Multifunctional Laminated Composite Materials for Protective Clothing

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*Abstract***— Protective clothing performs a vital role in maintaining the safety of human in workplace. The developments in this field are proceeding to fulfill the needs with multifunctional materials at competitive costs. Recently, the protective clothing field introduces the usage of composite materials taking advantage of their outstanding properties. In this paper, the multifunctional performance of hybrid laminated composites (HLC) was investigated aiming to be utilized in protective clothing. The influences of reinforcement and resin properties on the physical properties of the laminated composites and their resistance to puncture load and UV transmittance were studied. ANOVA test was used for the statistical analysis of the results. The results showed that, the reinforcement material and structure and the fiber/matrix interface have major influences on the laminated composites performance. It was revealed that, the HLC fabricated from (polyester/glass) fabric with satin 4 structure and nonwoven glass fiber mat exhibited the best functional performance**.

Keyword- Hybrid laminated composites, Protective Clothing, Physical properties, Puncture resistance, UV transmittance.

I. INTRODUCTION

Protective clothing is considered one of the most interesting and rapidly growing areas in the technical textiles market. The main factors driving for this development are the requirements concerned with human health and safety during work. Personal protective equipment (PPE) is used to reduce worker exposure to hazards when engineering and administrative controls are not effective to reduce these risks to acceptable levels. The protective clothing (PC) field is diverse and involves many areas; each has its own requirements and special materials [1],[2]. PPE include a wide range of items and can be divided into six major categories according to the area needed to be protected such as: eye and face, head, foot and leg, hand and arm, body and hearing. PPE consist of both flexible and rigid components. Flexible components include textiles and films, either polymeric or metallic. Rigid components may include plastic, metallic, ceramic and fiber reinforced composites. There are several types of hazards that protective clothing can help in reducing exposure to such as: mechanical, chemical, biological, thermal, electrical, noise, radiations…etc. In addition, most situations involve a combination of several types of hazards, thus requiring a multirisk approach [3]-[5]. In the absence of appropriate protection, this may eventually lead to the need for superimposed layers of protective clothing, each corresponding to a certain type of risk, with all the drawbacks this implies in terms of loss of dexterity and motion freedom, among others [6]. The demand for healthy lifestyle and comfort in addition to protection requirements drives to explorer new techniques to impart more functional properties in textiles. Since, it controls the impact of PPE on task performance and the wearer's health. Many of the "high-tech" fibers and products, such as Kevlar, Nomex, Spectra, Carbon, Aramid, Fiberglass…etc., even Steel, Copper and other metal fibers have applications in the protective clothing areas. Conventional materials such as nylon and polyester, cotton and wool are also used and provide satisfactory protection in certain applications depending on the type of hazard or exposure [1],[7].

Textile composite materials are suitable for the making of protective garment and accessory to afford protection against weather hazards, high shocking/impacting, flame retardant or toxic chemicals. Composites are the material of choice for light-weight structures, due to their excellent weight/strength and weight/stiffness properties. They consist of a combination of materials which are mixed together to achieve specific structural properties, that are superior to the properties of the individual materials from which it is constructed [8]-[10]. Puncture resistance is among the major mechanical properties required in protective clothing [11]. Its efficiency in fabrics is affected by using composite materials and coatings. Hassim , N. *et al.* [12] investigated the puncture resistance of nonwoven natural rubber latex unidirectional (NRL-UD) coated fabrics. It was indicated that, the NRL-UD coated fabrics gave higher puncture resistance than the uncoated fabrics, and the fabric structure had an influence on the puncture resistance of fabrics due to different interlacing points. Lin, C.C. *et al.*[13] studied the puncture resistance of multi-layer integrated composites comprised of glass fabric or Kevlar fabric as reinforcement and nonwovens. The results showed that, the puncture force increases linearly with number of layers. Sun, B. *et al.* [14] studied the puncture behaviour of woven fabrics using finite element analysis and experimental tests. It was reported that, yarn strength and behaviour affected on the fabric puncture resistance. Puncture resistant materials are used for protective armor, gloves, helmets, boots, and shields [15].

Another important property needed to be provided in protective clothing which is ultraviolet radiation (UVR) resistance. The increasing awareness of the negative effects of UVR and regular effective protection are actual themes in general public in many countries. High, short-term exposure to UVR from the sun causes sunburns and long-term exposure leads to skin cancer [16],[17]. The UVR band consists of three regions: UV-A (320 to 400 nm), UV-B (290 to 320 nm) and UV-C (200 to 290 nm). UV-C is totally absorbed by the atmosphere and does not reach the earth. UV-A causes little visible reaction on the skin but has been shown to decrease the immunological response of skin cells. UV-B is most responsible for the development of skin cancers [18]. Fabrics or clothing have the ability to absorb, reflect, or scatter radiant energy thereby preventing the radiant energy from reaching the skin. A fabric's ability to block UVR depends on fiber chemistry; fabric construction particularly porosity, thickness and weight; moisture content and processing history of the fabric such as dye concentration, fluorescent whitening agents, UV-absorbers, and other finishing chemicals that may have been applied to the textile material. UV radiation is also known to be damaging to aramid fibers, while carbon and glass fibers are insensitive to UV exposure [19],[20]. Polymers with pendant aromatic ring groups, such as polyester and polyvinylnaphathalene are known to show a new fluorescence band at longer wavelength under irradiation due to the interaction between excited and ground state aromatic groups, i.e. the formation of intermolecular excimers [21].

The aim of this work was to investigate the protection performance of new hybrid laminated composites (HLC) to be used in protective clothing for outdoor applications. The HLC were reinforced with woven fabrics and nonwoven glass fiber mat. SEM images were used for visual analysis of the specimens. The properties of the laminates such as weight and thickness as well as puncture resistance and UV transmittance were examined. Also, the influence of reinforcement and resin properties on the performance of the laminated composites was studied.

II. MATERIALS AND METHODS

A. Materials

In this study, nine types of woven fabrics were used; the fabrics were woven using polyester fibers as warp yarns and three types of weft materials. Three types of weaving structures were used with 10 ends/cm and 15 picks/cm. Nonwoven glass fiber mat was chosen to be used due to its good performance and cost effectiveness in the field of fiber reinforced composites. The specifications of the woven fabric samples and the nonwoven glass fiber mat used in the study are presented in tables I & II.

