Comfort Properties of the Inner Padding Layer for Motorcycle Helmet

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Abstract: The inner padding layer of the motorcycle helmet is one of the important components that control the factors of comfort during wearing the helmet, and provides a perfect fit and stability of the helmet on the head. The inner padding consists of a low-density flexible polyurethane layer attached to soft fabric layer that is in direct contact with the head. The study aimed at improving the functional properties of the soft fabric used in the inner padding of the helmet. In this regard, six woven samples were produced mostly from natural materials with different parameters such as; weft yarn material and count as well as weaving structures to assess in achieving the comfort properties. In addition, applying chemical treatments on the fabrics to impart antimicrobial properties, UV resistance and self-cleaning properties. The properties of the fabric samples before and after treatment were evaluated using radar charts in terms of the functional performance. The results revealed that 100% cotton treated fabric with twill 1\4 structure was the best sample in achieving high mechanical, physical and protection properties for granting comfort factors.

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Key Words: Motorcycle helmet; Comfort padding; Soft fabric; Antimicrobial finishing; UV resistance; Self-cleaning.

1. Introduction:

Motorcycle helmets are widely used to protect the rider during road accidents thus prevents or reduces head injuries. Extreme weather conditions cause the rider to feel with discomfort and discourages him from wearing the helmet. The comfort padding liner in the motorcycle helmet consists of a sufficiently firm synthetic foam e.g. polyurethane foam pad covered with a skin-friendly fabric that sits next to the head. The polyurethane foam layer used cannot be dispensed in all helmets, but its thickness and density varies according to the design and size of the helmet. Continual refinements in helmet technology have resulted in fully removable, washable and replaceable padding [1,2].

Generally, comfort is defined as "The absence of displeasure or discomfort"[3]. Comfort parameters of textiles as stated by Higgins and Anand [4] that; anti-microbial, anti-bacterial and anti-odour properties are important in garments, which tend to remain in contact with sweat for long periods. UV resistance can be vital for clothing exposed to high levels of sunlight. Air permeability can be measured on either dry or damp fabrics and is likely to be lower in fabrics where the absorption of water leads to swelling of the fiber and the yarn. Water absorption is the capacity of a fabric to absorb the sweat generated by the body and the rate at which it is able to do so.

Clothing has an important role in regulating human body temperature by transferring some of the heat into the environment and releasing the rest. So, major fabric characteristics as; yarn count, number of warp and weft threads per inch, fineness of thread and weight can result in different degrees of moisture resistance and thermal resistivity [5].

In markets, there are many textile supplements for motorcycle helmets enhancing comfort properties such as; ***Head scarves*** that enable the rider to stay warm and keep the sun off, ***Shellaclava*** is an excellent cold-weather riding accessory; it is thin enough to fit under a helmet, easily stowable and very comfortable. ***Jimi cap*** consider as a high tech helmet liner that designed for professional athletes to keep hair and sweat out of eyes, it is made from advanced microfiber fabrics to keep helmet cleaner and drier. ***Respro bandit scarf*** combines a comfortably stretchy 100% cotton scarf with a washable activated charcoal filter to protect face from diesel smoke, dust and similar airborne pollutants and filth [1].

The development work performed at SHOEI suggests the creation of a three-dimensional liner shape in conjunction with surprisingly thin cheek-shaped comfort padding; the liner guarantees a perfect fit that prevents any helmet vibrations even at high speeds. If the comfort padding exerts pressure on specific points of the rider's head, the rider will develop a headache after a couple of hours' riding, which will in turn impair the rider's concentration and increase the risk of accident [6].

The study worked on the idea of using woven fabrics made from natural and synthetic fibers in the inner layer of the comfort padding instead of using the mesh fabric commonly used, in order to improve comfort properties and increase the durability. The mesh fabric used is easily subjected to erosion by time since it is in contact with the scalp which increases the feeling of discomfort.

Cotton is commonly used as an apparel textile material; it has excellent moisture absorption ability. Also blending of natural and synthetic fibers repels moisture, pulling it off the skin and into the fabric. In addition, it has high air permeability with better thermal resistance values and giving warmer feeling with lower absorptive values [5,7]. Milenkovic *et al.* [3] proved that fabric thickness, enclosed still air and external air movement are the major factors that affect the heat transfer through fabric. Weight and protection are two of the most important facts to consider when consumers buy helmets. However, different people would have different requirements because of different purpose of wearing helmets [6].

As some lifestyles have become more active, apparels become more easily contaminated by perspiration leading to bacterial growth and body odours. To protect against disease-causing bacteria and pathogenic fungi, fibers and fabrics need treatment with anti-microbial finishes which should be non-toxic, non-irritating and where handled regularly, must be non-sensitizing [8,9]. An effective approach is the use of cyclodextrins, which can be obtained by enzymatic degradation of starch leading to the formation of oligosaccharides consisting of six, seven or eight units known as α, β or γ-cyclodextrin respectively.

Monochlorotriazinyl-β-cyclodextrin is the first reactive cyclodextrin derivative, manufactured on an industrial scale. Surfaces like textiles with nuclophilic groups can be modified with cyclodextrins and their derivatives via well-established methods [10]. Cyclodextrins are toroidal-shaped cyclic oligosaccharides with a hydrophilic outer surface and internal hydrophobic cavity, depending on their size and molecular structure. For this reason cyclodextrins behave as hosts and the hydrophobic species are the guests, the driving force for such inclusion process is the enthalpic contribution that arises from new covalent hydrophobic interactions [11,12].

Recently, nanotechnology helps in producing a new generation of textiles treated with nanoparticles which have some functional behaviors including antibacterial activity, UV-protection and self-cleaning [13].These properties increased in the modified fabrics by eco-friendly polymer modifications like chitosan and β-cyclodextrin [14,15]. Ag-NP's is used to impart anti-microbial property on fabrics. For a long time, silver nano-particles are non-toxic, have no tolerant disinfectant, which can remove more than 650 bacteria and viruses [16,17]. Cotton fabrics coated with TiO_2 nanoparticles have been successfully developed by dipping the fabrics into TiO_2 sol-gel, which was synthesized by a simple and effective method at ambient atmosphere. TiO_2-coated cotton fabrics have notable and stable self-cleaning functions as demonstrated by their photocatalytic degradation of bactericidal activities. TiO_2-coating not only prevents the formation of a bio-film of adsorbed bacteria but also destroyed the bacteria cell [18].

The objective of this study is to evaluate the functional performance of the woven fabric (soft fabric) used in the inner padding layer of the motorcycle helmet achieving comfort properties. These properties are; antimicrobial properties, UV resistance and self-cleaning, in addition to the physical and mechanical properties of the produced fabrics before and after applying chemical treatments.

