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Evaluate the Impact of UVB Radiation on Different High Performance Fabrics Treated with Nanomaterials

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THIS paper summaries the evaluation of using two different nano-particles as UV blocking standard materials for treatment of hi-performance fabrics after UVB exposure. Six woven samples are manufactured using three different weave structure (Twill 2/2, Satin 5, and Weft backed structure), two different high tenacity weft yarn count and materials (polyester and polypropylene) are used. Titanium dioxide - Zinc oxide nano-particles are used as a treated materials to reduce the effect of UVB radiations, after that the samples were exposed to UVB breaking strength and tear strength are performed according to standard test methods to estimate the fabrics performance. The data are statistically analyzed and evaluated for the six samples using t-test for mechanical properties. Scanning electron microscope and ultraviolet protection factor (UPF) are done for samples before and after treatment. The results of Ultraviolet protection factor test shows that nano-titanium oxide material has a better coating treatment than nano-zinc oxide.

Keywords: UV Radiation, High Tenacity Yarns, High Performance, Nanomaterials, Breaking Strength, Tear Strength.

Introduction

Technical textiles have been developed in many trends in both industrial sector and market segment with different levels of prosperity [1]. Woven technical textiles with its varying properties (thickness, porosity, strength, extensibility and durability) were designed to meet special requirements depending on fabric utility parameters [2] including raw materials, yarn and fabric structure linear density (count), fabric structure and twist factors for both warp and weft yarns. As the interlacing construction between warp and weft yarns is a result for an interlocked structure which is an essential feature that affects fabric properties [3].

Technical textiles were used as woven fabrics due to its superior dimensional performance in both warp and weft directions. Tensile strength one of the most important properties were applied for this type of fabrics depending on different factors (fiber specifications and yarn type or blend use, spinning systems and twist direction [4]. Many other factors can affect) to characterize the fabric performance and its quality [5]. Tear strength of fabrics is an important property used to determine the material strength with two action force either static or dynamic [2].

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Ultraviolet radiation (UVR) is described as an electromagnetic radiate, with two different sources, first source is the sun which is a natural source and the second source is the artificial source [6,7].

Ultraviolet radiation (UVR) is one of the main reasons for degradation of textile materials which cause damage on parts of the polymer molecule and on the nature of the textile fibers [8-15], due to a large surface area of textile materials are exposed to sun light and environmental condition factor.

Nanomaterials were known from many years ago, as it can be used in numerous applications to maintain different properties such as UV protection to be applied in many areas including coating, thin film and nanotechnology [16].

The various applications nanoparticles to different textile materials imparts its some different functional properties such as antibacterial properties, UV protection and self-cleaning properties. One of the important reasons of using nano metal oxide such as ZnO and TiO2 is UV rays blocking which scattering and absorbing UV radiation more than their traditional size. The nanoparticles have a more surface area -to-volume ratio than its materials [17]. Titanium dioxide and zinc oxide are non-toxic and photo-catalytic oxidative materials which are chemically stable under exposure to high sun rise temperature.

The purpose of this study was to give an overview for the effect of UVB radiation with certain dose on both tensile strength and tear strength after two nano coating materials with nano titanium oxide and nano zinc oxide with different weave structures and yarn densities. A previous study was done to investigate the performance of fabrics before treatment and UVB exposure [18].

Material and Method

Six woven fabrics were fabricated with different weave structures (Twill 2/2, Satin 5, Weft backed structure), with the same warp yarn count and density. Two different weft yarn counts, materials and densities were used. Two different nano coating materials (Titanium dioxide - Zinc oxide) were applied for each sample. The manufactured woven fabrics were tested after the exposure to UVB radiation, the change in both basic structural parameters and the characteristic of mechanical properties were applied (done).

A local manufactured irradiating chamber were used for the exposure of UV radiation, this chamber consists of 10 UVB 20W narrow band florescent lamps. The lamps are installed parallel to each other on one plane; the irradiated area was 50×50cm it was placed about 20 cm below the lamps plan. The irradiance levels over the irradiated area were measured using UVB radiometer from ILT Instruments ranging from (280 to 315) nm.

