 stitches/inch in the superimposed (SSa) and lapped seam (LSd) configuration. The sewing machine specifications are tabulated in Table 1. Ballpoint sewing needles of size 100 Nm manufactured by Groz-Beckert were used in this investigation.

*Table 1: Heavy-duty industrial sewing machine specification*

| Application | Heavy duty (DDL8300N) |
|---|---|
| Maximum sewing speed | 4000 rpm |
| Maximum stitch length | 5 mm |
| Needle bar stroke | 35 mm |
| Lubrication | Automatic |
| Lubricating oil | JUKI New defrix oil no. 1 |
| Feed dog | 3 row |
| Hook | Automatic-lubricating full-rotary hook |

## 2.2 Chemicals

The undyed workwear fabrics procured were subjected to the desizing and scouring process before the sewing. Following this, the workwear fabrics were separated into two halves, one half was coated with a fluorocarbon coating using padding mangles, in line with the methods specified by the manufacturer.

## 2.3 Methods

### 2.3.1 Physical characterisation of workwear fabrics

The workwear fabrics were characterised for thickness, weight, thread count and thread density (cf. Table 2). The weight of fabrics was calculated using a GSM cutter and an electronic balance. The thickness of the fabric was measured in a thickness tester under constant compressive load of 2 kPa. The warp and weft yarn counts were measured by using a Beesley's balance and the fabric construction was measured using counting glass. All these physical characterisations were performed according to the ASTM standards. The workwear fabric thread interlacement pattern is shown in Figure 1 and the symbols used to represent the test specimens are included in Table 3. The desized, scoured and uncoated drill, rip-stop and duck fabrics in superimposed seam (SSa) and lapped seam (LSd) were

*Table 2: Physical characteristics of workwear fabrics*

| S. No. | Fabric composition | Weave pattern | Thickness (mm) | Mass per unit area (g/m$^2$) | Fabric construction properties | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Thread count (tex) | | Threads in fabric (cm$^{-1}$) | |
| | | | | | Warp | Weft | Warp | Weft |
| 1 | 100% cotton | Duck (2/2) | 0.49 | 256 | 37 | 49 | 32 | 13 |
| 2 | 100% cotton | Rip-stop (1/1) | 0.52 | 238 | 30 | 37 | 37 | 21 |
| 3 | 100% cotton | Drill (3/1) | 0.71 | 309 | 37 | 49 | 36 | 22 |

| | | | |
|---|---|---|---|
| | X | | X |
| X | | X | |
| | X | | X |
| X | | X | |

a)

| | | | |
|---|---|---|---|
| | | | X |
| | | X | |
| | X | | |
| X | | | |

b)

| | | | |
|---|---|---|---|
| | | X | X |
| X | X | | |
| | | X | X |
| X | X | | |

c)

*Figure 1: a) Plain weave (rip-stop), b) drill weave and c) duck weave*

*Table 3: Nomenclature of test specimens*

| S. No. | Symbol | Specimen description | S. no. | Symbol | Specimen description |
|---|---|---|---|---|---|
| 1 | UST | Unsewn sewing thread | 8. | FRS-BC-LSd | Uncoated rip-stop fabric sewn in lapped seam |
| 2. | FDR-BC-SSa | Uncoated drill fabric sewn in superimposed seam | 9. | FRS-AC-LSd | Coated rip-stop fabric sewn in lapped seam |
| 3. | FDR-AC-SSa | Coated drill fabric sewn in superimposed seam | 10. | FDK-BC-SSa | Uncoated duck fabric sewn in superimposed seam |
| 4. | FDR-BC-LSd | Uncoated drill fabric sewn in lapped seam | 11. | FDK-AC-SSa | Coated duck fabric sewn in superimposed seam |
| 5. | FDR-AC-LSd | Coated drill fabric sewn in lapped seam | 12. | FDK-BC-LSd | Uncoated duck fabric sewn in lapped seam |
| 6. | FRS-BC-SSa | Uncoated rip-stop fabric sewn in superimposed seam | 13. | FDK-AC-LSd | Coated duck fabric sewn in lapped seam |
| 7. | FRS-AC-SSa | Coated rip-stop fabric sewn in superimposed seam | | | |

symbolically represented as FDR-BC-SSa, FRS-BC-SSa, FDK-BC-SSa and FDR-BC-LSd, FRS-BC-LSd, FDK-BC-LSd, while the desized, scoured and fluorocarbon coated drill, rip-stop and duck fabrics in superimposed seam (SSa) and lapped seam (LSd) were symbolically represented as FDR-AC-SSa, FRS-AC-SSa, FDK-AC-SSa and FDR-AC-LSd, FRS-AC-LSd, FDK-AC-LSd.