TABLE I
Woven Fabrics Specifications

Sample	Fabric materials	Weaving structure
1	Polyester 100%	Warp rib2/2
2	Polyester 100%	Twill 2\2
3	Polyester 100%	Satin 4
4	(Polyester/Polyamide)	Warp rib2/2
5	(Polyester/Polyamide)	Twill 2\2
6	(Polyester/Polyamide)	Satin 4
7	(Polyester/ Glass)	Warp rib2/2
8	(Polyester/ Glass)	Twill 2\2
9	(Polyester/ Glass)	Satin 4

TABLE II
Nonwoven Glass Fiber Mat Specifications

Material	Fiber Diameter (µm)	Thickness (mm)	Weight (g\m^2)
Glass fibers	12	0.65	144

B. Preparation of the Hybrid Laminated Composites

The hybrid laminated composite (HLC) samples were formed in a three layers structure as illustrated in figure 1. The HLC sample consisted of one layer of each type of the woven fabrics produced with two layers of the nonwoven glass fiber mat. The mould was prepared by adding a releasing agent to it. Polyester resin was used as the polymer matrix; it was mixed with suitable proportions of the accelerator and the catalyst, then the fabric samples were embedded in the resin matrix. The samples were fabricated by using the hand lay-up technique. After curing at room temperature, the HLC samples were prepared for testing to investigate their properties.

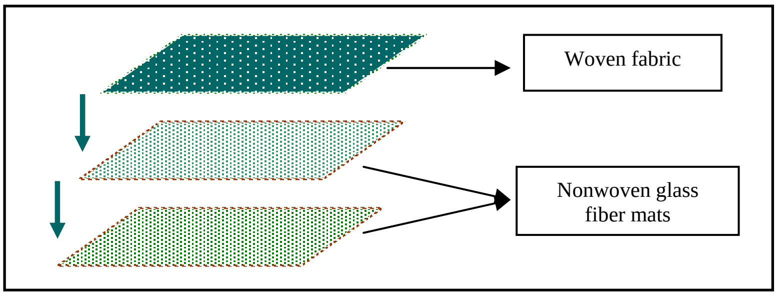

Fig.1. The Hybrid laminated composite structure.

C. Characterization of the Hybrid Laminated Composites

To evaluate the protection performance of the prepared hybrid laminated composites (HLC), numerous tests were conducted to characterize their physical and mechanical properties. The samples were put in standard testing conditions for 24 hours according to ASTM standard before testing. Mass per unit area (Weight) test was performed according to ASTM-D3776 [22]. Thickness test was performed according to ASTM D-1777 [23]. SEM was used to analyze the morphological images of the laminated composites. Puncture resistance test was carried out according to ASTM F-1342-05. This test method determines the puncture resistance of a material specimen by measuring the force required to cause a sharp-edged puncture probe to penetrate through the specimen [24]. The UV transmittance of the samples was examined using a UV-VIS/NIR Spectrophometer, JASCO. The tests were carried out in the Textile testing laboratory, Electron microscopy and thin films laboratory and the Central unit for analysis and scientific services at National Research Center.

D. Statistical Analysis

The tests results were statistically analyzed using two ways analysis of variance (ANOVA) test by the SPSS software. The test was performed for all the fabric samples and the HLC samples tests results at a level of significance ($P \leq 0.05$).

III. RESULTS AND DISCUSSION

The study displays all the results of the tests carried out on the fabric samples before and after application of polyester resin. The influences of reinforcement material and structure, in addition to the resin properties on the performance of the produced HLC samples were investigated.

A. Weight Test

Figure 2 shows the results of the weight test applied on the fabric samples before and after treatment with polyester resin. Before treatment, the fabrics weaved with satin 4 structure offered the highest value of weight especially for the (polyester/polyamide) blended fabrics, while the (polyester/glass) blended fabrics weaved with twill 2/2 structure offered the lowest values of weight and this is for one layer of the woven fabric. This is due to satin 4 weaving structure with high floats and fewer intersections which allow more yarns to compact together. After the addition of the glass fiber mat layers and treatment of the fabrics with polyester resin, the glass fiber mat porous structure help in good impregnation of the fibers with the resin. During the impregnation process, the resin flows through the pores created by the heterogeneous porous structure of the glass fiber mat and through the air gaps formed by the weaving structure in the woven fabrics, which leads to increasing weight of the laminates. The HLC samples fabricated from 100% polyester fabric weaved with twill 2/2 and rib2/2 structures with the glass fiber mat presented the highest values of weight. While the HLC fabricated from the (polyester/glass) blended fabrics weaved with satin 4 structure and glass fiber mat presented the lowest values of weight. This is due to the smoothness and gloss of glass fiber surface which allow less area for the resin to permeate, thus the weight decreased.

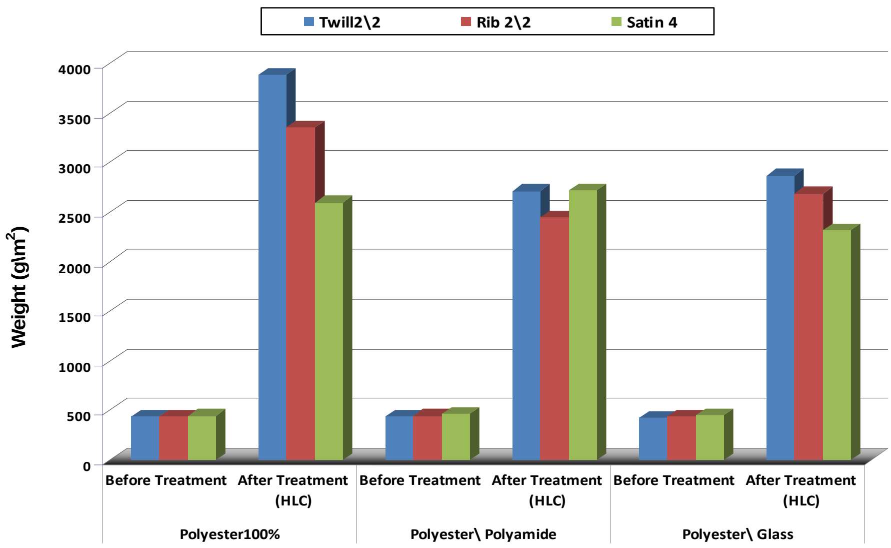

Fig.2. Weight values of the woven fabric samples before treatment and the HLC samples.

