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Impact of Sewing Needle Coating on Needle Heating

Adnan Mazari * and Funda Buyuk Mazari

Department of Clothing, Faculty of Textiles, Technical University of Liberec, 46117 Liberec, Czech Republic; fundabuyuk@hotmail.com

* Correspondence: adnan.ahmed.mazari@tul.cz

Abstract: Sewing needle heating is a common problem in the sewing of technical and medical textiles. The hot needle causes burnt spots on fabric, the breakage of thread and weak seam strength. The most economical way of reducing needle heat is to use thread lubrication, needle coating or air cooling. Multiple coated needles are commercially available on the market, including those coated with Nickel, Chromium, Ceramic or Titanium Nitride, etc. In this research, the needles are coated with Diamond-Like Carbon (DLC) for improved frictional properties. Commercially available needles are compared with the DLC-coated needles for sewing performance and needle heat. The results shows a significant decrease in needle friction as compared to the classic needle but the commercial needles coated with Titanium Nitride still performed better. Also, the coating of DLC peeled off in a shorter time during high-speed sewing; within 15 cycles of continuous sewing, there was a significant loss of coating near the needle eye. The novel DLC technique can be of future benefit to sewing needles, offering an improved technique and more cost-effective approach. The results for the DLC-coated needles showed a 9–12% reduction in the needle temperature and, overall, a 12–14% rise in the tensile strength of the thread after sewing as compared to sewing by classical needles.

Keywords: needles; sewing; heat; DLC; assembly

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1. Introduction

There is a significant increase in demand for the production of clothing, technical garments, car seat covers, bags and even shoes. All these fields of textiles require one major device and that is the sewing machine. Limited time in which to produce a large quantity of products with defined functional properties is a factor for all developed producers. But the major issue for fast sewing is unavoidable needle heat, resulting in low seam strength, damage to the textiles and an overall decrease in production. To resolve this issue, the most widely used system is to either lubricate the thread, use forced cooling or coat the needle to ensure it has a low coefficient of friction [1–5].

In last decade, the growth in improvements in the sewing process has been quite significant. With many products produced by sewing every day, any small improvement in the process can bring great advantages for researchers and industrial partners. In the sewing process, the abrasion between textile products like the thread and fabric and the needle and machine parts is considered to be the main factor causing weaker seams [6]. The functional performance of the seam, productivity loss due to thread breakage and the aesthetic looks of the sewn products are all important, especially for the companies producing technical garments. It is necessary to understand in depth the causes of the problems and possible improvement to the sewing process.

The lockstitch has at least two threads. One comes from the upper spool and the other is fed from the shuttle inserted under the needle. The stitch is made in the middle of the textile material and is considered much stronger than the chain stitch; these stitches are a top priority when strength is required [7]. Figure 1 shows a classical lockstitch sewing machine.

Figure 1. Lockstitch sewing machine.

Many researchers [8–10] have studied these parameters and have come to the view that high quality is dependent not only on the material but also for the majority of the time on the machine parameters and the expertise of the worker. Many factors like the sewing thread, machine parameters, flexibility of the material, and ability of the worker influence the final properties of a 3D garment made from a 2D textile material. Today, the development of new technologies and the demands of mass production require high production quality and also high productivity. This requires an understanding of the common problems that appear during the industrial production of clothing and of how to optimize the process and improve production. Sewability is measured according to the seam strength as compared to the original textile materials used [11]; sewability is affected by multiple factors like the ambient conditions, needle heating, material type, speed of machine, tension type and the efficiency of the worker.

In any sewing operation, aesthetic issues are visible and can be corrected with experience but hidden mechanical damage is either neglected or not considered important for producers, as some of the advancement causes extra capital costs or lost production; for example, running the machine at a slower speed causes production losses and using air cooling increases the fixed costs of the producers.