#### *2.3.2 Desizing and scouring process*

To remove the starch applied during the weaving process, the workwear fabrics were desized using the acid steeping method. In this method, the material is padded with mineral acid (sulphuric acid) 2 $cm^3$/L and stored in large vats at about 60 °C for about 45 minutes to allow the acid to hydrolyse the starch. After this, the material is thoroughly rinsed to remove the hydrolysed starch and then dried. The material to liquor ratio was maintained at 1 : 20, and laboratory-grade reagent sulphuric acid was used in this study. The scouring process is carried out to remove natural impurities such as fats, oils, pectins, pectos, ash, wax and other minerals from a greige cotton fabric for better bleaching and dyeing properties. Scouring is done by boiling the cotton material in strong sodium hydroxide (alkali) solutions for a few hours. Other reagents used to enable thorough scouring include surfactants to reduce the surface tension and an emulsifying agent to remove non-saponifiable fats and waxes held in the suspension in the liquor. In the scouring in this study, the material to liquor ratio was maintained at 1 : 20, and the chemicals used were 10% caustic soda, 15% soda ash, 15% wetting agent and 5% sequestering agent. The scouring bath temperature was maintained at 90–100 °C for 8 hours. Afterwards, the scouring bath was allowed to cool down for about 2 hours; then, the materials were removed, thoroughly rinsed and flat dried in shade.

#### *2.3.3 Padding process*

The fluorocarbon solution (Nuva HPU), procured from Clariant Chemicals Pvt. Ltd., was used for coating the workwear fabrics without any modifications. The coating recipe was made up of 60% fluorocarbon solution (Nuva HPU), 10% Printofix Thickener ECS and 30% water. The pretreated fabrics were then padded in continuous padding mangle range, followed by curing at 150 °C for 5 minutes.

#### *2.3.4 Seam preparation*

The three workwear fabrics were sewn on an industrial heavy-duty lockstitch machine with the stitch density of 2.5 mm stitch length at a constant speed of 3000 rpm to produce a balanced seam. Five replicates were sewn in each seam type in each workwear fabric, measuring about 2 meters in length. The static tension for bobbin threads was adjusted manually by trial runs to obtain a balanced stitch and maintained constant. The same sewing thread was used for needle and bobbin threads to prepare the seams. After the sewing, the needle threads were taken out for characterisation. The superimposed seam is one of the most familiar means of seaming. The most basic superimposed seam (SSa) is where one ply of a fabric is stacked upon another with thread stitching through all plies of fabric. The superimposed seam is used on many garment side seams. A lapped seam (LSd) is achieved with two or more pieces of a fabric overlapping each other. A lapped seam has commonly, yet not always, one ply of a fabric fold under itself for a finished edge. Lapped seams are common when working with leather and sewing side seams on jeans and dress shirts. The diagram of both seams is shown in Figure 2. After the sewing in the two-seam configuration above, the sewing threads in superimposed seams were removed by unravelling warp and weft yarns of the fabric and then the needle threads were separated from the seam. In lapped seams, bobbin threads were cut out and the needle thread was carefully removed for further characterisation. The mean values of the experiment results were statistically evaluated with Student's *t*-test at 95% confidence level.