TABLE III
ANOVA Test for the Weight of the Woven Fabrics and the HLC Samples

Parameter	**Weight Before treatment**			**Weight After treatment (HLC)**		
	Total Means ± SD	**F**	**P. value**	**Total Means ± SD**	**F**	**P. value**
Weft Material	4.44364E2 ±11.17	77.7	0.000**	2.83132E3 ±474.98	457.7	0.000**
Weaving structure		300.3	0.000**		254.6	0.000**
Weft Material & Weaving structure		48.5	0.000**		135.5	0.000**

* Significance at (0.05).
**Significance at (0.01).

Table III shows the means and standard deviation of the samples weight before and after application of resin. It was pointed to that the material, weaving structure and the interaction between the material & weaving structure had a high significant influence on the weight of the woven fabrics before treatment and on the produced HLC samples.

B. Thickness Test

Figure 3 shows the results of the thickness test applied on the fabric samples before and after treatment with polyester resin. Before treatment, the polyester fabrics weaved with satin 4 structure recorded the highest value of thickness, while the (polyester/glass) blended fabrics weaved with twill 2/2 structure presented the lowest value of thickness and this is for one layer of the woven fabric. This is because of satin 4 structure fewer intersections which assist the floats to appear on the surface of fabric resulting in increasing the thickness of fabric. After treatment of the fabrics with polyester resin and the addition of nonwoven glass mat layers, the results generally showed that the twill 2\2 structure achieved high values of thickness compared with the other weaving structures used. The HLC fabricated from 100% polyester fabric weaved with twill 2/2 structure offered the highest values of thickness, while the HLC fabricated from the (polyester/glass) blended fabrics with satin 4 structure and glass fiber mat offered the lowest values of thickness. This due to glass fibers properties which are characterized by the presence of very thin continuous fibers in their cross section and thus they have low thickness.

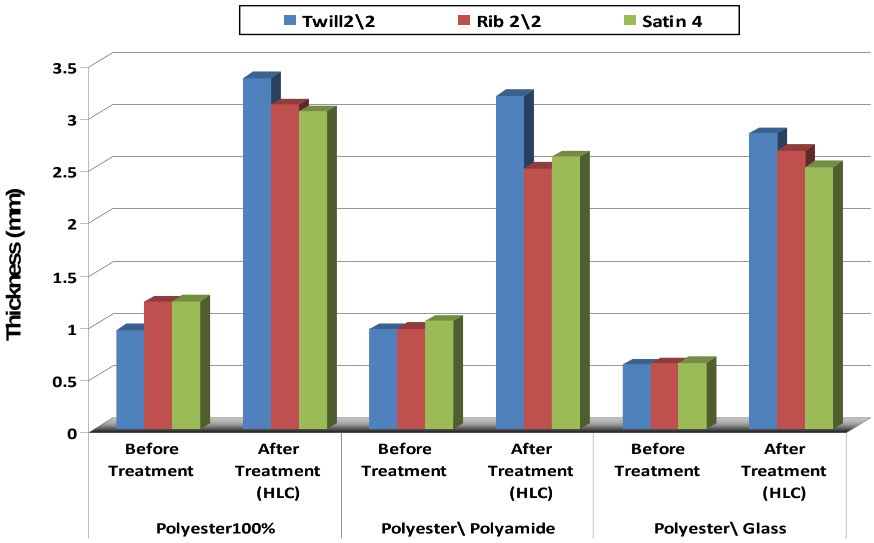

Fig.3. Thickness values of the woven fabric samples before treatment and the HLC samples.

TABLE IV
ANOVA Test for the Thickness of the Woven Fabrics and the HLC Samples

Parameter	Thickness Before treatment			Thickness After treatment (HLC)		
	Total Means ± SD	F	P. value	Total Means ± SD	F	P. value
Weft Material	0.91033 ±0.233	349.8	0.000**	2.859 ±0.328	30.8	0.000**
Weaving structure		22.6	0.000**		22.1	0.000**
Weft Material & Weaving structure		11.7	0.000**		2.9	0.049*

* Significance at (0.05).
**Significance at (0.01).

Table IV shows the means and standard deviation of the samples thickness before and after application of resin. It was pointed to that the material, weaving structure and the interaction between the material & weaving structure has significant influence on the thickness of the woven fabrics before treatment, and on the HLC samples.

C. Puncture Resistance Test

Figure 4 shows the results of the puncture resistance load test applied on the fabric samples before and after treatment with polyester resin. During applying load, puncture took place when the impact energy applied by the penetrator is absorbed by the sample. Before treatment, the (polyester/polyamide) blended fabrics weaved with twill 2/2 structure achieved high values of puncture resistance, followed by the polyester fabrics weaved with rib 2/2, while the (polyester/glass) fabrics recorded the lowest values. This can be interpreted due to nylon fibers low specific density and high specific volume, which lead more yarns to compact inside the air gaps of the fabric compared with glass fibers, which have low specific volume in addition to their smoothness and gloss which make them slide during applying load. After the addition of glass fiber mat layers and treatment of the fabrics with polyester resin, it was shown that, the HLC fabricated from the (polyester/glass) fabrics with satin 4 structure and glass fiber mat presented more resistance to puncture compared with the other samples. After load is applied, there is no delamination occurred between the laminate layers due to the good interfacial bonding between the fibers and the polyester resin, which enhanced the adhesion between them and adding more strength to the structure. There is matrix cracking damage happened but it didn’t propagate through the laminate structure, because of the good interlaminar fracture resistance and the glass fibers ability to bend and bearing loads. Also, the glass fiber mat porous structure allows more resin to fill in the gaps, thus gave the laminates high stiffness and increased their puncture resistance, although these laminates offered the lowest thickness. The satin fabric structure is highly pliable and stronger because of the presence of high floats as mentioned before. While the HLC fabricated from 100% polyester fabric with warp rib 2/2 structure presented the lowest values of puncture resistance. This is related to the fabric weaving structure with high yarns interactions that leads to increase the number of crimped yarns, and reduce the permeability of resin which affected on the laminate performance.