2. Experimental

2.1. Local market survey

In the local market, there are several models of motorcycle helmets imported with different specifications, designs and prices. It was observed that the popularity of helmet users are at the primarily for the proper price, however it doesn't fulfill all the required safety items. By analyzing of the comfort padding samples for common types of motorcycle helmets, it was found that it composed of a layer of polyurethane foam attached to a thin mesh polyester fabric. The mesh fabric commonly used is weft knitted fabric constructed from (single jersey or interlock). It was found that its weight ranges from (74 - 106.8 g/m^2) and its thickness ranges from (0.65 - 1.19 mm), see figure 1.

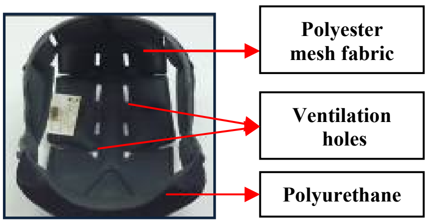


Figure 1. The common parts of the comfort padding.

2.2. Materials

-***Woven fabrics***: Six woven fabric samples were produced with different structure parameters for using in the inner soft layer of the padding such as: weft yarn material, count, and weaving structures. The fabrics specifications are illustrated in table 1. The mechanical and physical properties of the fabrics were tested before and after applying the chemical treatments.

-***Chemicals***:Monochlorotriazinyl-β-cyclodextrin (MCT-β-CD), was supplied by wacker-chemie GmbH, Munchen, Germany. Silver nitrate ($AgNO_3$-Sigma) trisodium citrate, Titanium tetraisopropoxide (Sigma), Nitric acid and Sodium hydroxide were analytical reagents grade. Hostapal® CV-ET (nonionic wetting agent based on alkyl aryl polyglycol ether, Clariant) was of commercial grade. Methylene Blue (C.I. Basic Blue 9, Merck).

Table 1. Specifications of the fabrics used in the inner layer

Warp material	Weft material	Weaving structure	Warp count (Ne)	Weft count (Ne)	Weight ($g\backslash m^2$)	Thickness (mm)	No. of ends\ cm	No. of picks\ cm
Cotton	Polyester	Weft rib 2\2	30\2	18\1	243.5	0.6	40	18
Cotton	Cotton	Weft rib 2\2	30\2	20\1	238.29	0.62	40	18
Cotton	Flax	Weft rib 2\2	30\2	16\1	248.51	0.64	40	18
Cotton	Polyester	Twill 1\4	30\2	18\1	281.8	0.89	40	18
Cotton	Cotton	Twill 1\4	30\2	20\1	282	0.91	40	18
Cotton	Flax	Twill 1\4	30\2	16\1	281.71	0.92	40	18

2.3. Fabric samples preparation:

The (cotton/polyester) fabrics with blending ratio (50%:50%) were emerged in a water bath with liquor ratio 1:40 containing 5g/L, non-ionic wetting agent at 95ºC for 30 min. After that, the fabrics were washed thoroughly in hot water and cold water several times. The cotton and the blended (cotton / flax) fabrics with blending ratio (50%:50%) were emerged in a water bath containing 10g/L NaOH and 5g/L non-ionic wetting agent at 90ºC for 30 min., then washed with hot water followed by cold water and drying.

2.4.Treatment of fabrics with Monochlorotrizanyl-β-Cyclodextrin (MCT-β-CD)

The fabrics were padded in a solution with different concentrations of (MCT-β-CD) from (2-10%) at pH=11, to 100% wet pick-up followed by drying at 100^0C for 5 min., curing at different temperature (120-180^0C) at various times (1-4) min. The treated fabrics were washed under rising water to remove unreacted and unfixed (MCT-β-CD) and finally dried at room temperature.

2.5. Preparation of Silver nanoparticles (Ag-NP's)

Ag nanoparticles were synthesized by chemical reduction method [19]. All solutions were prepared in distilled water. In a typical experiment, 50 ml of 1.10^{-3}M $AgNO_3$ was heated to boiling. 5 ml of 1 % trisodium citrate was added drop wise to this solution. The solution was stirred vigorously at boiling until the color changed to pale yellow, which is the evident of nanoparticles formation.The solution was cooled at room temperature. The mechanism of the reaction is as follows:

$$2Ag^+ + \underset{SC}{Na_3C_6H_5O_7} \rightarrow \underset{Ag\text{-}NP's}{2\,Ag} + Na_2C_5H_4O_5 + Na^+ + H^+ + CO_2$$

2.6. Preparation of Titanium Dioxide nano particles (TiO_2-NP's)

Titanium tetraisopropoxide 6ml was mixed with 2 ml of 1% acetic acid with continuous stirring using magnetic stirrer [20]. After 5 min., 56 ml of ethanol was added drop wise with continuous stirring then pH of the solution was adjusted to 1-2 by adding 2ml of concentrated HCl. The mixture was magnetically stirred well for 45 min., and then obtained the sol-gel. TiO_2 was characterized by TEM, it was used for treating of different substrate fabrics with (MCT-β-CD).

2.7. Antimicrobial finishing

The fabric samples were immersed twice in an aqueous solution containing (MCT-β-CD) at 40g/l and different concentrations between (15&20g/l) of mother solution of synthesized Ag-NP's. Then adjusted the pH at 11, to wet pick-up 80 %, followed by drying at 100^0C /5min then fixed at 120^0C / 2 min. The treated fabric samples were washed under running water for 5 min, to remove any untreated of (MCT-β-CD) and finally dried at room temperature.

2.8.Treatment of fabrics for imparting multifunctional finishes (Antimicrobial/UV-Protection/Self-cleaning)

The motorcyclist may be exposed to sun rays for several hours during driving. The helmet should provide protection from UV rays, which have negative effects on human. These rays pass from the helmet outer shell until reach the inner layer of the padding which sits next to the head. Therefore, to impart more protection to this layer, the fabrics were treated with TiO_2-nanoparticles to gain antimicrobial, UV-Protection and self-cleaning properties in one-step.

The fabric samples were padded twice in a finishing formulation containing 40g/l (MCT-β-CD) and aqueous solution of TiO_2-nano sol-gel (15&20 g/l) as self-cleaning and antimicrobial/UV-Protection agent at pH=11, to wet pick-up 80 %. After that, it was followed by drying at 100^0C /5min., and then fixed at 120°C/ 2 min. The treated fabric samples washed under running water for 5 min to remove any untreated of (MCT-β-CD) and finally dried at room temperature before testing. The chemical reactions that occur during the formation of TiO_2-NP's by a mixture of titanium tetraisopropoxide (Ttp) as precursor along with 2-propanol and nitric acid as follows:

i) Hydrolysis

$Ti(OR)_n + H_2O \longrightarrow Ti(OR)(OR)_{n-1} + ROH$

$Ti(OR)(OR)_{n-1} + H_2O \longrightarrow Ti(OR)_2(OR)_{n-2} + ROH$

ii) Condensation

$\equiv Ti\text{-}OH + HO\text{-}Ti \equiv \longrightarrow \equiv Ti\text{-}O\text{-}Ti \equiv + H_2O$

$\equiv Ti\text{-}OH + HO\text{-}Ti \equiv \longrightarrow \equiv Ti\text{-}O\text{-}Ti \equiv + H_2O$

Where R: is an isopropxide group, $\equiv Ti\text{-}O\text{-}Ti \equiv$ is a colloidal oxide network in the sol form.

