Electric static charge generated from the sliding of head scarf textiles against skin and hair

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ABSTRACT

Electric static charges building up on human skin and or clothes in direct contact with human body are very harmful and can create serious health problems. In the present work, electric static charge generated from the friction of hair and skin against head scarf of different textiles materials was measured. Test specimens of head scarf of common textile fibres such as polyester, cotton and polyacrylonitrile were tested by sliding under different loads against hair and skin. Ultra surface DC Voltmeter was used to measure the electrostatic charge of the tested textile composites.

The results showed that electric static charge generated on the skin and the tested textiles increased with increasing normal load. Friction between Caucasian hair and polyester scarf generated the highest electric static charge followed by African and Asian hairs when slid against cotton. Besides, sliding of polyacrylonitrile against skin displayed higher voltage than that generated from cotton and polyester. While, sliding of African hair against polyacrylonitrile textiles recorded the highest values of voltage which increases the risk of sparks of high energy enough to ignite flammable gases and vapours. Besides, the high voltage induces a similar charge on the human body and causes serious health problem. Although all human hair has the same basic chemical composition in terms of keratin protein content, the triboelectrification property differs for the three tested hair. This experimental evidence increases the demand to make proper selection of textile materials used as head scarf.

KEYWORDS

Electric static charge, friction, head scarf textiles, hair, skin, polyacrylonitrile, keratin protein

INTRODUCTION

Little attention has been devoted so far to the electrostatic properties of hair although these properties are very sensitive to the friction between hair and head scarf textiles. Hair has a tendency to develop static charge when rubbed with dissimilar materials like human skin, plastic and textiles. Human hair is a good insulator with an extremely high electrical resistance. Due to this high resistance, charge on hair is not easily dissipated, especially in dry environments. Friction coefficient and electrostatic charge generated from the friction of hair and head scarf of different textiles materials such as cotton, nylon and polyester were tested by sliding under different loads against African and Asian hair, [1]. The results showed that Asian hair displayed relatively higher friction coefficient than African hair when sliding against polyester head scarf, where friction coefficient decreased with increasing the applied load. Asian hair generated higher voltage than African hair and voltage significantly increased with increasing the applied load. Besides, friction coefficient generated from the sliding of the cotton head scarf against hair displayed higher values than that showed by polyester head scarf. The nylon head scarf when sliding against hair showed relatively lower friction coefficient than that observed for polyester and cotton scarf. Asian hair displayed higher friction values than African hair. Electric static charge measured in voltage represented relatively lower values. This behaviour may be attributed to the ranking of the rubbing materials in the triboelectric series where the gap between human hair and nylon is smaller than the gap between hair and cotton as well as hair and polyester.

Many macroscale studies have looked at the static charging of human hair, [2-4]. Most of these studies include rubbing hair bundles with various materials like plastic combs, teflon, latex balloons, nylon, and metals like gold, stainless steel and aluminum. Hair in these cases is charged by a macroscale triboelectric interaction between the surface and the rubbing element. The kinetics of the charging process and the resulting charge are then measured using modified electrometers.

The manageability and feel of human hair is significantly affected by its surface charge. Previous studies have looked at static charging characteristics of hair on a macroscale. The static charging characteristics of hair were studied on the nanoscale with an atomic force microscopy (AFM), [5-6]. The charge distribution was characterized by measuring the surface potential of the control area in situ with AFM based Kelvin probe microscopy. The rubbing load was progressively increased, and the effect of this increase on the charge build up was assessed. Virgin, damaged and conditioner treated hair samples were studied for a better understanding of charge build up and dissipation.

Asian, African, and Caucasoid humans are often distinguished by their straight, curly, and wavy hair features, respectively. Understanding the mechanism of the curly pattern of hair is a fundamental issue in anthropology, [7-10], and in physiology, for example helping detect various hair diseases and exploring possible therapeutic. The

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fundamental mechanical properties of human hair including Young's modulus and hardness have been investigated, [11-20], owing to the composite-like microstructure. The electrostatic properties and the wetting behaviour of the human hair surface at the nanometric scale have been investigated by using atomic force microscopy (AFM), [21]. Surface potential imaging was used to determine the electrostatic.