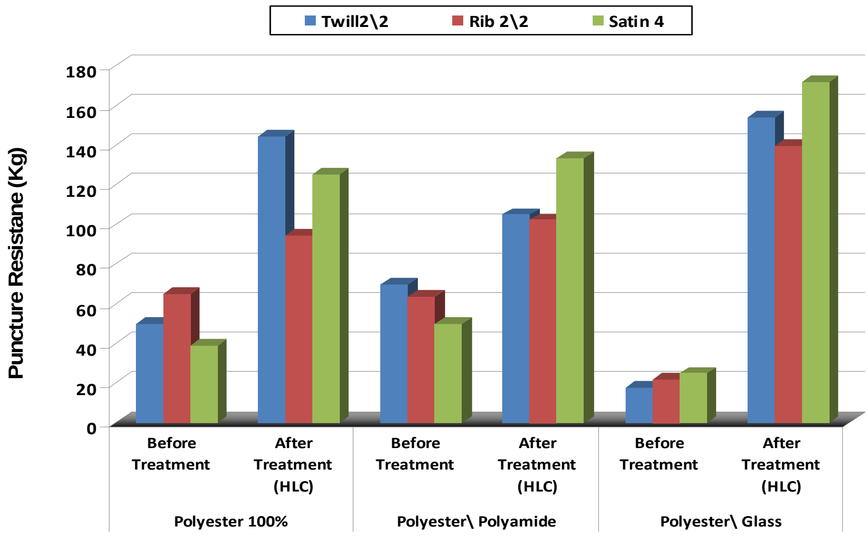

Fig.4. Puncture resistance values of the woven fabric samples before treatment and the HLC samples.

TABLE V
ANOVA Test for the Puncture Resistance Test of the Woven Fabrics and the HLC Samples

Parameter	Puncture resistance Before treatment			Puncture resistance After treatment (HLC)		
	Total Means ± SD	F	P. value	Total Means ± SD	F	P. value
Weft Material	4.46667E1 ±14.75	95.1	0.000**	1.30076E2 ±24.92	363.6	0.000**
Weaving structure		8.5	0.003**		192.6	0.000**
Weft Material & Weaving structure		6.5	0.002**		50.7	0.000**

* Significance at (0.05).
**Significance at (0.01).

Table V shows the means and standard deviation of the samples puncture resistance before and after application of resin. It was pointed to that, the material, weaving structure and the interaction between the material & weaving structure had a high significant influence on the puncture resistance of the woven fabrics before treatment, and on the HLC samples.

D. SEM Analysis

Figures (5-7) show SEM images of the surface morphology of the produced hybrid laminated composites (HLC). Fiber/matrix interface plays an important role in the laminates mechanical and physical properties. Polyester resin is characterized by its low viscosity, which allows good impregnation of the fibers within the polymer matrix and good fiber/matrix adhesion. The construction parameters of the fabrics such as the yarn material type and the weaving structures have an influence on the fiber/matrix interfacial bonding. Satin 4 weaving structure have long floats which provide air gaps between the interlacing yarns compared with other structures, which allow more permeability of the resin into the gaps between fibers in the fabric layers. While warp rib 2/2 weave structure has more intersections which obstacle the movement of resin into the fabric layers. It is observed from figure 6 that, the HLC fabricated using (polyester/polyamide) fabrics and glass fiber mat were more coated with the resin on their surface compared with the other samples in figures 5 and 7. This may be related to nylon fibers high specific volume which makes the yarns more compact together inside the fabric structure and decreases the air gaps between fibers. This makes it difficult for the resin to penetrate into the fabrics layers and thus covers the surface of the fabric. The glass fiber mat porous structure had also an effect on the permeability of the resin as clarified before. On the other hand, figure 7 clarifies that, the HLC fabricated using (polyester/glass) fabrics were well impregnated within the resin, since it is distributed uniformly over the fabric surface. There is a good interfacial bonding between the fibers and the matrix, and the high degree of fiber/matrix adhesion leads to high contribution of the fibers in each lamina and the matrix to resist loads.

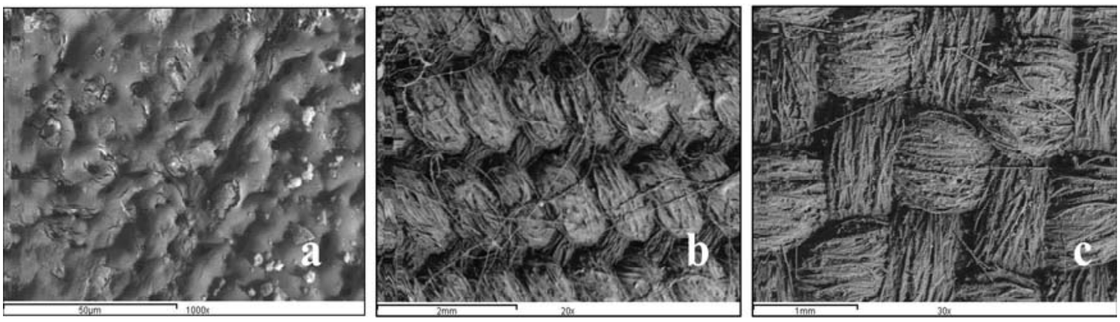

Fig.5. SEM images of the laminated composites specimens fabricated from the 100% polyester fabrics with weaving structures (a) rib 2\2, (b) twill 2\2 & (c) satin 4 and the nonwoven glass fiber mat, respectively.