The repeated friction and abrasion during the sewing process damages the sewing thread; then, the hot needle makes it much worse, and the repeated damage negatively impacts the strength of the thread; generally, a thread goes more than 20 times through the needle until it becomes part of the seam [12–15]. The abrasion not only causes mechanical damage to the thread but increases the needle temperature, making the situation worse for polymeric materials (fabric, thread).

Multiple researchers [16,17] have studied the effects of sewing speed, machine parameters and thread types on the final seam strength. There is a general trend of 25–30% lower seam strength at higher speeds as compared to lower sewing speeds. The fiber properties and its interactions to obtain a strong yarn/thread is also an important factor for thread quality and shows that the mechanical properties of fibers, the fiber–fiber friction coefficient and the twist angle have a significant impact on the strength and performance of sewing threads [18,19].

Improvements in the sewing process can be measured using either the final seam strength or better productivity.

Three common advancement/technologies used in the sewing field are as follows:

- Cooling the needle with forced air/vortex;
- Lubrication of thread (wax/oils);
- Surface coating of needle.

Companies try different techniques [20] to produce a better aesthetic look of the seam and the highest possible strength, and multiple techniques exist to decrease the needle temperature on the sewing floor, but the easiest technique is to use compressed air, whereas other methods like the surface finish of thread or the fabric are not often accepted by the client. These finishes can change the feel of the material and attract unwanted dust particles, which have to be removed by another process. On the other hand, applying compressed air to the hot needle is a quick technique but is not economical.

Hundreds of needle designs and shapes are available on the market and two of the most famous needle producers, Groz-Beckert® and Schmetz®, market needles with multiple low-friction surface coatings [21,22], such as Chromium, Nickel, Ceramic, Titanium Nitride, Teflon and even DLC (Diamond-Like Carbon). The design, material and finishes cause significant impacts on the aesthetic appearance and the mechanical performance of the seam. The needle producers are very keen on offering new products with better frictional properties. In this research, some of the existing coated needles will be compared.

Coated needles are made for a low frictional coefficient; researchers work on hard-to-find newer coating techniques to improve the sewing process. Needles in general last for weeks before the tip of the needle is not sharp any more. But when sewing leather or technical textiles, the needles are changed on a daily basis as not only the tip but also the coating inside the needle eye and on the shaft scratches off after multiple cycles of sewing. To keep the seam strength at the maximum possible level, it is advised to change the needle as it is much more viable to change the needle as compared to having a lower seam strength.

The main objective of the article is to coat and compare DLC-coated needles with commercially available sewing needles. The most popular needle on the market with a low frictional coefficient and that is commonly used for technical sewing is marketed under the name Gebedur™. A comparison of classical, Gebedur™ and DLC-coated needles will provide useful information for industrial partners.

The research work includes the preparation of the DLC coating of the sewing needles, following parameters for the optimum coating of the needle. Later, the DLC-coated needle will be compared with classic, Chrome-coated and Titanium Nitride-coated (Gebedur™) needles. Properties such as the fractional coefficient, needle temperature during sewing and thread properties after sewing will be compared to determine the overall performance of the DLC-coated needles.

2. Experiments

DLC coatings are famous for a low frictional coefficient and better hardness properties and these are among the reasons they are used in engine pistons, etc. [23–26]. The needles are coated with DLC using Plasma-assisted vapor magnetron sputtering. These needles are also commercially available but to obtain different depths of coating and final finishes, they were self-prepared for the experiments. The needles turned black due to the DLC coating and later the needles were compared with classical and Gabeduer® needles from the company Goz-Beckert which is the most famous needle on the market in terms of low friction and better sewability. Atomic force microscopy was used to measure the surface friction and the subsequent seam thread strength was measured by making 5 samples during 30 s of sewing at 4500 r/min using an industrial lockstitch machine.