The electrostatic charge generated from the friction of polytetrafluoroehylene (PTFE) textiles was tested to propose developed textile materials with low or neutral electrostatic charge which can be used for industrial application especially as textile materials, [22]. Test specimens of composites containing PTFE and different types of common textile fibers such as cotton, wool and nylon, in a percentage up to 50 vol. % were prepared and tested by sliding under different loads against house and car padding textiles. Ultra surface DC Voltmeter was used to measure the electrostatic charge of the tested textile composites. The results showed that addition of wool, cotton and nylon fibers remarkably decreases the electrostatic discharge and consequently the proposed composites will become environmentally safe textile materials.

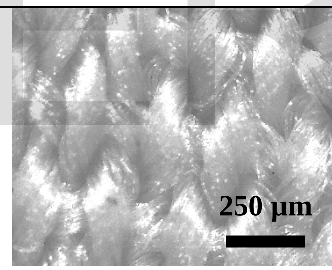
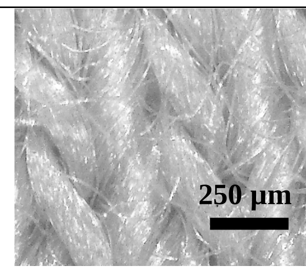
Research on electrostatic discharge (ESD) ignition hazards of textiles is important for the safety of astronauts. The likelihood of ESD ignitions depends on the environment and different models used to simulate ESD events, [23]. Materials can be assessed for risks from static electricity by measurement of charge decay and by measurement of capacitance loading, [24]. Tribology is the science and technology of two interacting surfaces in relative motion and of related subjects and practices. The popular equivalent is friction, wear, and lubrication, [25]. Tribological behavior of polymers is reviewed since the mid-20th century to the present day. Surface energy of different coatings is determined with contact adhesion meter. Adhesion and deformation components of friction were discussed. It was shown how load, sliding velocity, and temperature affect friction. Different modes of wear of polymers and friction transfer were considered, [26]. The ability to engineer a product's tactile character to produce favorable sensory perceptions has the potential to revolutionize product design. Another major consideration is the potential for products to produce friction-induced injuries to skin such as blistering, [27, 28]. Sports activities may cause different types of injuries induced by friction between the skin and sport textiles. Focusing on runners who are often bothered with blisters, the textile foot skin interface was studied in order to measure and predict friction. The characteristics of mechanical contacts between foot, sock and shoe during running were determined. It was found that textiles with conductive threads did not give ignitions provided they were adequately earthed, [29]. When isolated, all textiles were capable of causing ignitions regardless of the antistatic strategy employed.

In the present work, the electric static charge generated from the sliding of head scarf of different materials against hair and skin is investigated.

EXPERIMENTAL

Electric static charge effects occur when an excess of either positive or negative charge becomes confined in a small volume, isolated from charges of the opposite polarity. Because of mutual repulsion, the charges try to escape. As a result, the charges may move or redistribute themselves, sometimes rapidly, such as with a spark. This redistribution usually causes problems. The electrostatic fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electric static charge (electrostatic field) for test specimens. It measures down to 1/10 volt on a surface, and up to 20 000 volts (20 kV). Readings are normally done with the sensor 25 mm apart from the surface being tested. The different tested textiles of head scarf as illustrated in Table 1.

Table 1
The tested textiles of head scarf.

	
Cotton	Polyacrylonitrile

RESULTS AND DISCUSSION

Electric static charge gained by the hair will migrate to the human body. After more rubbing, the clothes gain more charge. Then the electric static charges move to the air by sparking or by flowing to earth ground if the charged volume touches ground. The mechanism of charge generation is based on considering most of materials to be electrically neutral. When the atom loses an outer electron it has an excess positive charge, and the atom that gains that electron has an excess negative charge. This mechanism occurs at the interface between two dissimilar materials. Generally, polyester attracts electrons from the surface of the hair and causes static charging. Generation of electric field (E-field) can increase the electric static charge on the friction surface. Electric field depends on the presence of atoms that are missing electrons close to an object that is negatively

ISSN 2229-5518

charged. The (positive) atoms will be attracted toward the (negative) object with a force. The strength of the E-field is proportional to the total force acting on the negative object and positive atoms. The relationship between electric static charge, measured in volts, and normal load is shown in Fig. 1. It can be noticed that electric static charge generated on the skin and polyester increased with increasing normal load. For skin, the maximum value of electric static charge was 195 V at 3.2 N normal load, while the minimum value was 6 V at 2 N normal load. The maximum value of electric static charge generated on polyester scarf was -50 V at load of 3.4 N, while the minimum was – 2 V at 2.6 N normal load.