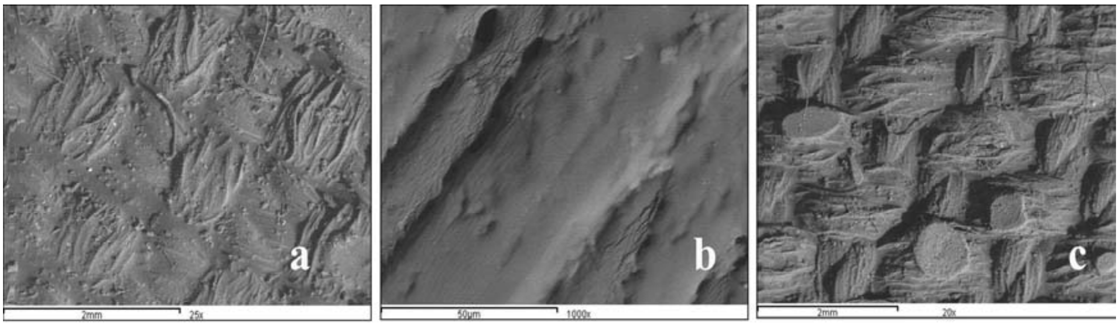

Fig.6. SEM images of the hybrid laminated composites specimens fabricated from the (polyester/polyamide) fabrics with weaving structures (a) rib 2\2, (b) twill 2\2, & (c) satin 4 and the nonwoven glass fiber mat, respectively.

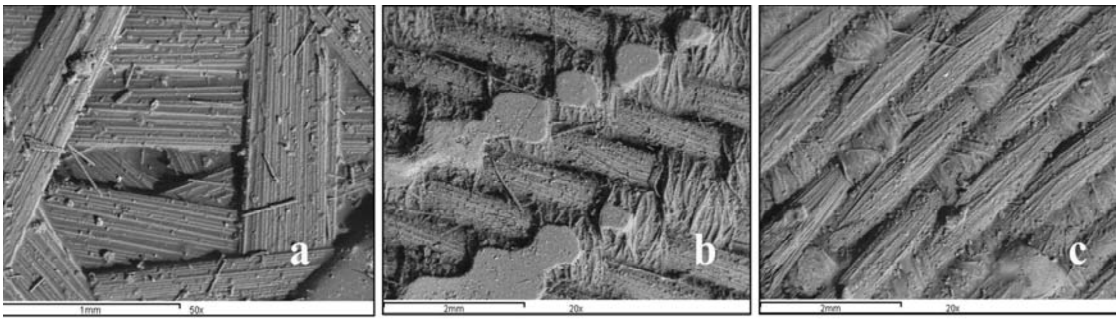

Fig.7. SEM images of the hybrid laminated composites specimens fabricated from the (polyester/glass) fabrics with weaving structures (a) rib 2\2, (b) twill 2\2 & (c) satin 4 and the nonwoven glass fiber mat, respectively.

E. UV Transmittance Test

The spectral UV transmittance curves of the hybrid laminated composites (HLC) samples and the reinforcements (woven fabrics and nonwoven glass fiber mat) are shown in figures (8-16). The wavelengths range from (280 to 400 nm) was chosen in comparing the UV transmittance of the samples. It was clear from the figures that, after 450 nm wavelengths, there is an increase in UV transmittance for all the samples that showed similar behaviour. The UV transmittance was reduced for all the laminated composite samples. The lowest transmittance was observed in the HLC samples fabricated from 100% polyester fabrics and glass fiber mat as shown in figures (8-10). This is due to the reinforcement material and the polyester resin properties. Polyester has large conjugated aromatic polyethyleneterephthalate polymer systems, which contains benzene rings in their polymer chains and this may account for the increased absorption of UV light. Also, it is a highly hydrophobic fiber and known to have a high protective factor against UV transmittance, so it was more effective in reducing UV transmittance. The HLC fabricated from polyester fabrics had high weight compared with other samples, which affect on the UV transmittance with reduction. The HLC fabricated from (polyester/glass) fabrics and glass fiber mat shown in figures (11-13), achieved better results compared with the HLC fabricated from (polyester/polyamide) fabrics and glass fiber mat. This can be interpreted to glass fibers insensitivity to UV radiation which affected on its efficiency in reducing the transmission, while the aliphatic polyamide fiber is relatively permeable to UV radiation [25]. On the other hand; it was observed that the UV transmittance was higher in the nonwoven glass fiber mat samples as shown in figures (8-16). There was difference in their values which may be related to the nonwoven heterogeneous porous structure that makes it vary in its thickness, thus it can be easily penetrated by the UV waves. In comparing the woven fabric samples in all figures, it was clear that, the woven fabrics were better in reducing UV transmittance than the glass fiber mat, and this is related to the weaving structure properties. The UV waves pass through the air gaps formed by the interlacing of yarns in the fabric structure. The (polyester/polyamide) woven fabric with rib 2/2 structure has the highest UV transmittance. This can be related to rib 2/2 structure, which has more intersections and low cover factor compared with twill 2\2 and satin 4 structures which have high floats and different shape of air gaps.

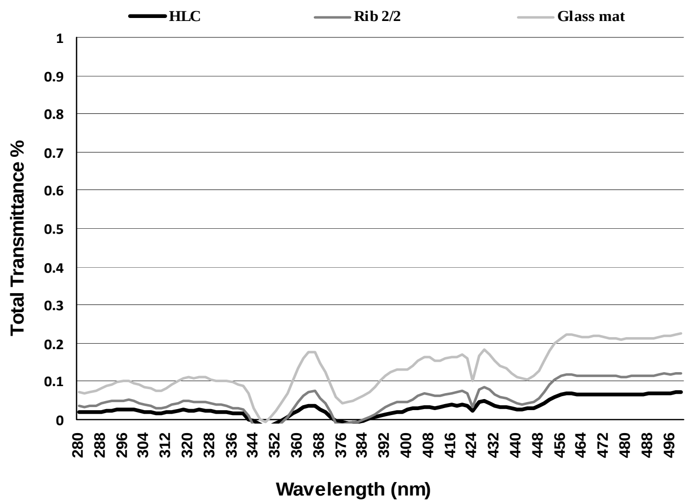

Fig.8. Transmittance spectrum of the HLC sample, the 100% polyester fabric with rib 2/2 structure and the glass fiber mat.