In our research, the needles (Groz-Beckert®, 100 Nm, R type) were coated with DLC using the RF/PAVCD/MS method. The system consists of a cylindrical chamber 290 mm in diameter and 190 mm high, with a water-cooled bottom electrode connected through a feeder box to a power generator at the radio frequency of 13.56 MHz. A magnetron equipped with a 60 mm Ti-cathode was mounted in the center of the chamber top cover. The parameters and steps of the sample preparation are set out below.

Sample cleaning: The specimens (needles) were ultrasonically cleaned in methanol for 20 min before deposition. The base pressure of the reaction chamber was kept at less than 10^{-3} Pa.

Etching: The samples mounted on an RF electrode were etched in argon plasma for 10 min at self-bias voltage = −500 V, pressure = 4 Pa, and an Argon gas flow rate of 10 sccm.

Deposition of Ti coating: Firstly, the Ti layer was applied by magnetron sputtering for 5 min at a pressure of 1.2 Pa and self-bias voltage of −300 V; the flow rate of Ar. was 10 sccm and the power on the Ti-sputtered target was 1025 W.

Deposition of DLC coating: The DLC layer synthesis was conducted by the RF/PACVD process for 20 min with methane gas at a constant flow rate of 20 sccm, pressure of 20 Pa and self-bias voltage of −600 V.

- Atomic force microscopy (AFM)

The surface topography was examined using an NT-MDT NTEGRA Spectra AFM microscope working in a tapping mode. Commercial silicon cantilevers of the type NSG10 (NT-MDT) were used. For each sample, 2 different areas (10 × 10 µm and 100 × 100 µm) were scanned. All the investigations were performed under ambient conditions. The area roughness parameters—S_a (average roughness) and S_q (root mean square (RMS) roughness)—were determined from the obtained 10 × 10 µm scans.

Figure 2 shows the needle after the DLC coating in comparison to the Gebedur™ and classic needles. The needle color changes to grayish-black due to the DLC layer.

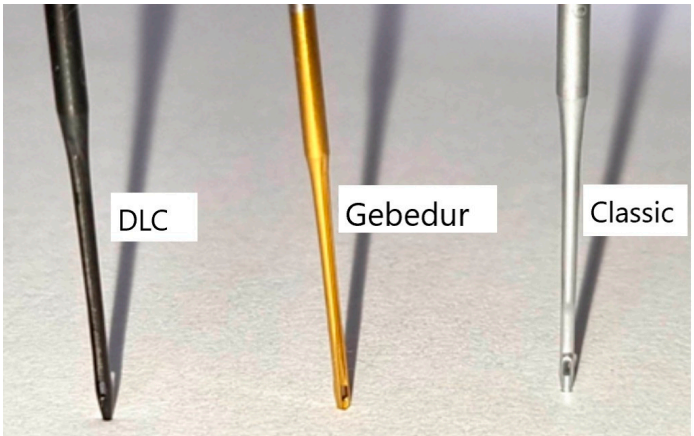

Figure 2. Sewing needles.

The DLC thickness was measured using Scanning Electron Microscopy (SEM) and was found to be 960 nm, whereas the Ti gradient layer was found to be nearly 150 nm.

2.1. Needle Temperature Measurement

A lockstitch machine (Brother Company, DD7100-905, Berlin, Germany) was run at a high speed of 1000 and at 4000 r/min and the needle temperature was measured with the embedded thermocouple technique [20]. In this method, a thin wire thermocouple is inserted inside the needle grove and the needle temperature is received wirelessly by

computer during the sewing process. The tip of the thermocouple is placed just above the needle eye inside the groove. The needle with the thermocouple is shown in Figure 3.