Iii) Gel formation / fixation of titanium cluster TiO_2-nanosol network $\xrightarrow{\Delta}$ gel formation.

2.9. Self-cleaning finishes and testing

The untreated and TiO_2-loaded fabric samples were dipped in a basic blue dye solution (1% owf) for 15min. for staining, then dried and conditioned. The samples were exposed to day light irradiation for 12 hr. The color strength, expressed as K/S value, of untreated and TiO_2-loaded fabric samples was measured. The K/S values are directly proportional to the amount of dye presented on the substrate .The decrease in K/S values is a direct consequence of the degradation of the dye stains [13,14]. It is determined according to the following relation:

Extent of discoloration (%) = $\mathbf{(K/S)_a \times 100 \backslash (K/S)_b}$

Where $(K/S)_a$ is the color strength after exposing to daylight , and $(K/S)_b$ is the color strength before exposing to daylight .

$K/S = (1-R)^2/2R$, where K/S is the ratio of absorption and scattering coefficient and R is the reflectance at the wave length of maximum absorbance of the used basic dye.

2.10. Testing and Analysis

The tests were conducted on all samples after conditioning for 24 hours under the standard atmospheric conditions (20±2°C, 65±2% RH). The physical and mechanical tests were performed on the fabrics before and after applying the chemical treatments. These tests were tensile strength and elongation according to ASTM D-5035, mass per unit area (weight) according to ASTM-D3776, thickness according to ASTM D-1777, air permeability according to ASTM D-737.Water permeability according to ASTM D-461 and wetability according to AATCC test method 392-1993.

Nitrogen content (N%) was determined according to micro-kjeldahl method. Color strength (K/S) values were determined from the reflectance measurements using Kubleka-Munk equation. Self-cleaning action of the TiO_2-loaded substrates were assessed, as described elsewhere. UV-Protection factor (UPF) was determined according to the Australian /New Zealand Standard AS/NZS (4399-1996).

The morphology and particle size of Ag-NP's and TiO_2-NP's were obtained by transmission electron microscope (TEM) using a JEOL JEM 2100F electron microscope. The surface morphology of selected samples was observed with SEM Model Quanta SEM 250 FEG (Field Emission Gun) attached with EDX unit (Energy Disperse X-ray Analysis with accelerating voltage -30KV FEI Co., Netherlands) for the composition analysis of nano-Ag and TiO_2-loaded fabric samples. Antibacterial activity assessment against G+ve (S.aureus) and G-ve (E.coli) bacterial was evaluated qualitatively according to AATCC test method (147-1988), and expressed as a zone of growth inhibition (ZI, mm). Test results of both untreated and treated samples were evaluated using radar charts for determining the best sample performance, providing comfort and protection during wearing.

3. Results and Discussion

The study investigated the functional performance of the woven fabrics produced for using in the padding with respect to its physical, mechanical and chemical properties that fulfill comfort properties as presented in the following results.

3.1. Tensile strength and Elongation:

Figure 2 shows the results of tensile strength test of fabrics in warp and weft direction. The blended fabrics (cotton/flax) woven with twill 1/4 weaves recorded the highest value of tensile strength, while the blended fabrics (cotton/polyester) woven with weft rib 2/2 weaves recorded the lowest value of tensile strength in warp direction. This is due to the tenacity of cotton and flax yarns, since they contain high number of twists, which leads to increasing the strength of the single yarns. In addition, the twill 1/4 weaves contains long floats inside the structure, which increases the coefficient of filling yarns within the floats. Also, it was shown that the blended (cotton/polyester) fabrics woven with twill 1/4 weaves recorded the highest value of tensile strength in weft direction; this is due to the twill 1\4 structure, which increases the tenacity of fabric. While the blended fabrics (cotton/polyester) woven with weft rib 2/2 weaves recorded the lowest value of tensile strength in weft direction.

Figure 3 shows the results of elongation at break of fabrics, it is clear that the blended fabrics (cotton/flax) woven with weft rib 2/2 weaves recorded the highest value of elongation. This is due to the morphological structure of the natural fibers and natural twists found in it, which keeps air gaps between the fibers throughout spinning. Thus helps in increasing the elongation during exposure of the yarns to load. While the blended fabrics (cotton/polyester) woven with weft rib 2/2 weaves recorded the lowest value of elongation in warp direction. Also, it was shown that the blended fabrics (cotton/polyester) woven with twill 1/4 weaves recorded the highest value of elongation in weft direction. This is due to twill 1/4 structure that contains floats which offers easy movement for the yarns within the fabric, hence increases the elongation. While the cotton fabrics woven with weft rib 2/2 weaves recorded the lowest value of elongation in weft direction, this is due to that the compact yarns in structure as well as the twists in the cotton yarns.

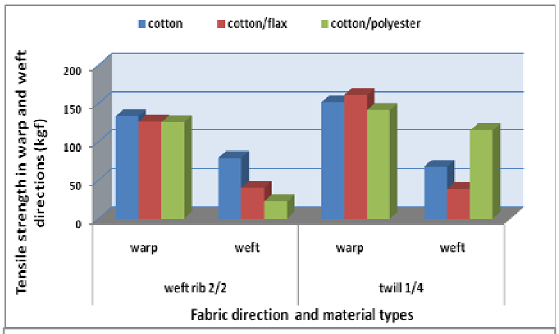


Figure 2. Tensile strength values in warp and weft directions of fabric samples.

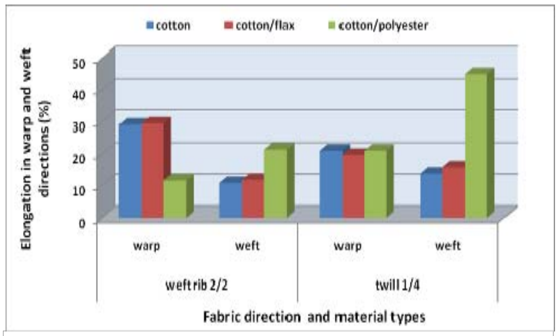


Figure 3. Elongation at break values in warp and weft directions of fabric samples.