*Figure 2: Seam configuratzion: a) superimposed seam (SSa) and b) lapped seam (LSd)*

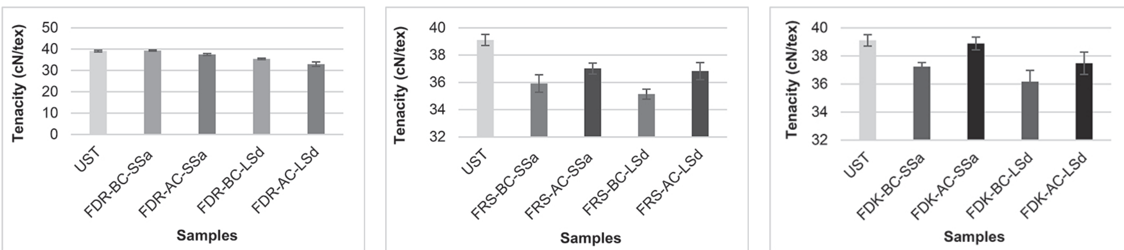
## 2.4 Characterisation

### 2.4.1 Tenacity, breaking elongation and initial modulus

The axial strength and elongation of the sewing thread determine the effectiveness of the tensile force acting on the sewing thread. Highly extensible threads are generally preferred for garments. These parameters are necessary for good seam quality. The tensile testing of the needle thread before and after the sewing was performed at a gauge length of 100 mm with a traverse speed of 500 mm/min on an Instron 3369 tensile testing machine as per ASTM standard D2256. An average of thirty tests were carried out for each sample and the mean values were reported (Figures 3–8). The threads extracted from the seams before and after the coating were tested, and compared with the unsewn sewing thread.

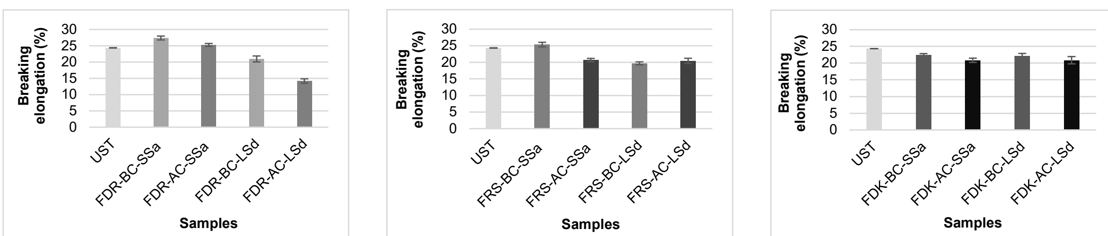
# 3 Results and discussion

The tensile properties of the polyester-cotton core-spun sewing thread, in superimposed and lapped seams, before and after the sewing of coated and uncoated workwear fabrics are shown in Figures 3–8. It can be observed that there is a considerable change in tenacity, breaking elongation and initial modulus of the sewing threads after the sewing of workwear fabrics.



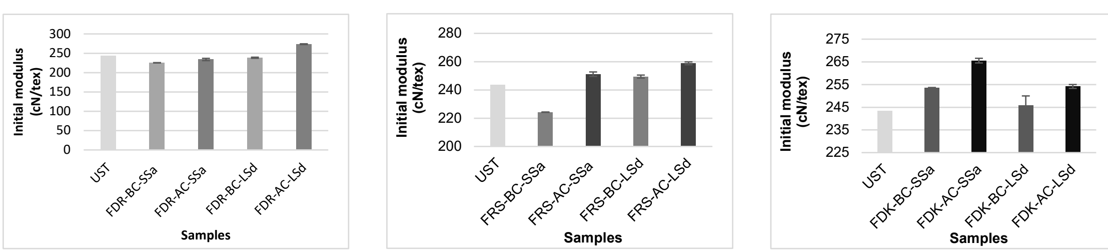

a) b) c)

*Figure 3: Effect of coating and seam configuration on tenacity of (a) drill, (b) rip-stop and (c) duck fabrics*




a) b) c)

*Figure 4: Effect of coating and seam configuration on breaking elongation of (a) drill, (b) rip-stop and (c) duck fabrics*




a) b) c)

*Figure 5: Effect of coating and seam configuration on initial modulus of (a) drill, (b) rip-stop and (c) duck fabrics*