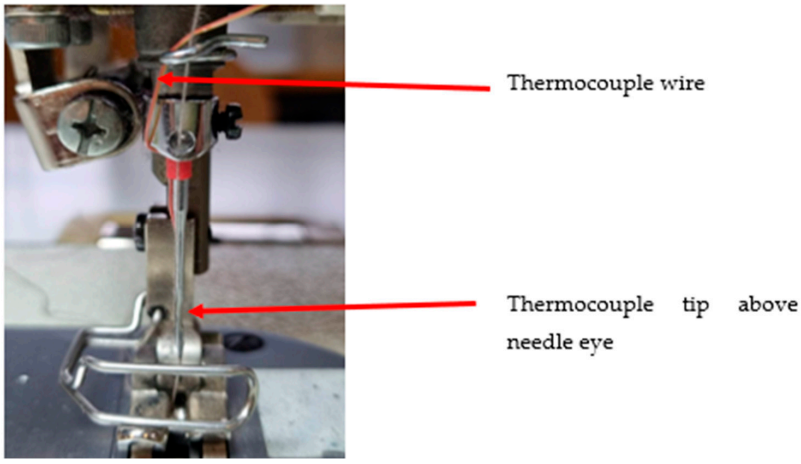

Figure 3. Sewing needle with thermocouple.

In this research, 40 Tex PET–PET core-spun thread is used for the experiment. The properties of the sewing thread are shown in Table 1. The properties of the denim fabric used for the sewing process are shown in Table 2.

Table 1. Sewing thread used for the experiments.

Thread Type	Company Name/Product Name	Fineness [Tex]	Twist (t/m)	Twist Direction (ply/Single)	Coefficient of Friction μ
Polyester–polyester core spun	AMANN/ Saba C-80	40 (20 × 2)	660 (±12)	Z/S	0.20 (±0.015)

Table 2. Fabric used for the experiments.

Fabric Type	Weave	Weight	Ends/cm	Picks/cm	Fabric Thickness
100%cotton Denim	2/1 Twill	257 g/m^2	25	20	0.035 cm

2.2. Tensile Properties Measurement

The breaking tenacity and elongation values of the sewing thread were measured using an INSTRON tensile (CZ) strength tester according to standard TS245EN ISO 2062 [20]. The tensile properties of all the sewing threads were tested before sewing, and, after the sewing process, the sewing thread was carefully removed from the seam by cutting the bobbin thread. Each thread was measured 10 times each for all the speeds of the sewing process, respectively. This experiment was necessary to compare the effects of the normal and DLC-coated needlse on the sewing threads after the sewing process.

3. Results and Discussion

For the classic, Chrome-coated, Titanium Nitride-coated (Gebedur™) and DLC-coated needles, the surface properties were compared using atomic force microscopy and the frictional coefficient of the needles was compared using the standard ASTM D-310 [20]. These needles are commonly used in the industry and are well known for their low frictional performance. The initial results of the surface properties are shown in Table 3. Each test was performed five times and the results are shown with standard deviation.

Table 3. Surface properties of needles.

-	Needle Without Coating	Chrome-Coated Needles (Groz Beckert)	Titanium Nitride-Coated Needle (Gebedur™, Groz Beckert)	DLC-Coated Needle
Frictional coefficient	0.32 (±0.03)	0.21 (±0.04)	0.14 (±0.02)	0.19 (±0.04)
Peak-to-valley roughness R_t	3.95 µm	3.86 µm	3.59 µm	3.72 µm

It can be seen in Table 3 that the coating of the needles caused significant improvement to the coefficient of friction. The DLC-coated needles are much better than most of the coated needles but still the marketed product of Groz-Beckert with Titanium Nitride coatings was much better in terms of the low coefficient of friction. This technique is unique for coating sewing needles and in future with better methodology it is possible that these coated needles can be made more economical and better than other coatings.

3.1. Sewing Needle Temperature

The embedded thermocouple approach [20] was used to measure the needle temperature at different speeds of sewing with three different coated needles. The needle temperature was measured with 40 and 60 Tex Polyester thread after 15 s of continuous sewing. The following results were obtained.