3.2. Air Permeability:

Figure 4 shows that the blended fabrics (cotton/flax) woven with twill 1/4 weaves recorded the highest value of air permeability, while the 100 % cotton fabrics woven with weft rib 2/2 weaves recorded the lowest value of air permeability. This is due to twill 1\4 structure that contains long floats, which make it looser, increases the size of air gaps between the interlaced yarns in the structure, and thus increases the air permeability.

3.3. Water Permeability:

Figure 5 shows that the blended fabrics (cotton/polyester) woven with weft rib 2/2 weaves recorded the highest value of water permeability, while the blended fabrics (cotton /flax) woven with twill 1/4 weaves recorded the lowest value of water permeability. This is due to that the rate of absorption in the natural materials is higher than that in synthetic materials, because they are hydrophilic fibers. When absorbing the water they become bulkier, thus closing the inter-spaces between the yarns and decreasing the rate of water transmission.

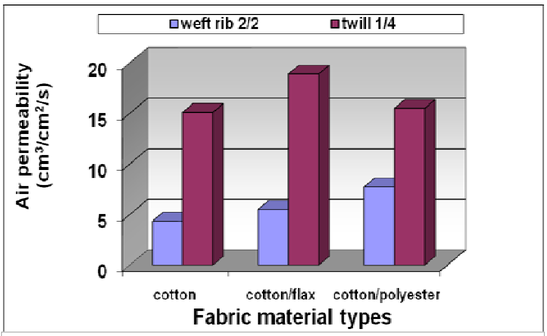


Figure 4. Air permeability values of fabric samples.

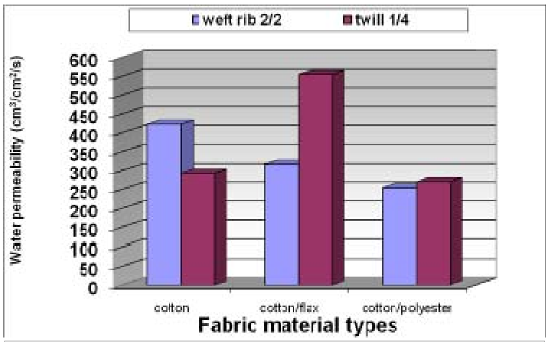


Figure 5. Water permeability values of fabric

3.4. Wetability:

Figure 6 shows that cotton fabrics woven with weft rib 2/2 weaves recorded the highest value of wetability. This is due to using natural material like cotton fibers in warp and weft yarns, which takes time for water to appear on the fabric surface for a high degree of absorption. In addition to the weft rib 2\2 structure that has high number of intersections per unit area compared with the other structure used, which reduces the percentage of wetability. While the blended fabrics (cotton /polyester) woven with twill 1/4 weaves recorded the lowest value of wetability, and this returns to the twill structure which has long floats ,thus gives the ability to the passage of water through the structure pores more than adsorption on the surface.

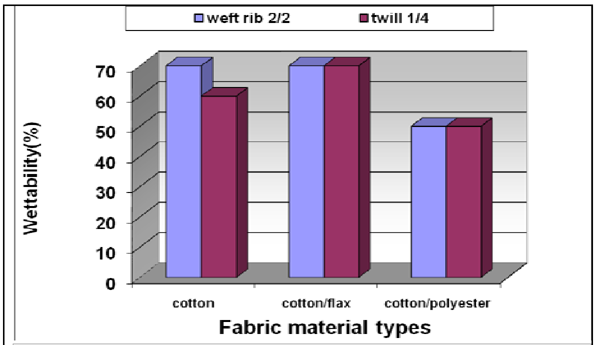


Figure 6. Wetability values of fabric samples.

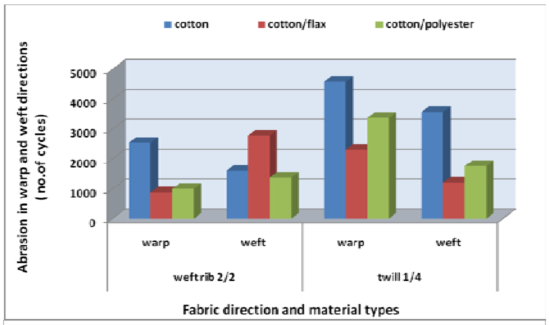


Figure 7. Abrasion values in warp and weft directions of fabric samples.

3.5. Abrasion resistance:

Figure 7 clarifies that the 100 % cotton fabrics woven with twill 1/4 weaves recorded the highest values of abrasion resistance in warp and weft directions and this can be referred to the twill 1/4 structure. Also, the blended fabrics (cotton/flax). woven with weft rib 2/2 weaves recorded the lowest values in the warp direction. While the blended (cotton /polyester) fabrics woven with weft rib 2/2 weaves recorded the lowest values in the weft direction.

Evaluation of fabrics performance

Figures 8-10 show the evaluation of the fabric samples test results. It was found that, the 100% cotton sample weaved with twill 1\4 structure achieved the highest area of radar chart statistical analysis for all tests which represented the functional purpose of comfort, followed by the (cotton/polyester) weaved with weft rib2/2 structure .Then the 100% cotton sample weaved with weft rib 2\2 structure and the (cotton \flax) weaved with twill 1\4 structure.

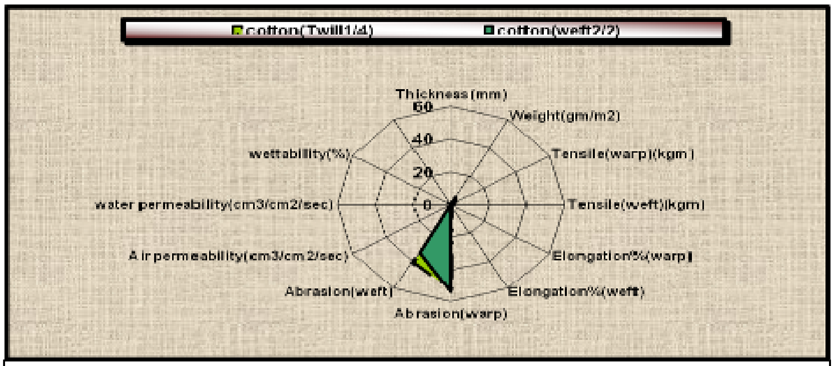


Figure 8. Evaluation of the 100% cotton fabrics properties.