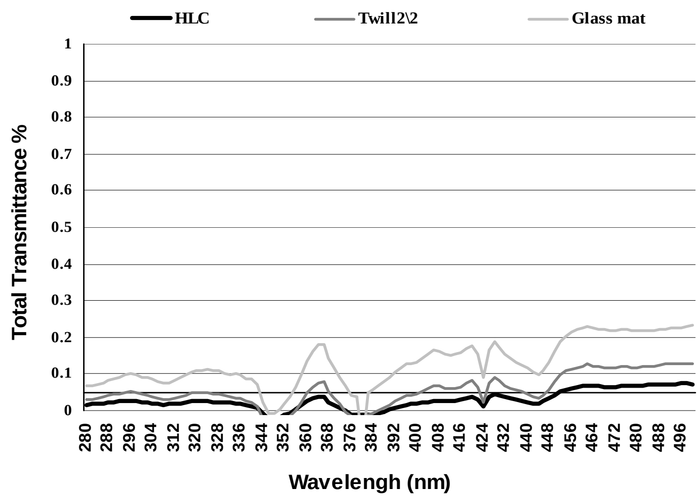

Fig.9. Transmittance Spectrum of the HLC sample, the 100% polyester fabric with twill 2/2 structure and the glass fiber mat.

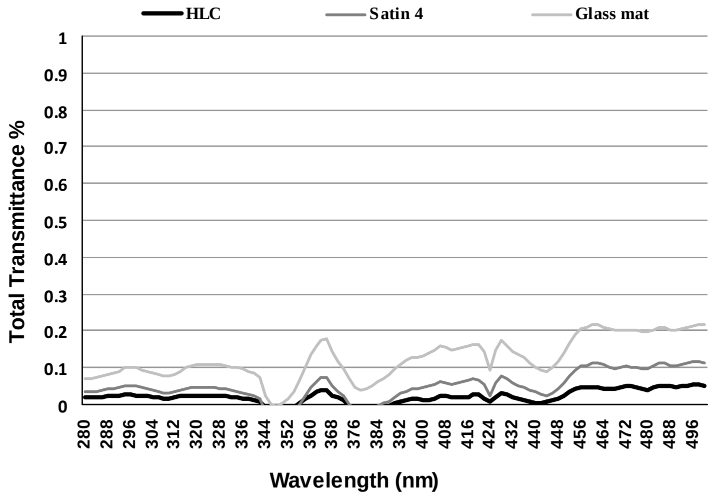

Fig.10. Transmittance Spectrum of the HLC sample, the 100% polyester fabric with satin 4 structure and the glass fiber mat.

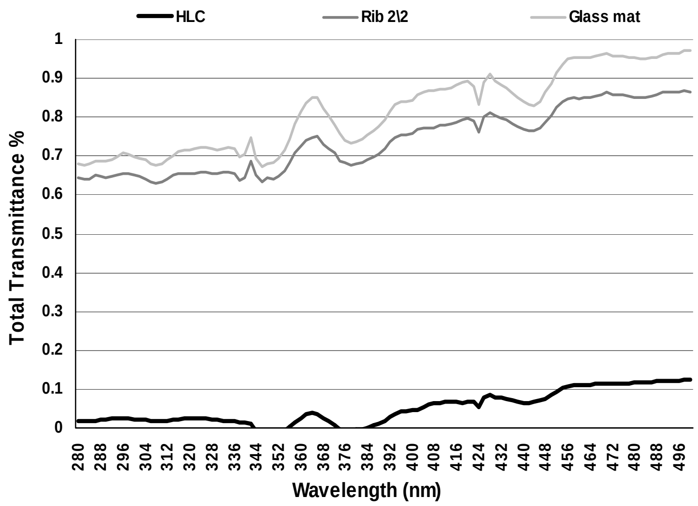

Fig.11. Transmittance Spectrum of the HLC sample, the (polyester /polyamide) fabric with rib 2/2 structure and the glass fiber mat.

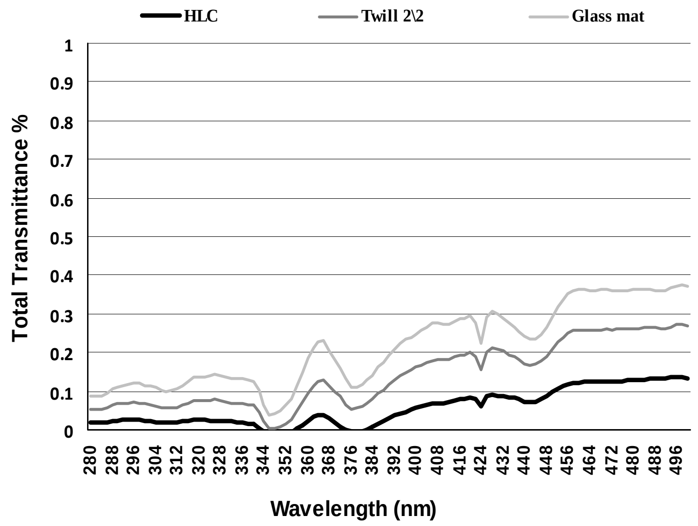

Fig.12. Transmittance Spectrum of the HLC sample, the (polyester /polyamide) fabric with twill 2/2 structure and the glass fiber mat.

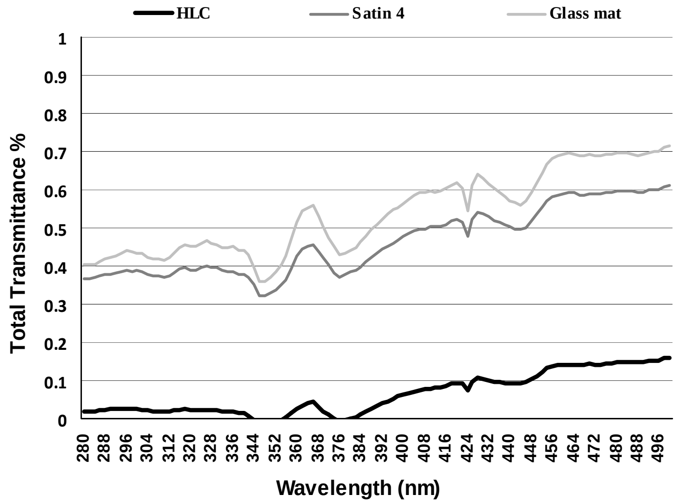

Fig.13. Transmittance Spectrum of the HLC sample, the (polyester /polyamide) fabric with satin 4 structure and the glass fiber mat.