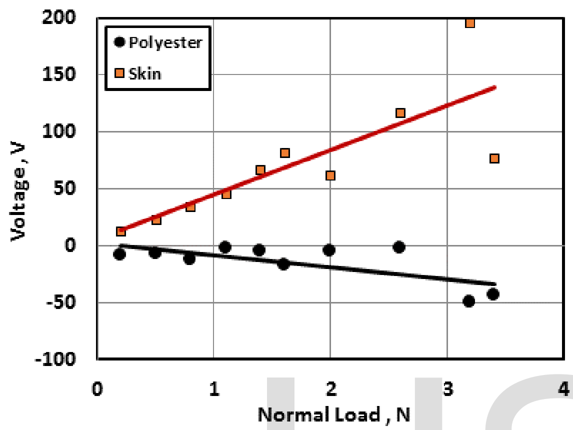
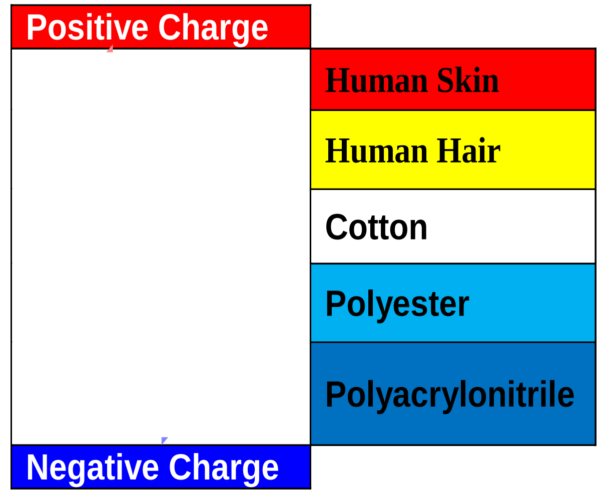


Fig. 1 Electric static charge generated from sliding of skin against polyester textiles.

The charge generated on the hair by friction against polyester was found to be of positive sign because keratin is close to the positive end of the tribolectric series, Table 2, [30], so that when it is rubbed against other materials which are lower than keratin in the triboelectric series, a positive charge is developed on the keratin, [31-32]. Besides, when two objects are rubbed together under conditions where the bodies contribute unequal areas to the rubbing surface, the body which contributes the larger area tends to develop a positive charge.

Table 2
Triboelectric Series of the Tested Materials and Textiles, [30]



The friction between African hair and polyester scarf generated relatively high electric static charge, Fig. 2, where the maximum value reached 1255 V. In the other hand the electric static charge generated on the polyester reached – 120 V. It seems that corrugations of the African hair are responsible for that behavior. It can be noticed that for African hair voltage significantly increased with increasing normal load. It seems that, as the load increases the pressure applied on the textile fibre fringes increases, flattens the fringes and increases the contact area leading to the increase of friction coefficient.

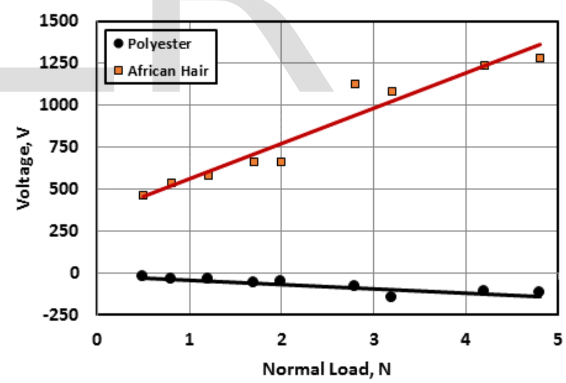


Fig. 2 Electric static charge generated from sliding of African hair against polyester textiles.

Electric static charge generated from sliding of Asian hair against polyester textiles is shown in Fig. 3 relative to the normal load. It is clearly shown that for Asian hair as well polyester scarf, voltage increases with increasing normal load. For polyester, the maximum value of electrostatic was -83 V at load of 5.2 N, while the minimum value was -35 V at normal load of 0.2 N. For Asian hair, the maximum and minimum values of electric static charges were 991 and 614 V at normal loads of 5.2 and 0.2 N respectively. Caucasian hair displayed higher values of electric static charge than Asian hair, Fig. 4, especially at relatively higher load. The charge significantly increased with increasing the load.