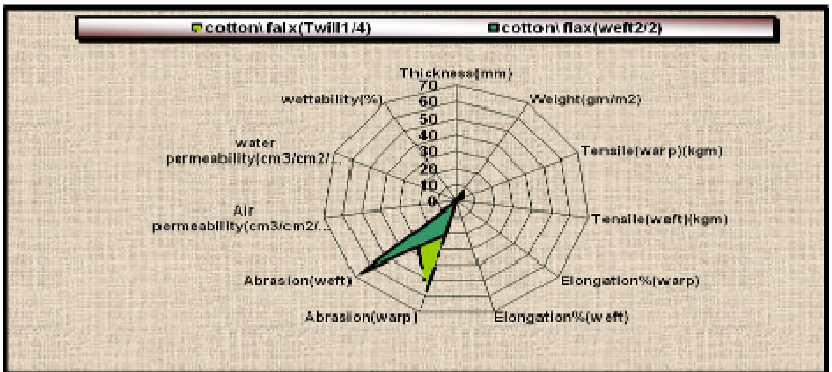


Figure 9. Evaluation of the (cotton/flax) fabrics properties.

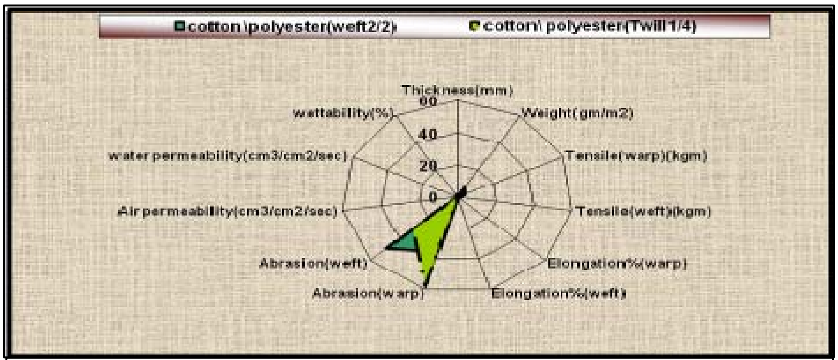


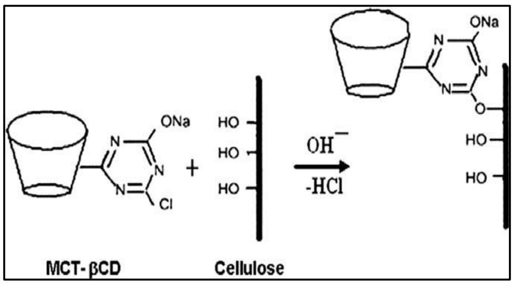
Figure 10. Evaluation of the (cotton\polyester) fabrics properties.

4. Treatment and functional finishing:

Chemical treatments for gaining protection properties from bacteria and UV rays , in addition to self-cleaning properties were applied on the fabric samples that achieved the comfort properties in terms of the mechanical and physical properties. The blended fabric (cotton /flax) with twill 1/4 weaves was proposed for applying the chemical treatments to obtain the optimum conditions. It was selected due its high mechanical properties which ensuring its suitability to different treatments conditions, aiming to improve the functional properties, since it is manufactured from blending two natural fibers. The most important physical tests studied after applying chemical treatments were air and water permeability tests, which are directly related to the thermal comfort and moisture transfer during wearing the helmet.

4.1. Effect of the concentration of Monochlorotriazinyl-β-cyclodextrin (MCT-β-CD)

It was clear in table 2 that increasing the concentration of (MCT-β-CD) in the range studied (4-10%) loaded on the (cotton/flax) with twill1/4 weaves at pH=11, leads to increasing of N % from 0.4 to 0.60. Any further increase of (MCT-β-CD) above 6% had no effect on N%, this confirmed the fixation of (MCT-β-CD) onto/into the (cotton/flax) twill1/4 fabric where the presence of (MCT-β-CD) as a reactive polysaccharide on the fabric as shown in scheme 1. As well as by increasing the concentration of (MCT-β-CD), the tensile strength and elongation increased, but air permeability decreased due to coating of β-CD on the pores of fabric. The water permeability had its highest value at 6% of the (MCT-β-CD) then decreased due to the absorption of water by the natural materials. Tables 3&4 show the effect of curing temperature and curing time on the treated fabric (cotton/flax) twill1/4 weaves. It was clear that N % recorded its highest value at curing temperature 120^{0}C, at time 2 min. This confirming that the optimum condition to fix (MCT-β-CD) is at 120^{0}C for 2 min. Figure 11 shows the morphology of the (cotton\flax) fabric before and after treatment with (MCT-β-CD); (a) untreated which was significantly different from the treated one (b). It can be seen the agglomeration of (MCT-β-CD) on the surface of (cotton/flax) twill1/4 fabric.



Scheme 1. Treatment of (MCT-β-CD) on fabric.

Table 2. Effect of changing (MCT-β-CD) concentration on fabric properties

Conc.of (MCT-β-CD) %	N %	Air permeability ($cm^3/cm^2/s$)	Water permeability ($cm^3/cm^2/s$)	Wetability (%)	T.S. warp (kgf)	EL. warp (mm)	T.S. weft (Kgf)	EL. weft (mm)
2	-	17.36	0.54	50	65	14	65	16
4	0.40	16.72	0.59	70	133	38	80	21
6	0.58	16.12	0.66	70	135	29	70	22
8	0.58	16.64	0.59	80	143	33	50	22
10	0.60	16.48	0.58	80	105	35	65	18

Condition: Cotton/flax (twill1/4) fabric; pad/dry/cure method; 80% wet pick-up; drying at 100^{0}C for 5 min.; and curing at 140^{0}C for 2 min.; pH =11.

Table 3. Effect of changing curing temperature on the treatment using MCT-β-CD

Curing temp. (^{0}C)	N %	Air permeability ($cm^3/cm^2/s$)	Water permeability ($cm^3/cm^2/s$)	Wetability (%)	T.S. warp (kgf)	EL. warp (mm)	EL. Weft (mm)	T.S. Weft (Kgf)
120	0.40	17.48	0.55	80	170	40	18	60
140	0.33	16.04	0.43	100	160	38	20	70
160	0.33	16.88	0.55	100	153	40	20	70
180	0.12	16.08	0.55	100	158	42	18	60

Condition: Cotton/flax (twill1/4) fabric**;** pad/dry/cure method,4 % (MCT-β-CD); 80% wet pick-up; drying at 100^{0}C for 5 min.; curing for 2min.; pH =11.

Table 4. Effect of changing curing time on the treatment using MCT-β-CD

Curing time (min.)	N %	Air permeability ($cm^3/cm^2/s$)	Water permeability ($cm^3/cm^2/s$)	Wetability (%)	T.S. warp (kgf)	EL. warp (mm)	T.S. Weft (Kgf)	EL. Weft (mm)
1	0.30	17.55	0.39	70	142	28	65	18
2	0.35	16.32	0.52	80	132	35	78	20
3	0.35	16.88	0.40	60	155	37	60	18
4	0.32	15.96	0.49	60	105	38	72	12

Condition: Cotton/flax (twill1/4) fabric**;** pad/dry/cure method;4 % (MCT-β-CD); 80% wet pick-up; drying at 100^{0}C for 5 min.; curing at 120^{0}C/1,2,3&4 min.; pH =11.