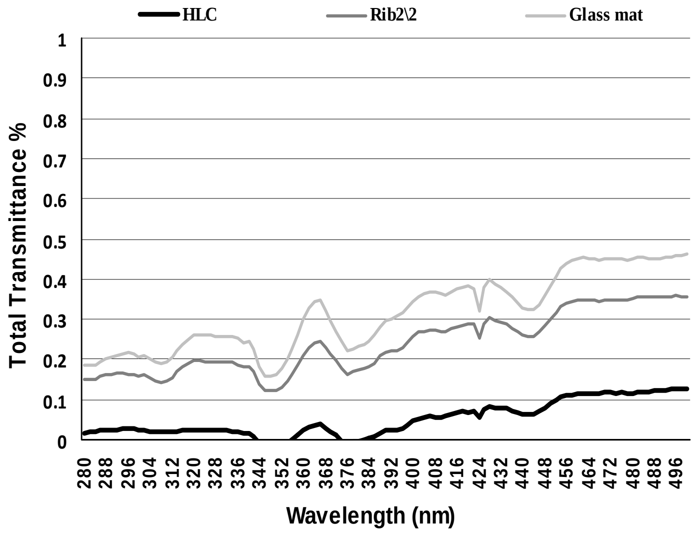

Fig.14. Transmittance Spectrum of the HLC sample, the (polyester/glass) fabric with rib 2/2 structure and the glass fiber mat.

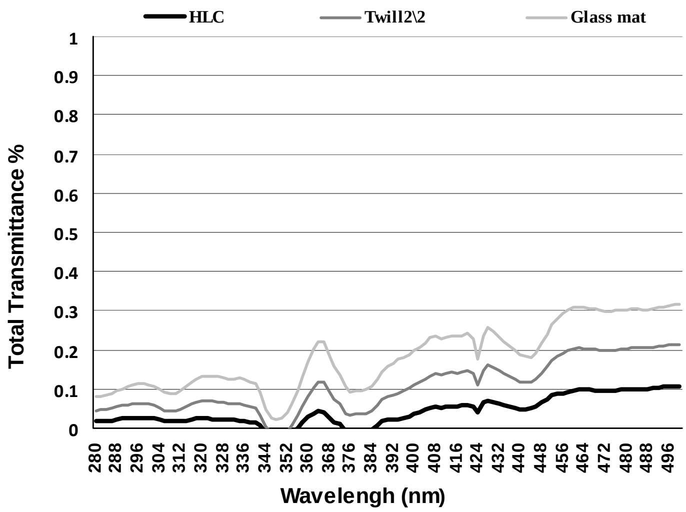

Fig.15. Transmittance Spectrum of s the HLC sample, the (polyester/glass) fabric with twill 2/2 structure and the glass fiber mat.

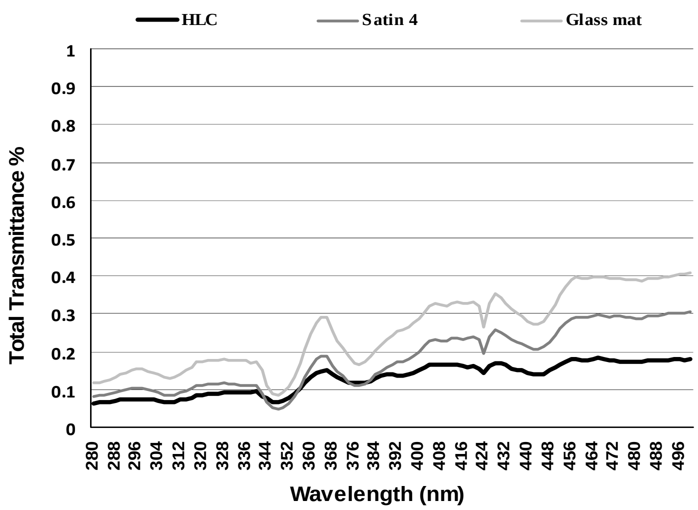

Fig.16. Transmittance Spectrum of the HLC, sample, the (polyester/glass) fabric with satin 4 structure and the glass fiber mat.

TABLE VI
ANOVA Test for the UV Transmittance of the Woven Fabrics and the HLC Samples

Parameter	**UV transmittance Before treatment**			**UV transmittance After treatment (HLC)**		
	Total Means ± SD	**F**	**P. value**	**Total Means ± SD**	**F**	**P. value**
Weft Material	0.15195 ±0.213103	1.500E4	0.000**	0.2660 ±0.30259	205.4	0.000**
Weaving structure		6.438E3	0.000**		206.3	0.000**
Weft Material & Weaving structure		3.790E3	0.000**		197.3	0.000**

*Significance at (0.05).
**Significance at (0.01).

Table VI shows the means and standard deviation of the samples UV transmittance before and after application of resin. It was pointed to that, the material, weaving structure and the interaction between the material & weaving structure had a high significant influence on the UV transmittance the woven fabrics before treatment, and on the HLC samples.

IV. CONCLUSION

Protective clothing is used to provide adequate protection against hazards in workplace. In several situations, there is a need for new materials with multifunctional properties to be used in protective clothing. The diverse characteristics of composite materials have caused increase in their utilization in various applications. The objective of this study was to investigate the performance of new hybrid laminated composites (HLC) proposed to be used in protective clothing. The paper reported the results of the tests performed on the HLC reinforced with woven fabric and nonwoven glass fiber mat embedded in polyester matrix. It was revealed that, the reinforcement material and structure together, in addition to resin properties had a significant effect of on the weight, thickness, puncture resistance and UV transmittance of the produced HLC. The fiber/matrix interface was a major factor influencing the interlaminar fracture toughness of the laminated composites.The HLC fabricated from the (polyester/glass) fabrics with satin 4 structure and glass fiber mat was the best in achieving the functional performance. This multifunctional HLC is suggested to be used in protective clothing as a headwear, since it presented high puncture resistance and improvement in the UV transmittance and it will offer comfort because of its low weight and thickness.