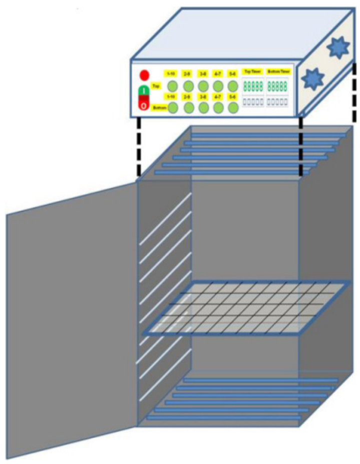

Fig. 1. Instrument Diagram

The specimens were fixed on a sheet of paper 50 × 50 cm at the midline of the instrument, each sheet exposed for period of 10 hours. The irradiated area plane was divided into 5 × 5 square matrix resulting on 25 measuring points at the center of each square, as shown in Fig. 1. The average irradiance level was 1.06 mW/cm^2 ± 0.01 specimens was irradiated 10 hours resulting 67 K $J/m^2/nm$, as shown in Fig. 2.

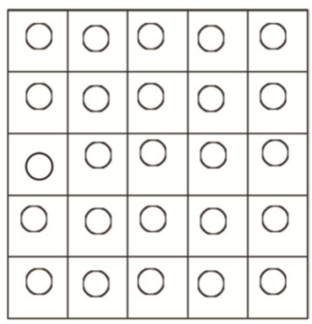

Fig. 2. The irradiated area plane

Mechanical properties

Breaking strength and elongation (strip method) test

The tensile strength test was performed using universal testing machine, and test samples were done in both warp and weft directions. A Raveled Strip Test-1R, 25 mm was done according to ASTM D5035 [19] to determine the breaking strength and elongation, the loading rate for testing machine was set at 300 ± 10 mm/min., also the gage length was set at 75 ± 1mm.

Tear strength (tongue single rip method) test

The tear strength test was performed using universal testing machine, and test samples were done in both warp and weft directions. A tongue (single rip) procedure was done according to ASTM D2261 [20] to determine the tearing strength, the loading rate for testing machine was set at 50 ± 2 mm/min., and also the gauge length was set at 75 ± 1mm.

Coating materials methods

Coating of fabrics with nano-Zno/ nano- TiO2

Nano-ZnO, nano- TiO2 were applied on fabrics using the 'pad–dry–cure' method. The fabrics were immersed in the solution containing nano-ZnO/nano- TiO2 (2 %) and sodium hypophosphate as a cross linker and cataylst (1%) for 30 min. and then it was passed through a padding to remove excess solution and 100% wet pick-up was maintained for all the samples. After padding, the fabric was air-dried for 5 min. at 85 then cured for 2 min. at 110 for thermo fixation.

Ultraviolet protection factor (UPF)

This method was used to assess the UV protection of the fabric as per the AATCC-183 (2004) [21] test method. It measures the transmittance or blocking of UV radiation through fabrics by UV-VIS Spectrophotometer. The UV profiles of the untreated samples were compared with the fabrics treated with nanoparticles, and the effectiveness in shielding; UVB radiation was evaluated by measuring the UV protection,

TABLE 1. Manufactured specimens specification

Fabric Code	Yarn Count (Denier)		Yarn Material		Density Threads/cm		Weight after Nano Titanium oxide (g/m2)	Weight after Nano Zinc oxide (g/m2)	Thickness after Nano Titanium oxide (mm)	Thickness after Nano Zinc oxide (mm)	Textile Structure
	Warp	Weft	Warp	Weft	Warp	Weft					
Sample 1						14	726.66	419.5	0.97	1.1	Twill 2/2
Sample 2		1200/144		Polypropylene High Tenacity		14	370.31	500	1.01	1.01	Satin 5
Sample 3						12	556.44	611.55	1.3	1.35	Weft backed structure
Sample 4	150/48		Polyester		72	12	689.77	710	1.17	1.15	Twill 2/2
Sample 5		3000/288		Polyester High Tenacity		12	714.66	734.22	1.34	1.22	Satin 5
Sample 6						10	1095.31	923.33	1.72	1.73	Weft Backed Structure

transmission and reflection.

Scanning electron microscope (SEM)

SEM of the treated fabrics was studied using a scanning electron probe micro analyzer (type T-scan) – Czech Republic. Surface morphologies were imaged at different magnifications, using 5kV accelerating voltage.

Statistical Analysis

The results were presented as mean value and standard deviation for different mechanical properties (Tensile Strength and elongation at break and Tear Strength) in warp and weft directions. It was statistically analysis using (t-test). The significant level at $p \leq 0.05$ was assigned using IBM® SPSS® (SPSS Inc., IBM Corporation, NY, USA) Statistics Version 22 for Windows.