It can be clearly seen in Figures 4 and 5 that the needle temperature is impacted by the coating of the needle; nevertheless, the DLC-coated needles performed significantly better than the classic sewing needles, but the commercially available Gebedur™ needles still performed much better in terms of needle heat. Both sewing speeds of 1000 r/min and 4000 r/min showed similar trend lines. The DLC-coated needles showed a 9% lower temperature than the classic needles, whereas the Gebedur™ performed quite well with 17% less needle temperature.

It is important to know the tensile strength of the sewing thread after sewing at 4000 r/min. The tensile properties of all the sewing threads were tested before sewing and after the sewing process. The sewing process was performed for 15 s and the sewing thread was carefully removed from the seam by cutting the bobbin thread. Each thread was measured 10 times each for all the thread types using TS245EN ISO 2062.

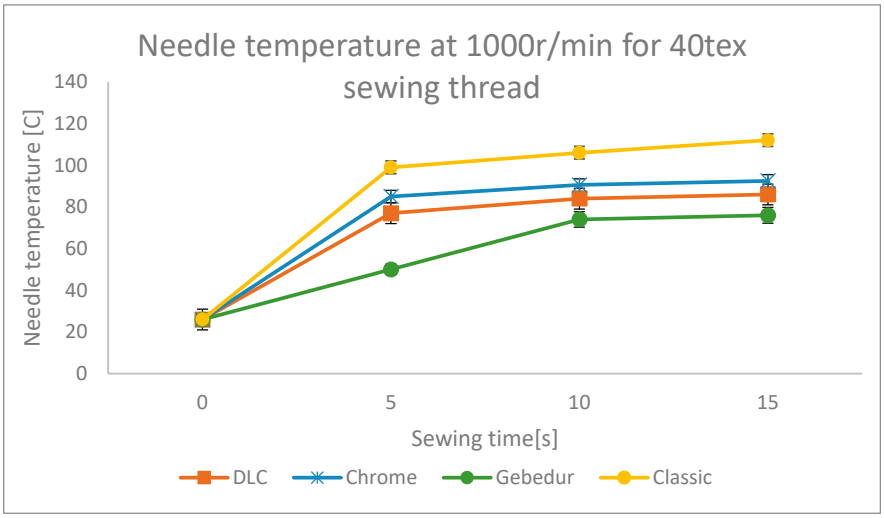

Figure 4. Needle temperature at 1000 r/min sewing.

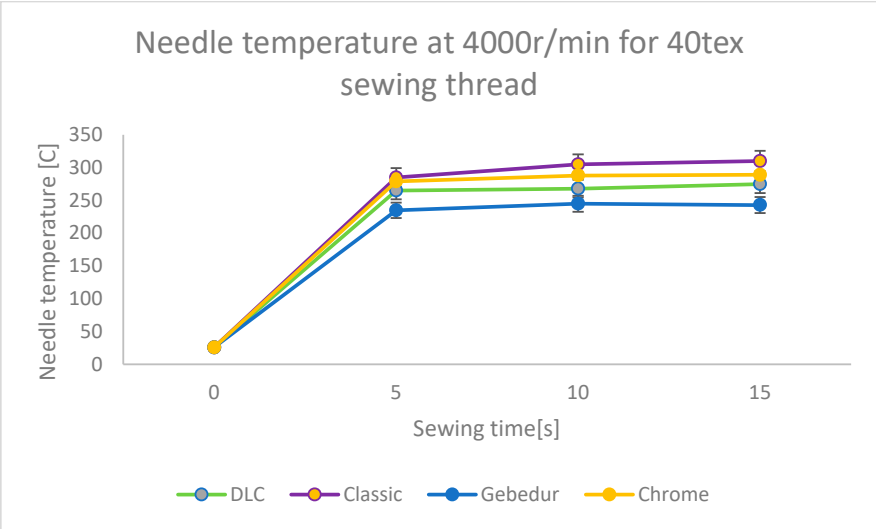

Figure 5. Needle temperature at 4000 r/min sewing.