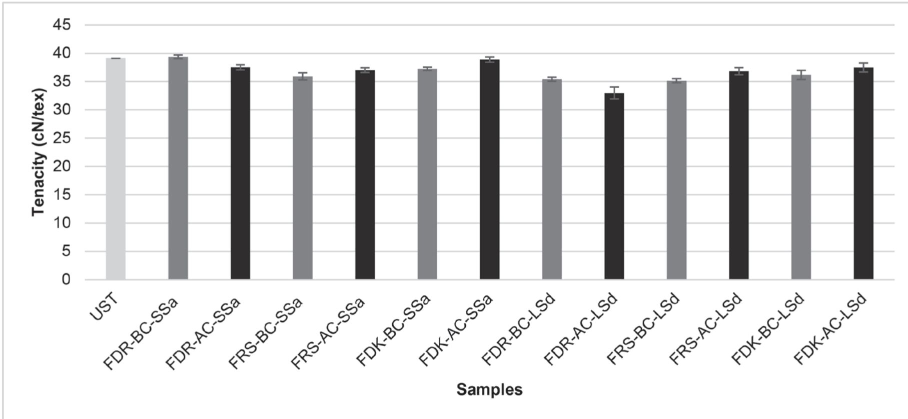



*Figure 6: Comparison of tenacity changes between sewing threads from bobbins and sewing threads extracted from workwear fabrics*

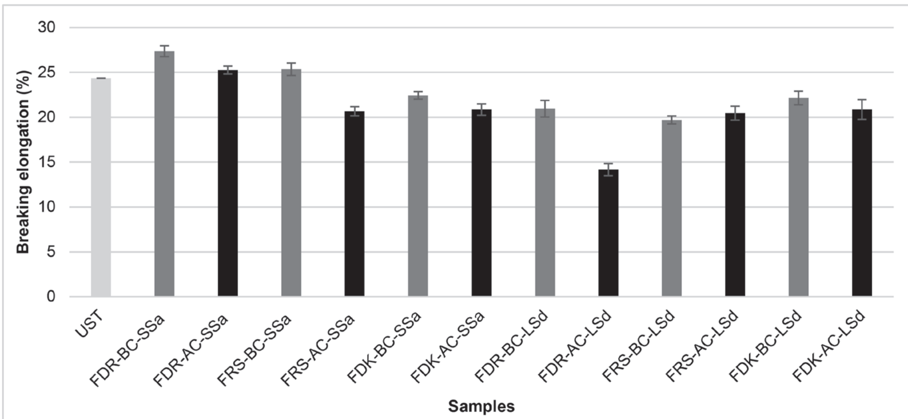



*Figure 7: Comparison of breaking elongation changes between sewing threads from bobbins and sewing threads extracted from workwear fabrics*

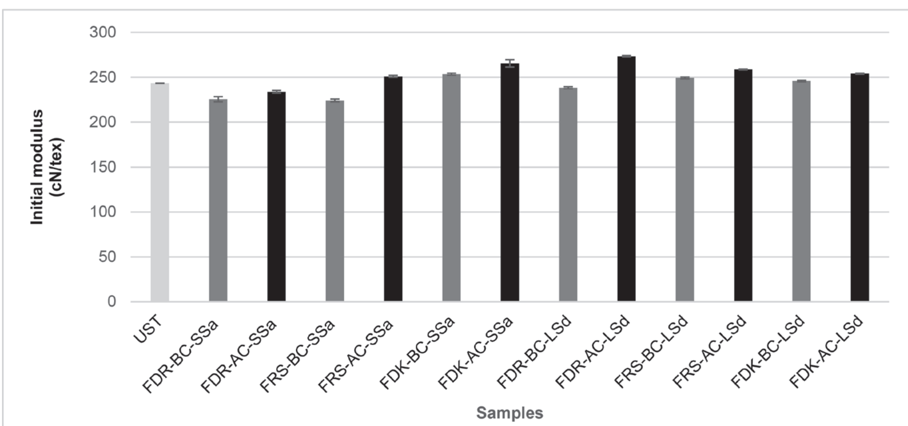



*Figure 8: Comparison of initial modulus changes between sewing threads from bobbins and sewing threads extracted from workwear fabrics*

