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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

A Comparison of Nanotribological Characteristics between Synthetic Fiber and Human Hair

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DOI: https://doi.org/10.30880/ijie.2020.12.03.025
Received 18 December 2019; Accepted 14 January 2020; Available online 27 February 2020

Abstract: In this paper, an analysis of the nanotribological properties of human hair and nanocomposite artificial fibers is reported to discover a contiguous human hair replica. Investigation of a perfect artificial hair whose measurement properties should be nearby to the real hair is needed for and proposed. In practice, shallow experimental data exists for nanoscale correlation between heterogeneous subunits and their tribological properties. Synthetic fiber, Polyvinyl Chloride (PVC) fiber & Mod-Acrylic fiber are used as a model of composite artificial fibers. This paper designs and conducts the experimental range of nanotribological properties such as Surface roughness, Friction force, and Adhesive force. Therefore, associating with the closest tribological ranges, we have established a composite fiber which is healthy to human hair skin and suitable to wear without side effect or uncomfortable feelings.

Keywords: Atomic force microscopy, artificial fiber, human hair, nanotribology.

1. Introduction

Human hair is a complex tissue comprising of numerous morphological and tribological components [1]. Evaluation of these properties is essential if we aspire to progress hair products. For instance, due to some syndrome such as alopecia areata, alopecia totalis, cancer chemotherapy, female pattern baldness, burns, scalp injury etc., people lose their hair and never regenerate. Therefore, as a hair product, a hairpiece plays a very important role to comprise these deficiencies. Wigs can be divided into artificial fibers and natural hair by the materials. While wigs made of artificial fibers are less expensive than natural hair and hence people opt to select artificial fiber products. However, for long-term use, it can lead to adverse reactions or uncomfortable feeling if the properties of artificial hair diverge from regular human hair. Therefore, to develop a better hairpiece, nanoscale characterization of mechanical and tribological properties is essential for a case of discussion and its simplicity.

Atomic Force Microscopy (AFM) is the technique that allows measuring of tribological properties which include surface roughness (R_a), friction force ($F_{friction}$), and adhesive force ($F_{adhesion}$) [1-2]. However, there are some desirable features of natural hair corresponding tribological attributes of conditions by which we fixed a range for artificial fibers. For smooth, bouncing and easy to comb feelings, tribological attributes should conserve (i) Low $F_{friction}$ between hair and skin (ii) Low $F_{friction}$ between hair fibers and groups of hair and (iii) Low $F_{friction}$ with low $F_{adhesion}$ between hair and comb respectively. Therefore, in order to develop better artificial fibers, it is essential to differentiate their nanotribological (R_a, $F_{friction}$, $F_{adhesion}$) properties. Usually, AFM holds a sharp tip (probe) at its free end which is used for scanning the specimen of a sample surface, and, it is typically silicon or silicon nitride with a tip radius of curvature on the order of a nanometer [1-3, 15-17]. The probe analyzes the R_a and $F_{friction}$ by the topography of the sample. Therefore, the interaction between the tip and the sample makes a way to measure the $F_{adhesion}$ while sharp cantilever tip creates difficulty to calculate the adhesion properties [1-5]. On a previous study, we developed a new microsphere probe for nanotribological measurement of human hair and to evaluate the performance of hair. This present study aims to determine the adhesion as well as the tribology of

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three types of artificial fiber such as synthetic fiber, polyvinyl chloride (PVC) fiber and mod-acrylic fiber using microsphere AFM probe.

The objective of this paper is to find out the average range of surface roughness (R_a), friction force ($F_{friction}$) and adhesive force ($F_{adhesion}$) for both human hair and artificial hair. Therefore comparing the range of tribology, we propose a healthy artificial fiber for human skin. If any of fibers meet the range of human hair, this means, the artificial hair is suitable for people wearing, and will not make side effects or some uncomfortable feeling on skins or original hairs.

2. Material and Methodology

The human hairs were tested under three categories of samples: (i) Normal hair (ii) Curly hair and (iii) Colored hair. Each sample hair was selected approximately 1.0~1.5 cm long of three specimen points: Contiguous part, Middle part & Distal part. Though the exact location from the root was unknown, the contiguous part was estimated between 0.1 and 0.2 cm from the scalp. Table 1 shows the prepared list of all human hair samples entitled as Group A. Moreover, the types of artificial fibers were: (i) Synthetic fiber, (ii) PVC (Polyvinyl Chloride) synthetic fiber and (iii) Mod-Acrylic synthetic fiber. All these samples had identical specimens with Group A. Table 2 presents a list of all artificial fibers with their composition types.