It can be seen in Figure 6 that the DLC-coated and Gebedur™ needles showed almost identical tenacity of the threads, whereas there was a nearly 40% loss of tensile strength for the classic needles as compared to the parent thread. The main reason for this decrease is more abrasion of the needle with the thread and also the Gebedur™ and DLC-coated needles showed a nearly 10–17% lower needle peak temperature as compared to the classic needles.

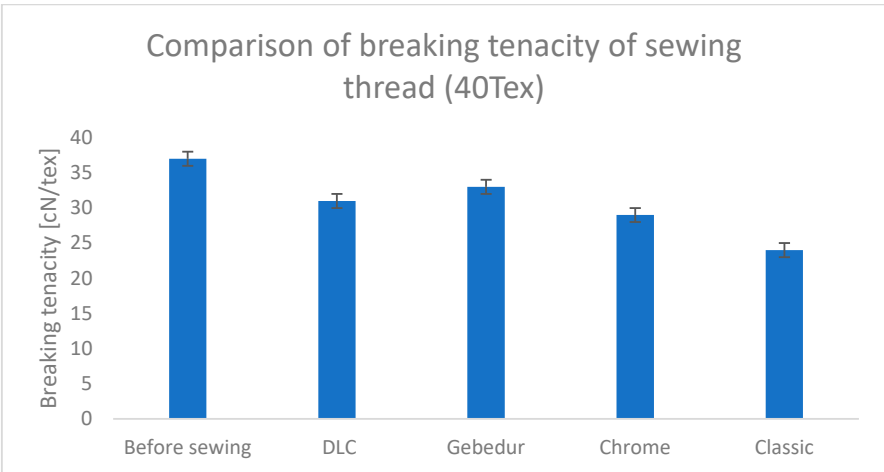

Figure 6. Tensile strength of thread with different needle coatings.

3.2. Comparison of Wear Test Until Breakage of Thread

In this experiment, the coated and non-coated needles were mounted on a wear-test machine and the thread was passed through the needle eye and tied to a 150 g load, as shown in Figure 7. The needles were moved up and down and each double stroke was counted till the thread broke. It is visible from Figure 8 that the thread through the DLC-coated needles underwent nearly 30% more strokes before the breakage of the thread as compared to the other needles.

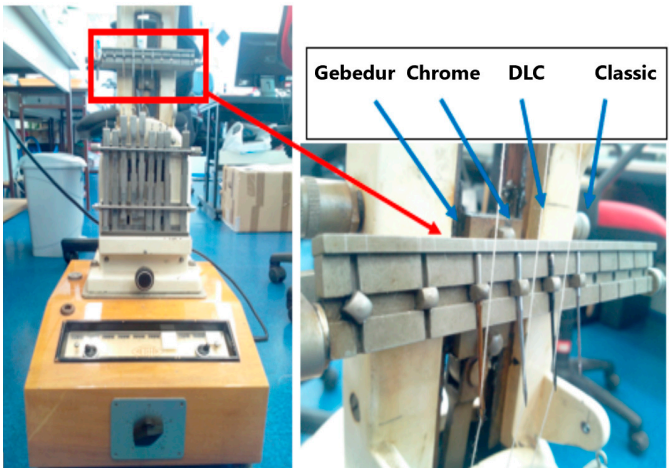

Figure 7. Thread wear-test machine.