## 3.1 Effect of tenacity

The tenacity changes in the sewing threads before and after the sewing of uncoated and coated workwear fabrics (drill, rip-stop and duck fabrics) are shown in Figures 3a, 3b and 3c. From the results, it is clear that the sewing threads lost their strength after the sewing. The highest strength reduction was observed in rip-stop workwear fabrics and the smallest strength reduction was observed in drill workwear fabrics. The strength reduction in drill workwear fabric was about 4.7% in the test specimen FDR-AC-SSa and 6.89% in the specimen FDR-AC-LSd, both being significant at 95% confidence level. An exact opposite trend was observed with rip-stop workwear fabrics. The coated fabric sewing thread strength increased by 3.06% in the test specimen FRS-AC-SSa and 4.81% in the specimen FRS-AC-LSd. However, the strength increase was significant for the specimen FRS-AC-LSd and insignificant for the FRS-AC-SSa test specimen. An almost similar trend was observed with duck workwear fabrics with strength improvements of 4.40% in the specimen FDK-AC-SSa and 3.62% in the specimen FDK-AC-LSd. The strength improvement was statistically significant for the former and insignificant for the latter specimen.

The tenacity loss percentage observed among workwear fabrics (Figure 6) was 8.16%, 4.76% and 0.6%, respectively, for the specimens FRS-BC-SSa, FDK-BC-SSa and FDR-BC-SSa with respect to the UST specimens. With the test specimens FRS-BC-SSa and FDK-BC-SSa, the abrasive damage was much higher compared to FDR-BC-SSa. This behaviour could be attributed to the weave structure. Rip-stop being a plain-woven structure with threads interlacing alternately, the core-spun polyester sewing thread is subjected to higher abrasive damage as it enters the fabric. Similarly, the duck weave is a plain structure with two yarns working together in the warp direction, meaning that the abrasive damage is intermediate compared to rip-stop fabrics. Nevertheless, drill fabrics with one interlacement for every four repeating threads underwent the least abrasive damage. A significant increase in tenacity in the specimen FDR-BC-SSa could result from variations in the sewing thread. Furthermore, all the specimens considered showed a significant tenacity loss in lapped seams. The specimens FDR-BC-LSd, FRS-BC-LSd and FDK-BC-LSd showed 9.43%, 10.15% and 7.52% tenacity loss compared to UST. This behaviour could be attributed to the higher number of layers in the seam configuration leading to higher abrasion. The tenacity loss of sewing threads removed from the coated workwear fabric amounted to 6.89% and 4.7% for the specimens FDR-AC-SSa and FDR-AC-LSd., whereas all other specimens showed an improvement in tenacity after the coating, which could be a consequence of inherent lubricity characteristics of fluorocarbon [17]. For the specimens FRS-AC-LSd, FDK-AC-LSd, FRS-AC-SSa and FDK-AC-SSa, the percentage increase was 4.81%, 3.62%, 3.06% and 4.40%, respectively.

### 3.2 Effect of breaking elongation

The changes in the breaking elongation of the sewing threads before and after sewing the uncoated and coated workwear fabrics (drill, rip-stop and duck fabrics) are shown in Figures 4a, 4b and 4c. The results did not show any clear trend, though in most specimens, the sewing threads lost their breaking elongation after the sewing. The highest breaking elongation reduction was observed in rip-stop workwear fabrics and the smallest breaking elongation reduction was observed in duck workwear fabrics. The breaking elongation reduction in drill workwear fabrics was about 7.68% in the test specimen FDR-AC-SSa and 32.36% in the specimen FDR-AC-LSd, both being significant at 95% confidence level. With rip-stop workwear fabrics, the loss in breaking elongation was 18.46% for the test specimen FRS-AC-SSa. However, for the specimen FRS-AC-LSd, the breaking extension increased by 3.81%. While the loss of breaking extension was significant for the former specimen, the increase in breaking extension for the latter specimen was insignificant. Duck workwear fabrics showed a reduction in breaking elongation across all specimens considered. The breaking elongation loss percentage after sewing coated duck fabrics was 7.04% and 5.78%, respectively, in the specimens FDK-AC-SSa and FDK-AC-LSd. The reduction in breaking elongation was statistically significant for the former and insignificant for the latter specimen at 95% confidence level.