ISSN 2229-5518

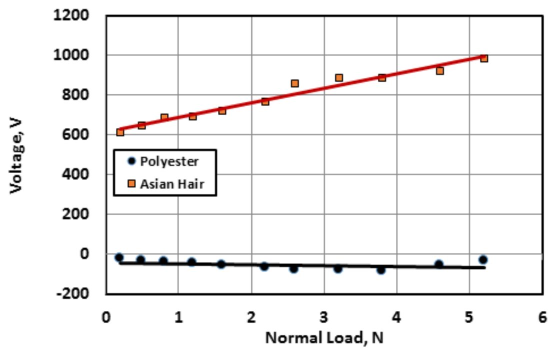


Fig. 3 Electric static charge generated from sliding of Asian hair against polyester textiles.

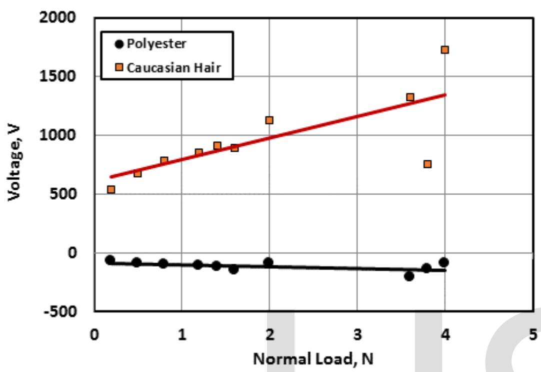


Fig. 4 Electric static charge generated from Caucasian hair sliding against polyester textiles.

The difference in the values of voltage measured for the three types of hair and textiles depends on the magnitude of charge which is generated by the sliding of hair and head scarf, the mobility of charge as well as its rate of dissipation from the fibres and the distribution of charge along the length of the fibres, [33-35]. Charge mobility depends on the conductivity of the rubbing materials which means that the rate at which charge develops on the body. Besides, the surface texture of hair influences its friction against textiles. However, African hair exhibits a characteristic tightly curled structure so that when sliding against the fibrous textiles a relatively high amount of electric static charge is generated. African hair grows in a tiny, spring-like helix shape. The density of African hair was found to be lower than that of Caucasian hair, [36-37].

African hair strands can possess elastic helix shape. On Asian hair, the cuticles are laid down with at a steeper angle. Caucasian hair has flatter cuticles, where the fiber can be circular or oval in cross section and thinner than Asian hair. African American hair is frequently tightly coiled, or spiral hair, [38 – 41]. In cross section it is elliptical or almost flat and ribbon-like in some cases. African hair is slightly flatter in shape than Asian and Caucasian hair and has more flat surface area. The flattened shape of the hair fibre makes the contact area relatively higher. African hair is slightly more dense than Asian hair and grows almost parallel to the scalp, twisting around itself as it grows. Caucasian hair has the highest density of all. It grows at an oblique angle to the scalp and is slightly curved.

Electric static charge generated from skin sliding against cotton is shown in Fig. 5. It can be noticed that for skin, voltage showed the same trend observed for sliding against polyester, value of voltage with increasing normal load, while cotton displayed consistent voltage values with increasing normal load.

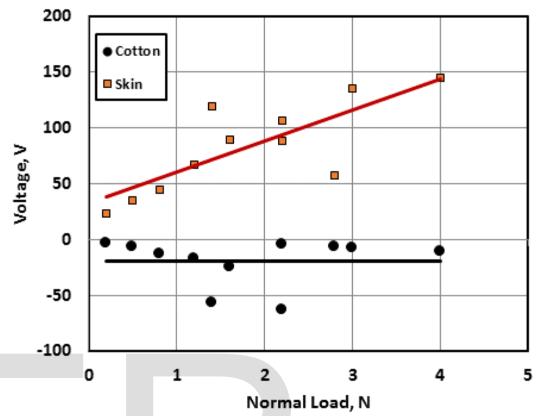


Fig. 5 Electric static charge generated from sliding of skin sliding against cotton textiles.