Results and Discussions

After the samples were manufactured and the coating treatment was applied. The breaking strength, elongation at break and tear strength were performed in both warp and weft directions for six samples using different structures and yarn counts. The average results were evaluated for breaking strength and elongation at break after five specimen for each sample in both warp and weft directions, also for tear strength five specimen for each sample in both warp and weft directions the results of highest five peak forces for each specimen were determined.

T-test analysis

The statistical analysis was done using t-test for samples (1), (2) and (3), from Table 5 it was found that for warp breaking strength that twill 2/2 structure has a significant difference at p value ($p=0.039$), this is could attributed to the short floats interlacement between yarns which results in a high breaking load rather than satin 5 and weft backed structure which have a non-significant difference, from that it can be showed that nano-titanium oxide material has a better coating treatment than nano-zinc oxide according to its mean values at mean difference =193.66, as shown in Table 7.

According to the results of statistical analysis for warp breaking elongation, from Table 5 it was illustrated that the three structures (twill 2/2, satin 5 and weft backed structure) have non-significant difference.

Table 5 of t-test results for weft breaking strength, it was clear that there is a significant difference for structure twill 2/2 at p-value ($p=0.038$), and the mean results show that nano-

TABLE 2. Breaking Strength Mean Values and S.D. for Samples after UVB Exposure and Coating Treatment

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction
	Mean (Newton) ± S.D.											
After UVB Exposure & Nano-Titanium Oxide Coating	961.5 ± 132.6	2385.96 ± 106.91	894.34 ± 54.79	2391.4 ± 137.33	874.3 ± 20.96	3957.86 ± 178.65	688.70 ± 34.65	4029.58 ± 197.30	939.32 ± 30.17	3873.72 ± 260.63	813.58 ± 34.48	7760.20 ± 627.28
After UVB Exposure & Nano-Zinc Oxide Coating	767.8 ± 114.37	2159.7 ± 172.86	914.88 ± 74.47	914.88 ± 74.47	871.02 ± 15.59	3991.06 ± 179.03	746.94 ± 29.89	4376.70 ± 292.32	921.38 ± 50.81	4072.96 ± 374.82	749.82 ± 56.38	7682.42 ± 473.80

TABLE 3. Elongation Mean Values and S.D. for Samples after UVB Exposure and Coating Treatment

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction
	Mean (%) ± S.D.											
After UVB Exposure & Nano-Titanium Oxide Coating	51.64 ± 10.45	38.09 ± 10.48	45.97 ± 1.33	35.72 ± 8.32	44.36 ± 1.64	37.50 ± 5.40	45.89 ± 1.30	25.16 ± 1.48	54.34 ± 3.19	22.87 ± 2.43	56.98 ± 3.48	27.77 ± 4.17
After UVB Exposure & Nano-Zinc Oxide Coating	44.60 ± 2.66	34.03 ± 11.73	45.62 ± 1.22	45.62 ± 1.22	44.35 ± 1.64	30.58 ± 3.72	45.54 ± 4.46	24.59 ± 0.86	51.96 ± 4.35	24.98 ± 4.87	49.49 ± 4.08	28.51 ± 5.43

TABLE 4. Tear Strength Mean Values and S.D. for Samples after UVB Exposure and Coating Treatment

	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction	Warp Direction	Weft Direction
	Mean (Newton) ± S.D.											
After UVB Exposure & Nano-Titanium Oxide Coating	81.14 ± 5.92	264.43 ± 30.02	109.35 ± 17.02	259.72 ± 26.90	99.03 ± 10.82	245.55 ± 24.93	93.67 ± 5.59	243.35 ± 25.10	114.93 ± 3.35	345.49 ± 39.19	106.29 ± 6.66	277.38 ± 17.08
After UVB Exposure & Nano-Zinc Oxide Coating	86.43 ± 8.17	244.57 ± 17.14	112.23 ± 7.71	242.28 ± 72.30	110.27 ± 9.86	211.79 ± 22.62	92.03 ± 4.71	230.68 ± 23.37	115.60 ± 6.46	363.57 ± 31.36	105.70 ± 5.15	251.06 ± 33.59

titanium oxide material has a better coating treatment than nano-zinc oxide material at mean difference = 226.26, as shown in Table 7. While satin 5 structure has significant difference at p-value (p=0.000), and the mean results show that nano-titanium oxide has a better coating treatment than nano-zinc oxide according to its mean values at mean difference =1476.52, as shown in Table 7, while weft backed has a non-significant difference.