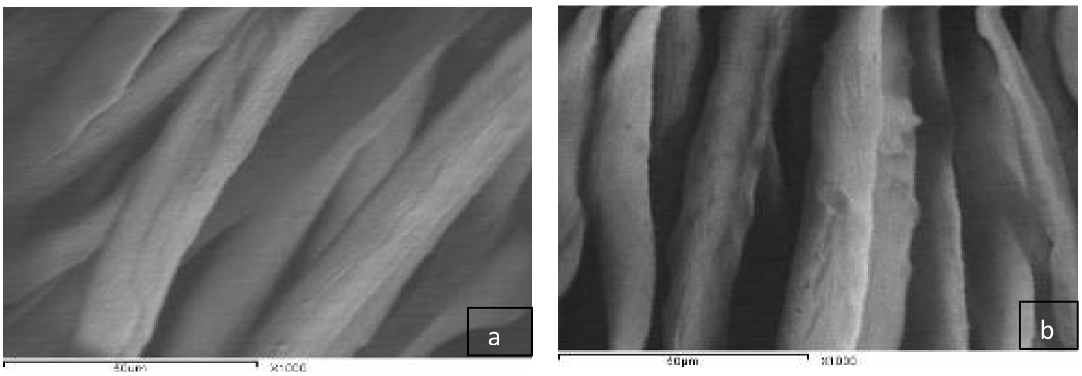


Figure 11. SEM images of cotton\flax (twill1/4), a; untreated sample, b; treated sample with 4 % (MCT-β-CD).

4.2. Treatment with antimicrobial finishing by Ag-NP's

After synthesis of Ag-NP's characterized by TEM micrograph as shown in figure12 demonstrating the colloidal solution and dispersion of mother solution which has the particle size between 6-9 nm. Table 5 shows the antimicrobial activity of the various treated fabric samples. The fabric samples; (100% cotton) twill1/4, (cotton/polyester) weft rib 2/2 and (cotton\flax) twill 1\4 was treated with (MCT-β-CD) at 40g/l with different concentration between (15& 20g/l) of mother solution of synthesized Ag-NP's to impart the fabric with antibacterial functionality. Then its efficiency was tested and evaluated against the selected bacteria (E.coli) and (S.aureus). It was clear that the antibacterial activity of the silver nanoparticles had its highest value in (100% cotton) twill1/4 > (cotton/polyester) weft rib 2/2 > (cotton/flax) twill1/4 respectively. This is evidence that silver nanoparticles are in inclusion with (MCT-β-CD) and loaded with fabrics. This antibacterial activity occurred due to the possible damage of DNA via interaction of Ag-NP's with sulfur or phosphorous containing protein ,and its negative impacts on the respiratory chain or cell division process thereby causing a cell death, ionic interaction between the cytoplasm membrane of the bacteria and Ag-ions released from Ag-NP's as follows:[19].

$O_{2\,(aq.)} + 4H_3O^+ + 4Ag_{(S)} \rightarrow 4Ag^+_{(aq.)} + 6H_2O$

The formation of active oxygen is according to the following reaction:

$$Ag + H_2O + 1/2O_2 \rightarrow H_2O_2 \rightarrow H_2O + O$$

Table 5. Antimicrobial activity of Ag-NP's

Fabric materials	Weaving structures	Conc.of Ag-NP's (g/l)	Antimicrobial test		Air permeability ($cm^3/cm^2/s$)	Water permeability ($cm^3/cm^2/s$)
			G(+ve) mm	G (-ve) mm		
Cotton /Flax	Twill 1/4	15	10	8.1	16.18	0.38
Cotton/ Polyester	Weft rib2/2	15	11	9.5	14.25	0.45
Cotton	Twill 1/4	15	14	12	15.89	0.28
Cotton /Flax	Twill 1/4	20	11	9.1	16.34	0.47
Cotton/ Polyester	Weft rib2/2	20	15.5	13	14.26	0.44
Cotton	Twill 1/4	20	21	20	14.78	0.15

Condition: pad/dry/cure method; 4 % (MCT-β-CD); (15& 20g/L Ag-NPs); 80% wet pick-up; drying at 100^0C for 5 min.; curing at 120^0C\ 2 min.; pH =11.

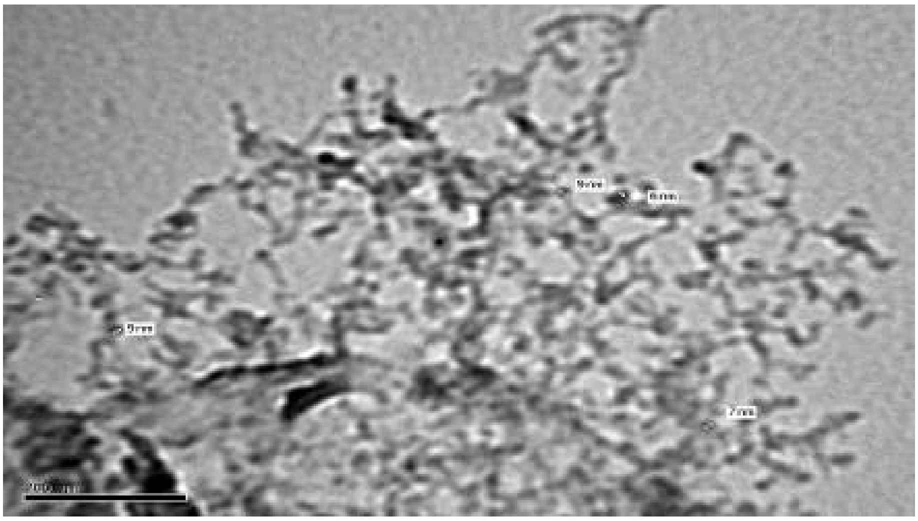


Figure 12. TEM image of Ag-NP's.

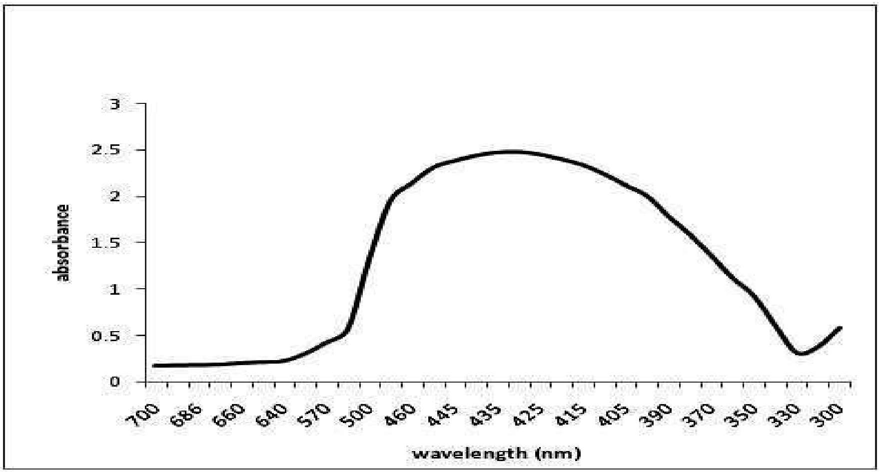


Figure 13. UV.vis- spectroscopy of Ag nanoparticles.