African hair displayed relatively lower voltage values when slid against cotton, Fig. 6. This behaviour may be attributed to the ranking of the rubbing materials in the triboelectric series where the gap between human hair and cotton is smaller compared to the gap between hair and polyester. It is commonly known that as the gap increases the amount of electric static charge increased. For cotton, the maximum voltage was - 40 V at 5.0 N load, while for hair was 500 V at 4.4 N load.

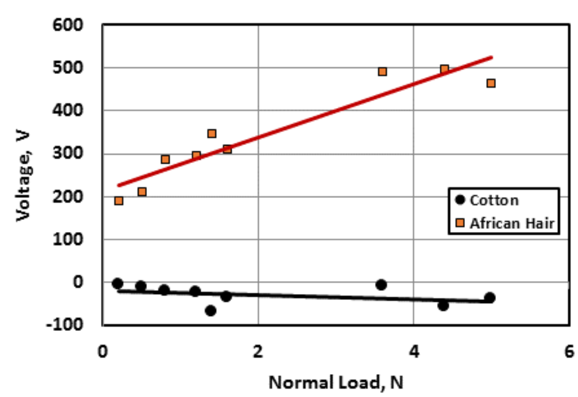


Fig. 6 Electric static charge generated from sliding of African hair against cotton textiles.

ISSN 2229-5518

Figure 7 shows the relationship between electric static charge generated from sliding of Asian hair against cotton specimen and normal load. It is shown that Asian hair displayed lower voltage than African hair, where the maximum value gained by the hair was 90 V. That behavior may be attributed to the fact that the cuticles of the Asian hair have lower density than African hair, where they are laid down with at a steeper angle.

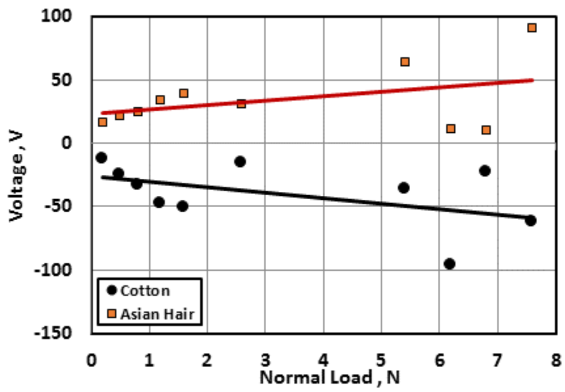


Fig. 7 Electric static charge generated from sliding of Asian hair against cotton textiles.

Electric static charge generated from sliding of Caucasian hair against cotton specimen showed the highest values compared to African and Asian hairs, where the maximum voltage reached to 920 V, Fig. 8. This is because Caucasian hair has more flat surface area as well as the highest density. The flattened shape of the hair makes the contact area relatively higher. Cotton textiles gained relatively low voltage values, where the highest value did not exceed – 100 V.

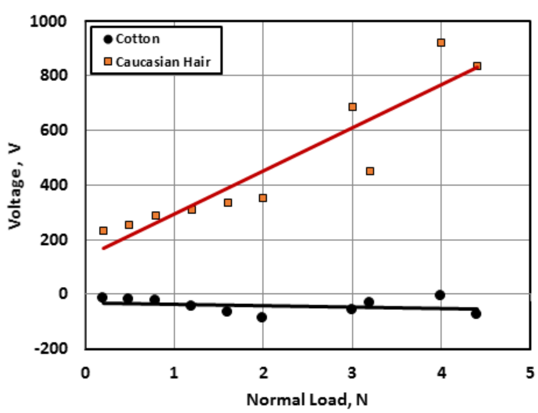


Fig. 8 Electric static charge generated from sliding of Caucasian hair against cotton textiles.

The results of the measurements of electric static charge generated from the sliding of polyacrylonitrile against skin are shown in Fig. 9. It is seen that polyacrylonitrile displayed the highest voltage due to the gap between skin and polyacrylonitrile in the triboelectric series. The maximum voltages (measured on skin) were 250, 195 and 145 for sliding of skin against polyacrylonitrile, polyester and cotton respectively. Besides, the voltage generated on polyacrylonitrile representsed the highest values compared to cotton and polyester.

Electric static charge generated from sliding of African hair against polyacrylonitrile textiles recorded the highest values of voltage, Fig. 10. The maximum values measured on African hair and polyacrylonitrile were 6800 and – 500 V respectively. The relatively high voltage values recorded for polyacrylonitrile can produce sparks of high energy enough to ignite flammable gases and vapours. Besides, the high voltage induces a similar charge on the human body and causes serious health problem.