It is clear from the statistical analysis of Table 5 for weft breaking elongation that satin 5 structure gave a significant difference at p-value (p=0.030), and it was found that nano-zinc oxide has a better effect for coating material than nano-titanium oxide according to its mean values at mean difference= 9.89, as shown in Table 7, while twill 2/2 and weft backed structure have a non-significant difference.

From Table 5 of statistical analysis of t-test for warp and weft tear strength, it was illustrated that for warp tear strength that gave significant difference for twill 2/2 at p-value (p= 0.012) and it was found that nano-zinc oxide has a better effect for coating material than nano-titanium oxide according to its mean values at mean difference= 5.29, as shown in Table 7, also weft backed structure has a significant difference at p-value (p=0.000) and nano-titanium oxide gave better effect for coating material than nano-zinc oxide according to its mean values at mean difference =11.24, as shown in Table 7, while satin 5 has a non-significant difference. For weft tear strength twill 2/2 has a significant difference at p-value (p=0.007), that results in that nano-titanium oxide has a better coating treatment than nano-zinc oxide according to its mean values at mean difference =19.85, as shown in Table 7, also weft backed structure has a highly significant difference at p-value (p=0.000) that it can be showed that nano-titanium oxide material has a better coating treatment than nano-zinc oxide according to its mean values at mean difference = 33.76, as shown in Table 7, while satin 5 has a non-significant difference.

According to the statistical analysis of Table 6 for samples (4), (5) and (6), for warp breaking strength that twill 2/2 structure gave a significant difference at p-value (p=0.022), and it was found that nano-zinc oxide has a better effect for coating material than nano-titanium oxide according to its mean values at mean difference= 58.24, as shown in Table 8, while satin 5 and weft backed structure have a non-significant difference.

Table 6 of t-test results for weft breaking elongation, it was clear that there is a significant difference for structure weft backed structure at p-value (p=0.014), It means that nano-titanium oxide material has a better coating treatment than nano-zinc oxide material according to its mean values at mean difference = 7.48, as shown in Table 8. While satin 5 and weft backed structures have a non-significant difference.

According to the results of statistical analysis for weft breaking strength, from Table 6 it was

TABLE 5. (t) test and grouping variables for samples (1), (2), (3) after coating treatment and UVB exposure

Variables	T-Value			P-Value		
	Twill 2/2	Satin 5	Weft Backed Structure	Twill 2/2	Satin 5	Weft Backed Structure
Warp Breaking Strength	2.473	0.497	0.281	0.039*	0.633 ns	0.786 ns
Warp Breaking Elongation	1.459	0.437	0.012	0.183 ns	0.674 ns	0.991 ns
Weft Breaking Strength	2.489	21.134	0.294	0.038*	0.000*	0.777 ns
Weft Breaking Elongation	0.576	2.630	2.358	0.580 ns	0.030*	0.046 ns
Warp Tear Strength	2.621	0.770	3.839	0.012*	0.446 ns	0.000*
Weft Tear Strength	2.871	1.130	5.014	0.007*	0.267 ns	0.000*

Significant level at p=0.05

(*)=Significant, (ns) = Non-significant

TABLE 6. (t) test and grouping variables for samples (4), (5), (6) after coating treatment and UVB exposure

Variables	T-Value			P-Value		
	Twill 2/2	Satin 5	Weft Backed Structure	Twill 2/2	Satin 5	Weft Backed Structure
Warp Breaking Strength	2.845	0.679	2.157	0.022*	0.516 ns	0.063 ns
Warp Breaking Elongation	0.169	0.983	3.114	0.873 ns	0.354 ns	0.014*
Weft Breaking Strength	2.201	0.976	0.221	0.059	0.358 ns	0.830 ns
Weft Breaking Elongation	0.742	0.864	0.244	0.479 ns	0.422 ns	0.814 ns
Warp Tear Strength	1.118	0.460	0.352	0.269 ns	0.648 ns	0.727 ns
Weft Tear Strength	1.848	1.801	3.493	0.071 ns	0.078 ns	0.001*