Figure 13 shows the UV Spectrum of Ag nanoparticles solution. It is clear from the figure that the characteristic surface plasmon (sp) resonance band of Ag nanoparticles centered at 430 nm.

4.3. Treatment of fabrics with Antimicrobial /UV-Protection/Self-cleaning Finishes

The morphology of the prepared TiO_2 particles was observed by TEM as shown in figure 14. The TiO_2 particles were spherical and small with average diameter between 3.7 to 6 nm and the particle size is almost uniform with narrow size distribution. Table 6 shows variations in performance and functional properties of the cotton (twill 1\4), cotton/polyester (weft rib2/2) and cotton/flax (twill1/4) which were treated by (MCT-β-CD) at 40g/l and different concentration between (15 and 20g/l) of mother solution of synthesized TiO_2-nanoparticles.

This result indicates the fixation of the TiO_2-NPs via inclusion with β-CD onto the finished fabric samples to impart antimicrobial properties against G+ve (E.coli) and G-ve (S. auereus) bacteria. Also, the zone of inhibition of Gram +ve bacteria was greater than that of Gram-ve bacteria .Regard the finishing of different substrates, the highest value of antimicrobial activity was in cotton (twill 1\4) > cotton/polyester (weft rib 2/2) >cotton/flax (twill 1/4). Additionally, the results also indicated that there was an improvement in UV-Protection, expressed as UPF values compared with the untreated ones, this enhancement in UPF values reflects the scattering /absorption ability of the TiO_2-NP's finished fabric surface [21]. The photocatalytic effect activity of TiO_2-NP's inclusion with β-CD onto the finished fabric samples, which was immersed in 0.1% of basic dye, then exposure to sunlight for 12 hours to compare the high self-cleaning performance with the untreated ones using stain release replica. Additionally, the extent of discoloration of basic dyed/finished fabric samples is far greater than the untreated ones, which expressed by the k/s, consequence of generation of highly oxidative free radicals such as HO, and HO_2 and their photocatalytic degradation effect on the dye stains under the visible light irradiation [22,14].

Figures 15&16 show that the EDX spectrum of Ag-NP's and TiO_2-NP's respectively, which confirm the presence of silver and TiO_2-nanoparticles on the treated cotton/polyester (weft rib 2/2) fabric. Figure 17 show that, the best fabric samples performance treated with 20 g\l TiO_2 after applying the self-cleaning test, A; (cotton\flax) fabric sample with twill 1\4 weaves, B; cotton\polyester fabric sample with weft rib2\2 weaves, and C; cotton fabric sample with twill 1\4 weaves. The light color area shows the self-cleaned part due to the K/S values, which are directly proportional to the amount of dye presented on the substrate. The decrease in K/S values is a direct consequence of the degradation of the dye stains.

Table 6. Effect of TiO_2- NP's on the extent of multifunctional (antimicrobial /anti-UV/self-cleaning)

Fabric material	Weaving Structure	Conc.of TiO_2-NP's (g/l)	Bacteria Zone of inhibition		UPF	K/S		Air permeability ($cm^3/cm^2/s$)	Water permeability ($cm^3/cm^2/s$)
			G(+ve) mm	G(-ve) mm		0	12hrs.		
Cotton\flax /Flax	Twill 1/4	15	12	10	48	7.20	0.43	16.68	0.15
Cotton/Polyester	Weft rib2/2	15	12	11.5	40	2.96	0.21	13.31	0.16
Cotton	Twill 1\4	15	18	15	35	5.34	0.27	14.88	0.11
Cotton\flax /Flax	Twill 1/4	20	15	12	52	8.27	0.28	15.54	0.17
Cotton/polyester	Weft rib2/2	20	15	13	45	3.11	0.24	13.48	0.32
Cotton	Twill 1\4	20	20	18.5	38	5.18	0.40	14.37	0.19

Condition: pad/dry/cure method; 4 % (MCT- β-CD) ; (15,20g/L TiO_2-NPs) ; 80% wet pick-up; drying at 100^0C for 5 min.; curing at 120^0C\2 min, pH =11.

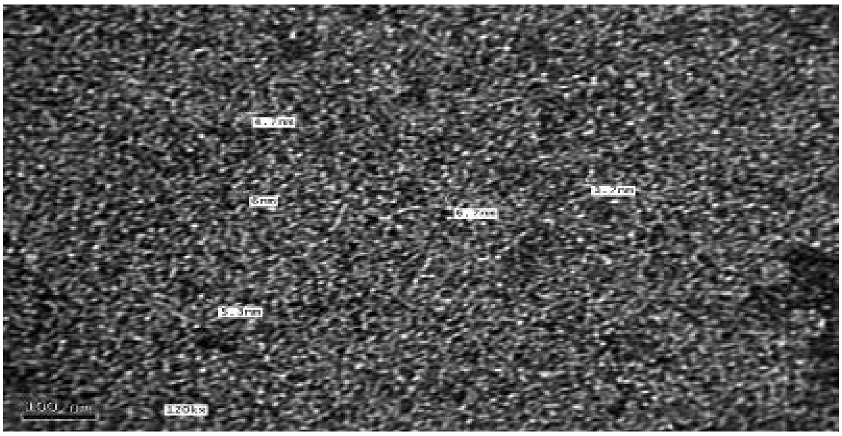
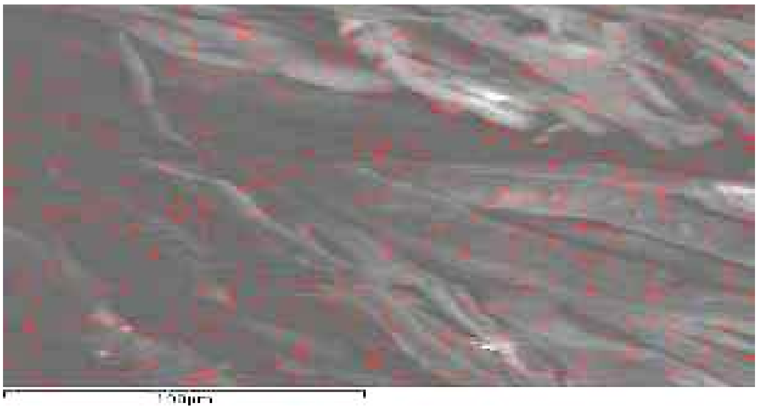
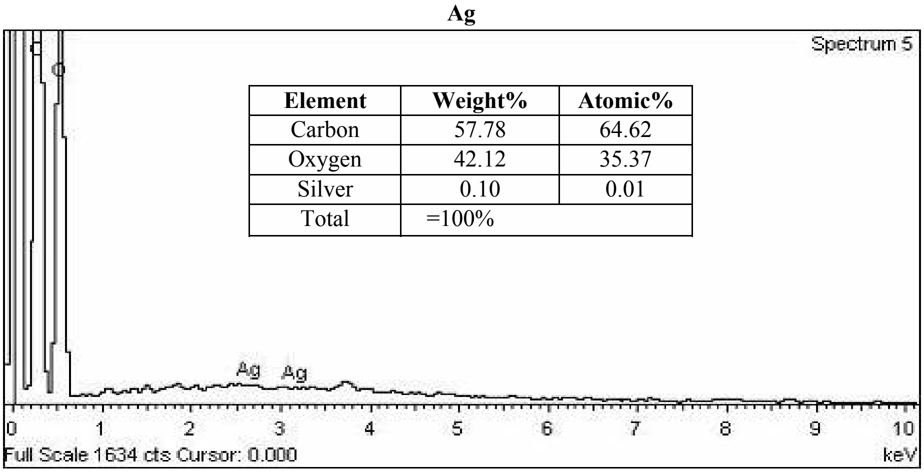