The breaking elongation loss percentage observed at the workwear fabric specimen (cf. Figure 7) FDK-BC-SSa was 7.81%, which could be attributed to the thermal damage of the core-spun polyester sewing thread. For the specimens FDR-BC-SSa and FRP-BC-SSa, there was an increase in breaking elongation by 12.41% and 4.15%, respectively, which can be attributed to the high extensibility of core-spun sewing threads. The breaking elongation loss percentage for the specimens FDR-BC-LSd, FRS-BC-LSd and FDK-BC-LSd were 13.93%, 19.06% and 8.99%, respectively, indicating higher mechanical restraint due to the presence of three layers of a fabric in the seam construction, which deteriorated the amorphous region of the polyester sewing thread [21].

A significant loss in breaking extension was observed in all test specimens after the coating except at the specimens FRS-AC-LSd and FDK-AC-LSd, which showed an improvement of 3.81% and 5.78% compared to their uncoated counterparts. Conversely, the breaking extension loss percentage was 7.68%, 18.46%, 7.04% and 32.36% for the specimens FDR-AC-SSa, FRS-AC-SSa, FDK-AC-SSa and FDR-AC-LSd. This can be attributed to the reduced mobility of threads and the increase in the coefficient of friction between the fabric and sewing thread leading to lower breaking extensibility.

### 3.3 Effect of initial modulus

The changes in the initial modulus of sewing threads before and after sewing the uncoated and coated workwear fabrics (drill, rip-stop and duck fabrics) are shown in Figures 5a, 5b and 5c. From the results, it is clear that the initial modulus of sewing threads sewn on coated fabrics across all three workwear fabrics improved after the sewing. The highest initial modules improvement was observed in drill workwear fabrics and the smallest improvement was observed in rip-stop workwear fabrics. The initial modulus in drill workwear fabric increased by about 3.7% in the test specimen FDR-AC-SSa and 14.70% in the specimen FDR-AC-LSd, both being significant at 95% confidence level. In rip-stop workwear fabrics, the initial modulus increase was 12.01% in the test specimen FRS-AC-SSa and 3.76% in the specimen FRS-AC-LSd. The initial modulus increase was significant for both specimens. Furthermore, in duck workwear fabrics, the initial modulus increase was 4.71% in the specimen FDK-AC-SSa and 3.36% in the specimen FDK-AC-LSd. The improvements were statistically significant for both specimens.

The initial modulus loss percentages among workwear fabrics (cf. Figure 8) were 7.37% and 7.93%, respectively, for the specimens FDR-BC-SSa and FRS-BC-SSa. The specimen FDK-BC-SSa showed an improvement by 4.13% compared to UST. Further, the loss percentage of 2.10 % was observed for the specimen FDR-BC-LSd, whereas the specimens FRS-BC-LSd and FDK-BC-LSd showed an improvement of 2.41% and 0.96% compared to UST. This behaviour could be attributed to the change in the viscoelastic properties of the sewing thread during dynamic loading as observed by Rudolf [21] in the study of polyester core-spun sewing threads.

After the coating, the initial modulus of all test specimens considered improved significantly. The improvements were 3.71%, 12.01%, 4.71%, 14.71%, 3.76 and 3.36%, respectively, for the specimens FDR-AC-SSa, FRS-AC-SSa, FDK-AC-SSa, FDR-AC-LSd, FRS-AC-LSd and FDK-AC-LSd, the specimen FDR-AC-LSd showing the highest increase and the specimen FDK-AC-LSd the smallest improvement. The latter can be attributed to the high flexibility of core-spun sewing threads, which remain flexible even after coating.

## 4 Conclusion

In this study, the effects of fabric structure, seam configuration and coating on tenacity, breaking elongation and initial modulus were investigated. During high-speed sewing, the tensile characteristics of needle threads were influenced by the fabric structure. The sewing process brought about elastic deformation in sewing threads. Tenacity and breaking elongation were significantly affected by the fabric weave structure. Moreover, drill fabric structures with longer floats in the weave structure imparted the least abrasive damage to polyester sewing threads among all structures considered. A higher mechanical restraint was observed in the lapped seam configuration due to the presence of three layers in the seam compared to the superimposed seam construction. After the coating, the initial modulus of all test specimens considered improved significantly, suggesting the flexibility of core-spun sewing threads.

### Declaration of conflict of interest

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