Significant level at p=0.05

(*)=Significant, (ns) = Non-significant

TABLE 7. Mean Differences for samples (1), (2), (3) after coating treatment and UVB exposure

Variables	Twill 2/2	Satin 5	Weft Backed Structure
Warp Breaking Strength	193.66		
Warp Breaking Elongation			
Weft Breaking Strength	226.26	1476.52	
Weft Breaking Elongation		9.894	
Warp Tear Strength	5.29		11.24
Weft Tear Strength	19.85		33.76

TABLE 8. Mean Differences for samples (4), (6) after coating treatment and UVB exposure

Variables	Twill 2/2	Satin 5	Weft Backed Structure
Warp Breaking Strength	58.24		
Warp Breaking Elongation			7.48
Weft Breaking Strength			
Weft Breaking Elongation			
Warp Tear Strength			
Weft Tear Strength			26.3280

illustrated that the three structures (twill 2/2, satin 5 and weft backed structure) have non-significant difference. From Table 6 it was found that for weft breaking elongation that the three structures (twill 2/2, satin 5 and weft backed structure) have non-significant difference.

From Table 6 of statistical analysis of t-test for warp and weft tear strength, it was illustrated that for warp tear strength that the three structures (twill 2/2, satin 5 and weft backed structure) have non-significant difference. For weft tear strength weft backed structure has a significant difference at p-value (p=0.001), that it can be showed that nano-titanium oxide material has a better coating treatment than nano-zinc oxide according to its mean values at mean difference =26.32, as shown in Table 8, while twill 2/2 and satin 5 have a non-significant difference.

Ultraviolet protection factor (UPF)

The UPF factors of untreated and treated samples are listed in Table 9.

From Table 9 The UPF factor of values of untreated samples (1, 2,3,4, 5, and 6) are 694, 782, 1289.6, 342.8, 5345 and 6928.4 respectively while the UPF values of treated fabrics with nano-zinc oxide (1, 2, 3, 4, 5, 6) are 1321, 4188.5, 2906, 30220, 6345.8 and 45723, respectively, which indicated that the UPF value of treated fabrics with nano- zinc oxide are more than untreated fabrics, the data indicate that the highly UV radiation protection by treated fabrics in comparison with the untreated fabric.

From Table 9 The UPF factor of untreated sample (1,2, 3, 4, 5, and 6) are 694, 782, 1289.6, 342.8, 5345 and 6928.4 respectively while the UPF values of treated fabrics with nano-titanium oxide oxide (1,2, 3, 4, 5, 6) are 1470, 3263.9, 4326, 14949.2, 8237.8 and 56279.3, respectively, which indicate the UPF value of treated fabrics with nano- titanium oxide are more than untreated fabrics, the data reflect the higher protection against UV radiation provided by treated fabrics in comparison with the untreated fabric.

The same results were obtained for the samples treated nano- titanium oxide but it will obtain the treated fabrics with nano titanium oxide are more UV protection than the another treated fabrics with nano zinc oxide.

Scanning electron microscope (SEM)

Surface morphology of treated and untreated fabrics were investigated by scanning electron microscopy in Fig. 3. Figures 3 (I) shows the SEM images of untreated fabrics which were fairly smooth surface existence of few small particles on the fiber surface due to insufficient removal of chemical materials during washing stage. Figures 3 (II, III) show the surface morphology of treated fabrics with nano zinc and nano titanium oxides were changed with appearance of new features on the fiber surface with nano thin film layer spread all over the fabric surface and the fabrics were closed to each other, This modification happens after collisions of fiber surface with metal ions.

TABLE 9. Effect of nano zinc oxide and nano titanium oxide treatment on UPF values of treated fabric

Sample number	UPF value	Sample treated with nano zinc oxide	Sample treated with nano titanium oxide
1	694	1321	1470
2	782	4188.5	3263.9
3	1289.6	2906.3	4326
4	342.8	30220	14949.2
5	5345.4	6345.8	8237.8
6	6928.4	45723.7	56279.3