Figure 14. TEM of TiO_2.



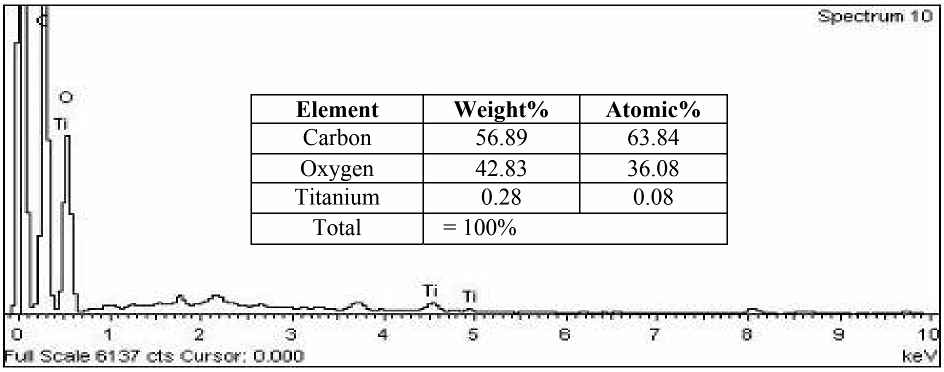
Ag



Element	Weight%	Atomic%
Carbon	57.78	64.62
Oxygen	42.12	35.37
Silver	0.10	0.01
Total	=100%	

Figure 15. EDX Spectrum of Ag-NP's on treated Cotton/polyester (weft rib 2/2).

TiO_2



Element	Weight%	Atomic%
Carbon	56.89	63.84
Oxygen	42.83	36.08
Titanium	0.28	0.08
Total	= 100%	

Figure 16. EDX Spectrum of TiO2-NPs on treated Cotton/PET(weft rib 2/2)

Figure 17. Fabric samples treated with TiO_2 after applying the self-cleaning test.

Evaluation of fabrics performance after applying multifunctional finishes

Figure 18 show the evaluation of the fabric samples test results after treatment with 20g\l TiO_2 to be proposed for using in the inner padding layer of the helmet, produced from 100% cotton, (cotton/flax) and (cotton/polyester) materials with weaving structures twill1/4 and weft rib2\2). It was found that, the 100% cotton treated sample weaved with twill 1\4 achieved the highest radar area for all tests. Revealing that it accomplished the functional performance of comfort and protection, followed by the (cotton/polyester) fabric weaved with weft rib 2/2 structure and the (cotton\flax) fabric weaved with twill 1\4 structure.

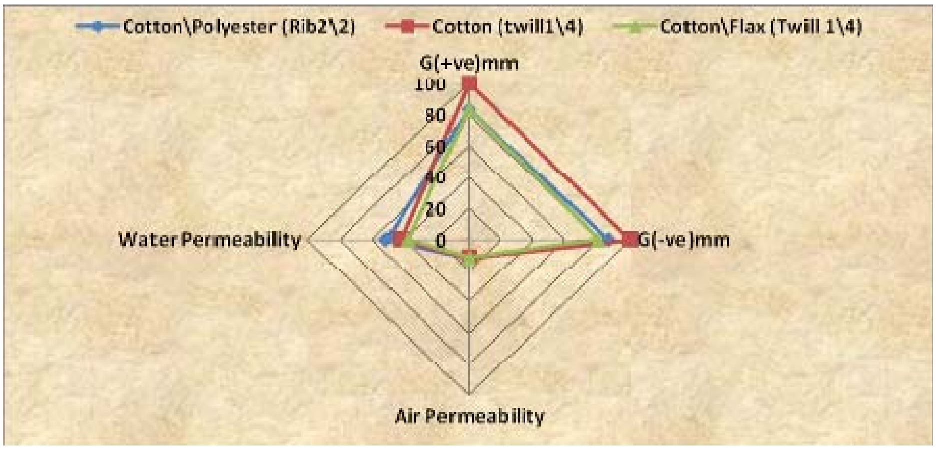


Figure 18. Evaluation of fabric samples treated with 20 g\l TiO_2.

4. Conclusion:

The inner padding layer of the motorcycle helmet is a vital layer that provides comfort during wearing the helmet while driving, especially for long-distances. This research had worked on the development of the helmet padding inner soft fabric layer structure, in order to afford comfort and protection properties. Woven fabrics with different structure parameters were used for applying multifunctional finishes. The results showed that the 100% cotton fabrics with twill 1/4 and weft rib 2\2 structures achieved the best functional performance, in addition to the (cotton/polyester) fabric with weft rib 2/2 structure and the (cotton\flax) fabric with twill 1\4 structure. Then, the fabrics were treated with (MCT-β-CD), $AgNO_3$ nanoparticles and TiO_2 nanoparticles on several stages to reach the optimum condition for the treatments, to impart multifunctional properties (Antibacterial protection, UV resistance and Self-cleaning).The effectiveness of these finishes was investigated and evaluated by surface morphology and testing. It was revealed from the results of evaluation that the 100% cotton treated fabric with twill 1\4 structure was the best sample in achieving the purpose of comfort in the inner padding layer efficiently**.**

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