Asian hair generated lower voltage than African hair, Fig. 11, where the maximum values were 5300 and -2500 V for hair and textiles respectively. The value of the generated charge can cause severe hazards in the places full of flammable materials, where probability of occurrence of fire accident is high.

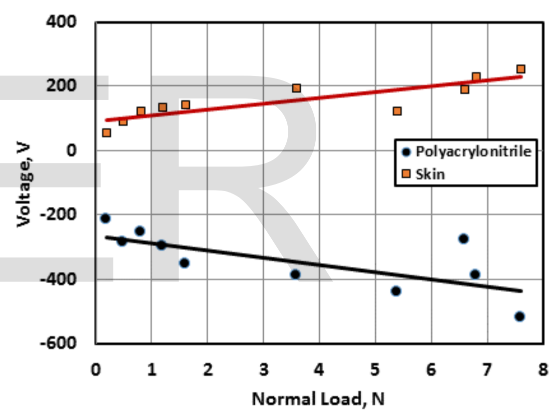


Fig. 9 Electric static charge generated from sliding of skin against polyacrylonitrile textiles.

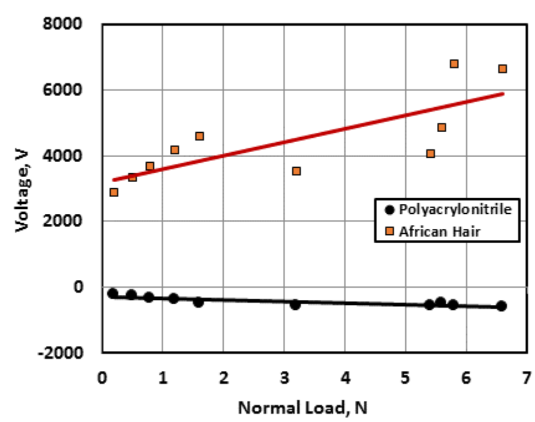


Fig. 10 Electric static charge generated from sliding of African hair against polyacrylonitrile textiles.

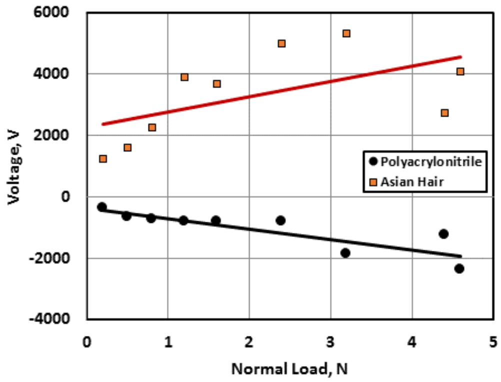


Fig. 11 Electric static charge generated from sliding of Asian hair against polyacrylonitrile textiles.

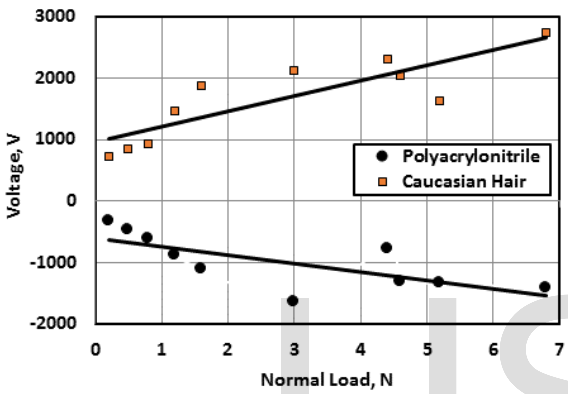


Fig. 12 Electric static charge generated from sliding of Caucasian hair sliding against polyacrylonitrile textiles.

Electric static charge generated from sliding of Caucasian hair sliding against polyacrylonitrile textiles showed the lowest values compared to African and Asian hairs, Fig. 12. Although all human hair has the same basic chemical composition in terms of keratin protein content, the triboelectrification property differs for the three tested hair. This experimental evidence increases the demand to make proper selection of textile materials used as head scarf.