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REFERENCES

[1] W.C. Smith. (1999) Industrial Textile Associates, Greer, SC, USA.[online].Available: http://www.intexa.com/downloads/pcc.pdf.

[2] Personal protective equipment (PPE).(2014). Wikipedia the Free Encyclopaedia. [online]. Available: http://en.wikipedia.org/wiki/Personal_protective_equipment.

[3] C. Berry, A. McNeely, K. Beauregard, and E.N.C Lewis.(2008). Department of Labor, Raleigh, NC. [online]. Avaliable: http://www.nclabor.com/osha/etta/indguide/ig25.pdf.

[4] P.Potluri, and P. Needham, Technical Textiles for protection, In Textiles for protection, Part I: Materials and Design, Chapter six, (Scott, R.AEditor), Woodhead Publishing Limited, Cambridge, England, 2005.

[5] D.N. Eiser, Problems in Personal Protective Equipment Selection, In Performance of Protective Clothing, Second Symposium, ASTM STP 989, (Mansdorf, S.Z., Sager, R. and Nielsen, A.P., Editors), American Society for Testing and Materials, PA, USA, 1988.

[6] J.D.A. Abeysekera, and K.Bergquist, The Need for Research on Human Factors Regarding Personal Protective Devices in the Cold Environment, In Performance of protective clothing, Fifth volume, ASTM STP 1237, (Johnson, J. S. and Mansdorf, S. Z. , Editors), American Society for Testing and Materials , PA, USA ,1996.

[7] P.L. Dolez, and T. Vu-Khanh, "Recent Developments and Needs in Materials Used for Personal Protective Equipment and Their Testing",Int J Occup Saf Ergon (JOSE),vol.5(4),pp.347-362,2009.

[8] Guangdong-Hong Kong Technology Cooperation Funding Scheme,Textiles and Clothing,(2013).[online].Available: http://www.hkrita.com/html/pdf/aiii-Textile_Composite_Material. pdf.

[9] S.Aarthy and T.Velmurugan," Investigation of Impact Performance of Glass/Epoxy Laminates", International Journal of Innovations in Engineering and Technology (IJIET), vol.2(2),pp.1-7, 2013.

[10] U.S. Department of Transportation, Federal Aviation Administration. In Regulation and Polices, Aviation Maintenance Technician Handbook, Advanced Composite Materials; Vol.1, Chapter 7,Federal Aviation Administration, Washington, DC, 2012.

[11] C.Thang Nguyen, T.Vu-Khanh, and J.Lara, "A Study on the Puncture Resistance Characterization of Protective Clothing Materials ", J ASTM Int, vol. 2(4),pp. 175-188, 2005.

[12] N.Hassim, M.R Ahmad, W.Y.W. Ahmad, A.Samsuri, and M.H.M. Yahya," Puncture Resistance of Natural Rubber Latex Unidirectional Coated Fabrics ", J Ind Text, vol. 42(2),pp.118-131,2012.

[13] C.C. Lin, T.T. Li, C. W. Lou, J. Y. Lin and J. H. Lin," Investigations on Dynamic Puncture Behaviors of Integrated Composite Reinforced with Varying Fabrics ", Applied Mechanics and Materials, vol.365-366(2) ,pp.1070-1073, 2013.

[14] B.Sun,Y.Wang, P. Wang, H.Hu,and B.Gu, "Investigations of Puncture Behaviors of Woven Fabrics from Finite Element Analysis and Experimental Tests ", Text Res J, vol.81,pp. 992-1007,2011.

[15] N.J.Manesis, K.S. Chitre, D.Leslie and N.S. Trilokekar , "Puncture Resistant Composite Materials", EP.Patent 2635236A1, Nov.1,2011.

[16] P.D. Dubrovski. Woven Fabrics and Ultraviolet Protection, In Woven Fabric Engineering, Chapter fifteen, University of Maribor, Faculty of Mechanical Engineering, Slovenia,2010.[online].Avalible:http://www.intechopen.com/books/woven-fabric-engineering/wowen-fabric-and-ultraviolet-protection.

[17] A.K. Sarkar, "An Evaluation of UV Protection Imparted by Cotton Fabrics Dyed With Natural Colorants", BMC Dermatology,vol.4(15),pp.1-8,2004.

[18] L.Capjack, N.Kerr, S.Davis, R.Fedosejevs, K.L.Hatch and N.L Markee," Protection of Humans from Ultraviolet Radiation Through the Use of Textiles: A Review ", Fam Consum Sci Res J,vol.23(2),pp.198-217,1994.

[19] A.K. Sarkar ,"On The Relationship between Fabric Processing and Ultraviolet Radiation Transmission, " Photodermatol Photoimmunol Photomed , vol. 23,pp.191-196, 2007.

[20] L.Tong, and J.R.White, "Photo-oxidation of Thermoplastics in Bending and in Uniaxial Compression", Polym Degrad Stabil, 53(3),pp. 381-396, 1996.

[21] T.Li, C.Zhou, and M. Jiang,"UV Absorption Spectra of Polystyrene", Poly Bull, vol. 25, pp.211-216, 1991.

[22] Standard Test Methods for Mass per Unit Area (Weight) of Fabric, Annual Book of ASTM Standards, Textiles, Vol.7.01, ASTM D3776, 2002.

[23] Standard Test Method for Thickness of Textile Materials, Annual Book of ASTM Standards, Textiles, Vol.7.01, ASTM D1777, 2002.

[24] Standard Test Method for Protective Clothing Material Resistance to Puncture, Annual Book of ASTM Standards, Occupational Health and Safety; Protective Clothing, Vol.11.03, ASTM F1342-05, 2011.

[25] B. R. Das, "UV Radiation Protective Clothing", The Open Textile Journal, vol.3,pp.14-21, 2010.