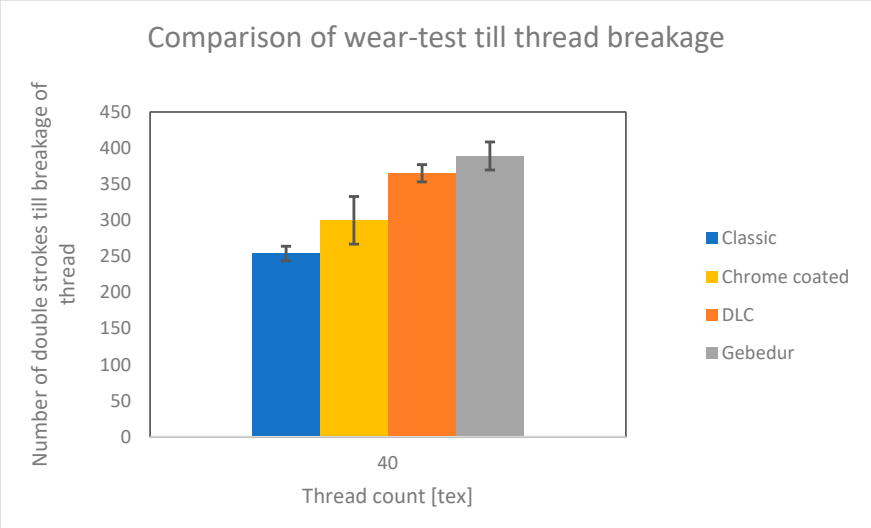

Figure 8. Wear test of sewing thread with coated needles.

Figure 8 shows a much clearer performance of the needles with respect to identical 40 Tex thread: the abrasion of the needles causes the thread to break and using this machine, it can be seen that thread broke significantly later for the DLC-coated and Gebedur™ needles.

3.3. Surface Properties of Needles

The DLC coating thickness was measured using AFM (Atomic force microscopy) and was found to be 960 nm, whereas the Ti gradient layer was found to be nearly 150 nm. The results (Table 4) from the AFM show that the DLC-coated needles showed lower average roughness parameters as compared to the normal needles.

The topographic images of all four needles (classic, Chrome-coated, Gebedur™, DLC-coated) are shown in Figure 9a–d, which clearly show the Gebedur™ needle was much smoother than the DLC-coated needles, but they both were still much better as compared to the classic needle and Chrome-coated needles. All the images are taken from the same spot of the needle eye.

It can be seen in Table 4 that coating the needles causes significant improvement to the coefficient of friction. The DLC-coated needles are much better than most of the coated needles but still the marketed product of Groz-Beckert with a Titanium Nitride coating is much better in terms of the low coefficient of friction. This technique is unique for coating

sewing needles and in future, with better methodology, it is possible that these coated needles can be more economical and better than other coatings.

Table 4. Roughness properties of needles (10 × 10 µm).

-	Classic Needle	Chrome-Coated Needle	Gebedur™ Needle	DLC-Coated Needle
Average roughness R_a	113 nm	98.6 nm	21.2 nm	48.3 nm
RMS roughness R_q	137 nm	78.3 nm	28.5 nm	57.6 nm
Peak-to-valley roughness R_t	683 nm	560 nm	211 nm	380 nm