CONCLUSIONS

1. Electric static charge generated on the skin and polyester increased with increasing normal load. Friction between Caucasian hair and polyester scarf generated relatively high electric static charge followed by African and Asian hair.
2. Cotton sliding against skin showed the same trend observed for sliding against polyester. Cotton sliding against Caucasian hair showed the highest values compared to African and Asian hairs.
3. Sliding of polyacrylonitrile against skin displayed the highest voltage. Besides, the voltage generated on polyacrylonitrile experienced the highest values compared to cotton and polyester. Sliding of African hair against polyacrylonitrile textiles recorded the highest values of voltage. The relatively high voltage values recorded for polyacrylonitrile can produce sparks of high energy enough to ignite flammable gases and vapours. Besides, the high voltage induces a similar charge on the human body and causes serious health problem.
4. Proper selection of textile materials used as head scarf should be considered based on the difference of triboelectrification properties of the three tested ethnic hairs.

REFERENCES

1. Al-Osaimy A. S., Mohamed M. K., Ali W. Y., "Friction Coefficient and Electric Static Charge of Head Scarf Textiles", Journal of the Egyptian Society of Tribology Vol. 9, No. 3, July 2012, pp. 24 – 39, (2012).
2. K. Morioka, "Hair Follicle-Differentiation under the Electron Microscope, Springer-Verlag, Tokyo, (2005).
3. Bhushan B., LaTorre C., "in: B. Bhushan (Ed.), Nanotribology and Nanomechanics - An Introduction", second ed., Springer, Berlin, (2008).
4. D.K. Schroder, Semiconductor Material and Device Characterization, third ed., Wiley, Hoboken, (2006).
5. Seshadri I. P., Bhushan B., "Effect of rubbing load on nanoscale charging characteristics of human hair characterized by AFM based Kelvin probe", Journal of Colloid and Interface Science 325, pp. 580 - 587, (2008).
6. Seshadri I. P., Bhushan B., "Effect of ethnicity and treatments on in situ tensile response and morphological changes of human hair characterized by atomic force microscopy", Acta Materialia 56, pp. 3585 - 3597, (2008).
7. Baoxing Xua, Xi Chen, "The Role of Mechanical Stress on the Formation of a Curly Pattern of Human Hair", Journal of the Mechanical Behavior of Biomedical Materials 4, 212 – 221, (2011).
8. Danforth, C. H., "Physiology of human hair", Physiological Reviews 19, pp. 94–111, (1939).
9. McMichael, A. J., "Ethnic hair update: past and presentstar, open", Journal of the American Academy of Dermatology 48, pp. 127 - 133, (2003).
10. Peytavi, U.B., Tosti, A., Whiting, D., Trueb, R., "Hair Growth and Disorders", Springer, Berlin, (2008).
11. Akkermans, R.L.C., Warren, P.B., 2004. Multiscale modelling of human hair. Philosophical Transactions of the Royal Society, A 362, 1783–1793.
12. Barnes, H.A., Roberts, G.P., The non-linear viscoelastic behaviour of human hair at moderate extensions. International Journal of Cosmetic Science 22, pp. 259 - 264, (2000).
13. Bhushan, B., "Nanoscale characterization of human hair and hair conditioners" Progress in Materials Science 53, pp. 585 – 710, (2008).