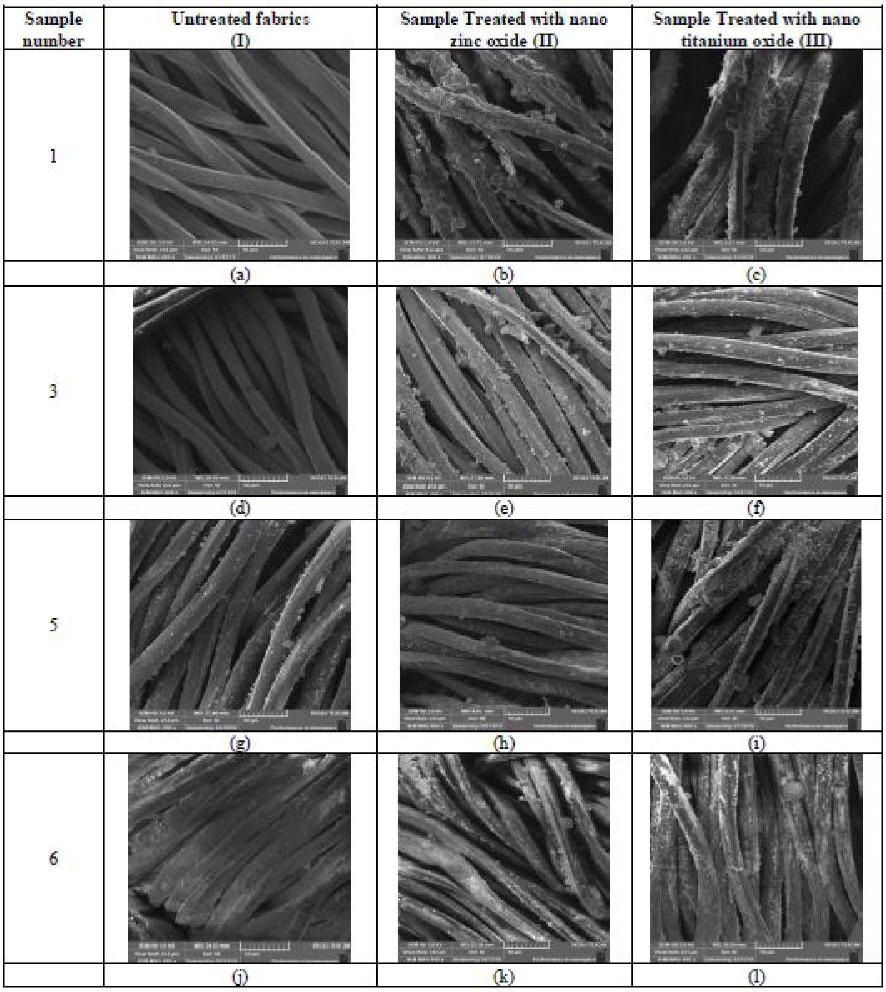

Fig. 3. The SEM images of the untreated fabrics, and treated fabrics with nano zinc oxide and nano titanium oxide.

Conclusion

Using Nano materials have a good effect against UV radiation, as treated fabric gave a higher protection against UV radiation in comparison with the untreated fabrics. Breaking load, elongation and tear strength mechanical properties were done to show the effect of nano materials coating against UV radiation.According to Ultraviolet protection factor (UPF) the test shows that the nano-titanium oxide material has a better coating treatment than nano-zinc oxide on manufactured samples.

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تقييم تأثير الأشعة فوق البنفسجية على مختلف الأقمشة عالية الأداء المعالجة بالمواد النانونية

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هذا البحث يدرس تقييم استخدام جزيئين نانويين مختلفين كمواد قياسية لمنع الأشعة فوق البنفسجية لعلاج الأقمشة عالية الأداء. تم تصنيع ست عينات منسوجة باستخدام ثلاثة تراكيب نسجية مختلفة, وقد تم استخدام نوعين مختلفين من خيوط اللحمة عالية الأداء (البوليستر والبولي بروبيلين). - تستخدم جزيئات (أكسيد الزنك - ثاني أكسيد التيتانيوم) النانوية كمواد معالجة للحد من تأثير الأشعة فوق البنفسجية ، وبعد تعرض العينات للأشعة فوق البنفسجية ،تم إجراء الخواص الميكانيكية في كلا الاتجاهين (قوة الشد والاستطالة) وذلك وفقًا للمواصفات القياسية . يتم تحليل البيانات الإحصائية وتقييمها للعينات الست باستخدام اختبار t للخصائص الميكانيكية. وقد أظهرت نتائج اختبار عامل الحماية من الأشعة فوق البنفسجية أن مادة ثانى أكسيد التيتانيوم النانوية تتمتع بمعالجة طلاء أفضل من أكسيد الزنك النانونية.