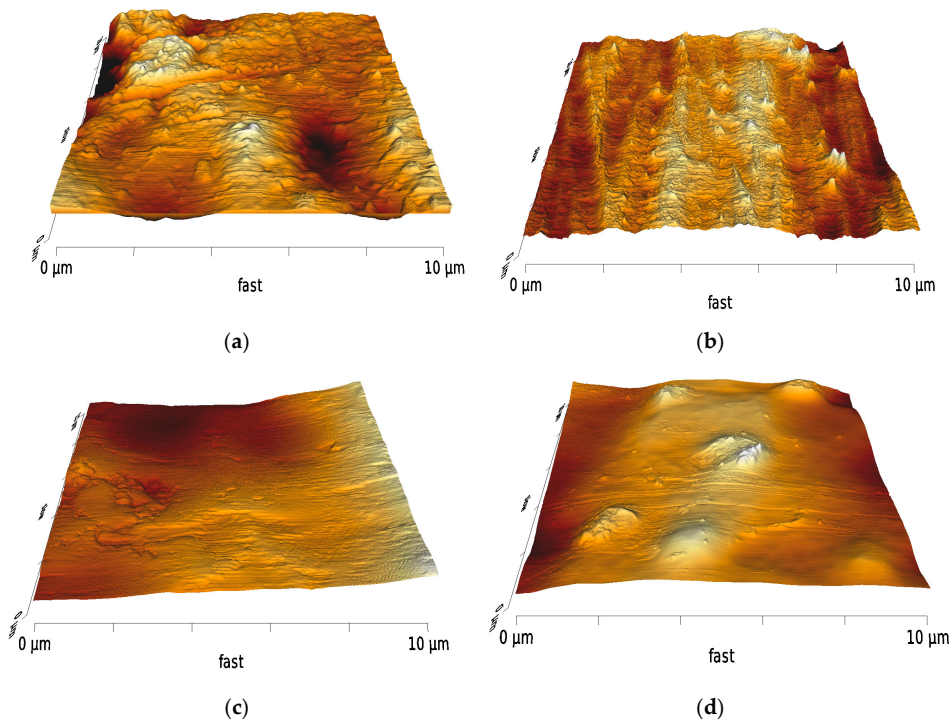

Figure 9. AFM images of different needle coatings. (**a**) Classic needle [14]; (**b**) Chrome-coated needle; (**c**) DLC-coated needle [14]; (**d**) Gebedur™ needle.

The other problem with the DLC-coated needles was the quality of the coating after multiple sewing processes. The DLC-coated needles were also tested for durability at 4500 r/min for 45 s and it was observed that the coating, especially at the eye of needle, was almost removed in just 15 cycles sewing for 45 s. The visible damage is shown in Figure 10a–c.

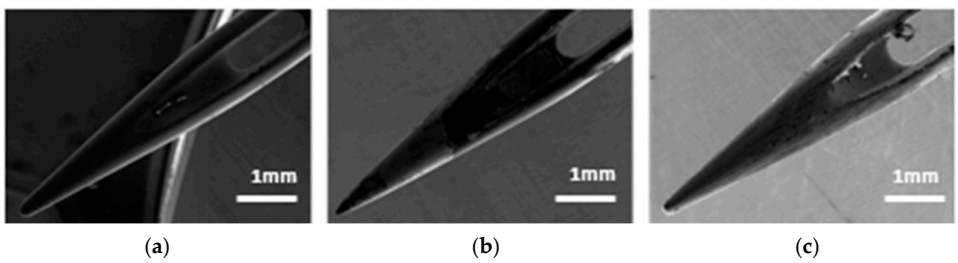

Figure 10. DLC-coated needle after multiple cycles of sewing. (**a**) Without sewing; (**b**) after 10 cycles of sewing; (**c**) after 15 cycles of sewing.

The same DLC-coated needle was run at 4000 e/min for 45 s and the loss of coating by abrasion is shown in Figure 10b after 10 cycles of sewing and in Figure 10c after 15 cycles of sewing.

4. Conclusions

Coated needles are definitely better for the sewing process to obtain better quality seams and less needle heating. The DLC coating technique is gaining popularity rapidly but the results shows that the commercial product Gebedur™ is still better as compared to the DLC-coated needle, but this may be because of the process parameters and maybe in future, with a better coating technique, it will be possible to coat the needle eye evenly. The low surface roughness and friction properties of the DLC-coated needles cause a decrease in the frictional heat between the needle and the fabric but it is impossible to determine the surface properties of the inside part of the needle's eye, which is the major contact for the thread to the needle. Diamond polishing is the final step in producing DLC-coated needles to ensure a smoother surface, but in the case of the needle it is impossible to polish the inside of the needle eye due to its complex and small shape. The results show that the DLC-coated needle has a significantly lower needle temperature: at a higher sewing speed of 4000 r/min, a decrease of almost 18 °C was recorded, whereas the tensile strength was nearly 14% better than the non-coated needles. The abrasion by the thread caused the DLC coating to erode from the needle and after only 10 cycles of sewing there was visible damage to the coating.

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