14. Cao, G., Chen, X., Xu, Z.-H., Li, X., Measuring mechanical properties of micro- and nano-fibers embedded in an elastic substrate: theoretical framework and experiment. Composites: Part B 41, pp. 33 - 41, (2010).
15. Sadaie M., Nishikawa N., Ohnishi S., Tamada K., Yase K., Hara M., "Studies of human hair by friction force microscopy with the hair-model-probe", Colloids and Surfaces B: Biointerfaces 51, pp. 120 - 129, (2006).
16. Wei G., Bhushan B., "Nanotribological and nanomechanical characterization of human hair using a nanoscratch technique", Ultramicroscopy 106, pp. 742 – 754, (2006).
17. LaTorre C., Bhushan B., "Nanotribological characterization of human hair and skin using atomic force microscopy", Ultramicroscopy 105, pp. 155 – 175, (2005).
18. Wei G., Bhushan B., Torgerson P.M., "Nanomechanical characterization of human hair using nanoindentation and SEM", Ultramicroscopy, 105, pp. 248 – 266, (2005).
19. Bhushan B., "Nanotribology and Nanomechanics - An Introduction", Springer, Heidelberg, Germany, (2005).
20. Bhushan B., Wei Guohua, Haddad P., "Friction and wear studies of human hair and skin", Wear 259, pp. 1012 – 1021, (2005).
21. Dupres V., Langevin D., Guenoun P., P. Checco P., Luengo G., Leroy F., “Wetting and electrical properties of the human hair surface: Delipidation observed at the nanoscale”, Journal of Colloid and Interface Science 306, pp. 34 - 40, (2007).
22. Ibrahim R. A., Khashaba M. I. and Ali W. Y., "Reducing the Electrostatic Discharge Generated from the Friction of Polymeric Textiles", Proceedings of The Third Seminar of the Environmental Contaminants and their Reduction Methods, September, 26 – 28, 2011, AlMadina AlMonawwara, Saudi Arabia, (2011).
23. Zhancheng W., Chen Y., and Xiaofeng L., Shanghe, “Research on ESD ignition hazards of textiles”. J. of Electrostatics 57, pp. 203 – 207, (2003).
24. Chubb J., New approaches for electrostatic testing of materials, J. of Electrostatics 54, pp. 233 – 244, (2002).
25. Bhushan B., “Introduction - measurement techniques and applications”, Handbook of Micro/Nanotribology, pp. 3 - 4, Boca Raton: CRC Press LLC, (1999).
26. Myshkin N. K., Petrokovets M. I., Kovalev A. V., “Tribology of polymers: Adhesion, friction, wear, and mass-transfer”, Tribology International, Vol. 38, pp. 910 - 921, (2005).
27. Matthew D. A., Christian S. J., “Investigation of skin tribology and its effects on the tactile attributes of polymer fabrics”, Wear, Vol. 267, pp. 1289 - 1294, (2009).
28. Derler S., Schrade U., Gerhardt L. C., “Tribology of human skin and mechanical skin equivalents in contact with textiles”, Wear, Vol. 263, pp. 1112 - 1116, (2007).
29. Poopathy K., Michael T. J., Juk H., Paul H., Jan L., Gabriele S. L., “Measurements of incendivity of electrostatic discharges from textiles used in personal protective clothing”, Journal of Electrostatics, Vol. 49, pp. 51 - 70, (2000).
30. Diaz AF, Felix-Navarro RM., "A semi-quantitative triboelectric series for polymeric materials", Journal of Electrostatics, 62, pp. 277 - 290, (2004).
31. Shashoua V. E., "Static Electricity in Polymer", I. Theory and Measurement, Polym. Sc., 33, 65 – 85, (1958).
32. Landwer R .C. Electrostatic properties of Corona-treated Wool and Mohair, Text Res. J., 39, pp. 792 – 793, (1969).
33. Gruner H., “An investigation of the mechanism of electrostatic charging of textile fibres”, Faserforsch. Textiltech. 4, pp. 249-460 (1953).
34. Henry P .S.H., L ivesey R. G., Wood A .M, A test of rliability to electrostatic charge”, J. Text. Inst., 58, pp. 55 - 77 (1967).
35. Ballou J .W. “Static electricity in textiles”, Text. Res. J., 24, 1, pp. 46 – 55, (1954).
36. Loussouarn G. "African hair growth parameters". Br. J. Dermatol. 145 (2), pp. 294 – 297, (2001).
37. Khumalo N. P., Gumedze F. "African hair length in a school population: a clue to disease pathogenesis?” Journal of Cosmetic Dermatology 6 (3), pp. 144 –151, (2007).
38. Lee H. J., Ha S. J., Lee J. H., Kim J. W., Kim H. O., Whiting D. A., "Hair counts from scalp biopsy specimens in Asians", J. Am. Acad. Dermatol. 2002 Feb., 46 (2), pp. 218 – 21, (2002).
39. Khumalo N. P., Doe P. T., Dawber R. P., Ferguson D. J., “What is normal black African hair? A light and scanning electron-microscopic study. J Am Acad Dermatol. 2000 Nov, 43, (5 Pt 1), 8, pp. 14 – 20, (2000).
40. Lucky A. W., Biro F. M hair., Daniels S. R., Cedars M. I., Khoury P. R., Morrison J. A., “The prevalence of upper lip in black and white girls during puberty: a new standard”, J. 2001 Jan., 138 (1), pp. 134 – 136, (2001).
41. Takahashi T., Hayashi R., Okamoto M., Inoue S., "Morphology and properties of Asian and Caucasian hair", J Cosmet. Sci. , 57 (4), pp. 327 - 338, (2006).