Table 1 - Human hair samples

Group	Categories	No of Specimens
A	Normal Hair	1) Contiguous Part 2) Middle Part 3) Distal part
	Curly Hair	1) Contiguous Part 2) Middle Part 3) Distal part
	Colored Hair	1) Contiguous Part 2) Middle Part 3) Distal part

Table 2 - Artificial fiber hair samples

Group	Categories	Specimens No	Composition
B	Synthetic Fiber	1) Contiguous Part 2) Middle Part 3) Distal Part	No Composition Cycle: No
	PVC Fiber	1) Contiguous Part 2) Middle Part 3) Distal Part	Synthetic Fiber + Poly Vinyl Chloride Cycle: 24 Hours
	Mod Acrylic Fiber	1) Contiguous Part 2) Middle Part 3) Distal Part	Synthetic Fiber+ PVC+ Acrylonitrile Cycle: 24 Hours

Table 2 shows the fibers which were composited with different chemical properties to get the aspiring composite fibers. There is plenty of synthetic fiber in retail therapy which properties were unidentified. Therefore, we have chosen random synthetic fiber to insert our desirable chemical properties. This section defines a simple method of formulating the Synthetic, PVC and Mod-Acrylic fibers as following steps:

(1) Synthetic Fiber: An arbitrary synthetic fiber was chosen from hair product retailer. Primarily its dust particle was rinsed off with deionized (DI) water. Later put it on the ultrasonic cleaner (Power Wash, HA207) for 1 minute and directly supplied to AFM sheet for the experiment.

(2) Poly Vinyl Chloride (PVC) Fiber: This type of fiber was formulated by PVC coating of synthetic fiber. The First material of coating was liquid PVC which was synthesized by raw PVC powder along with water. The number of mixture properties was 50 mL: 250 mL of PVC: Water. For appropriate mixing, a magnetic stirrer was used for long

10 hours. Therefore, synthetic fiber was composited in 10 mL of liquid PVC for 24 hours of the cycle. Completely, we obtained our PVC fiber hair for our test.

(3) Mod-Acrylic Fiber: This fiber was acquired by PVC and acrylonitrile liquid in the scale of 1:1 mL. First, PVC liquid was added to acrylic with the same portion of 5mL: 5mL and through a stirrer of 10 hours we have formulated the mod-acrylic liquid. Afterward, 10mL of mod-acrylic liquid were deposited on synthetic fiber for 24 hours cycles of configuration to obtain the coated mod-acrylic synthetic fiber for practice.

3. Result and Discussion

3.1 Measurement of Nanotribological Properties

3.1.1 Surface Measurement

An AFM (Park System Co. XE-100) with microsphere cantilever of spring constant 0.78 N/m was used to measure the average surface area of the human hair (Group-A) and artificial fiber (Group-B) samples. R_a is measured using AFM scan mode while the probe is scanned parallel over the sample hair along with the cross-sectional direction. Scan size was set at 10×10 μm² with a normal load of 5 nN, and its scan rate was 1 Hz. These data were extracted from the topography, and it can be selected at different specimens as well as the whole region. Therefore, this study applied a line mode to find out every three horizontal specimens [1-5].

As shown in Fig. 1(a), the structural investigation was done by the topography of human hair: Normal, Curly and Colored hairs, respectively. This shows the physical change of each individual hair and an equivalent structure of hair surface. In the scale of curvature, the cuticle of curly hair is more arched than that of others by which we can attribute its oval cross-sectional shape and curliness. Particularly by evaluating the cuticle shape we can aspect the characteristic of hair. [1-11]

Fig. 1(b) shows the complete experiment image of accurate artificial fibers: Synthetic, PVC, and Mod-Acrylic fiber respectively. In the cases of chemical synthesis hair, the cuticle structure is absent. Synthetic and mod-acrylic fiber were exhibited more shabby away cuticle scales than the PVC fibers. This is most likely due to the different effects of chemical and composition time on artificial hairs.

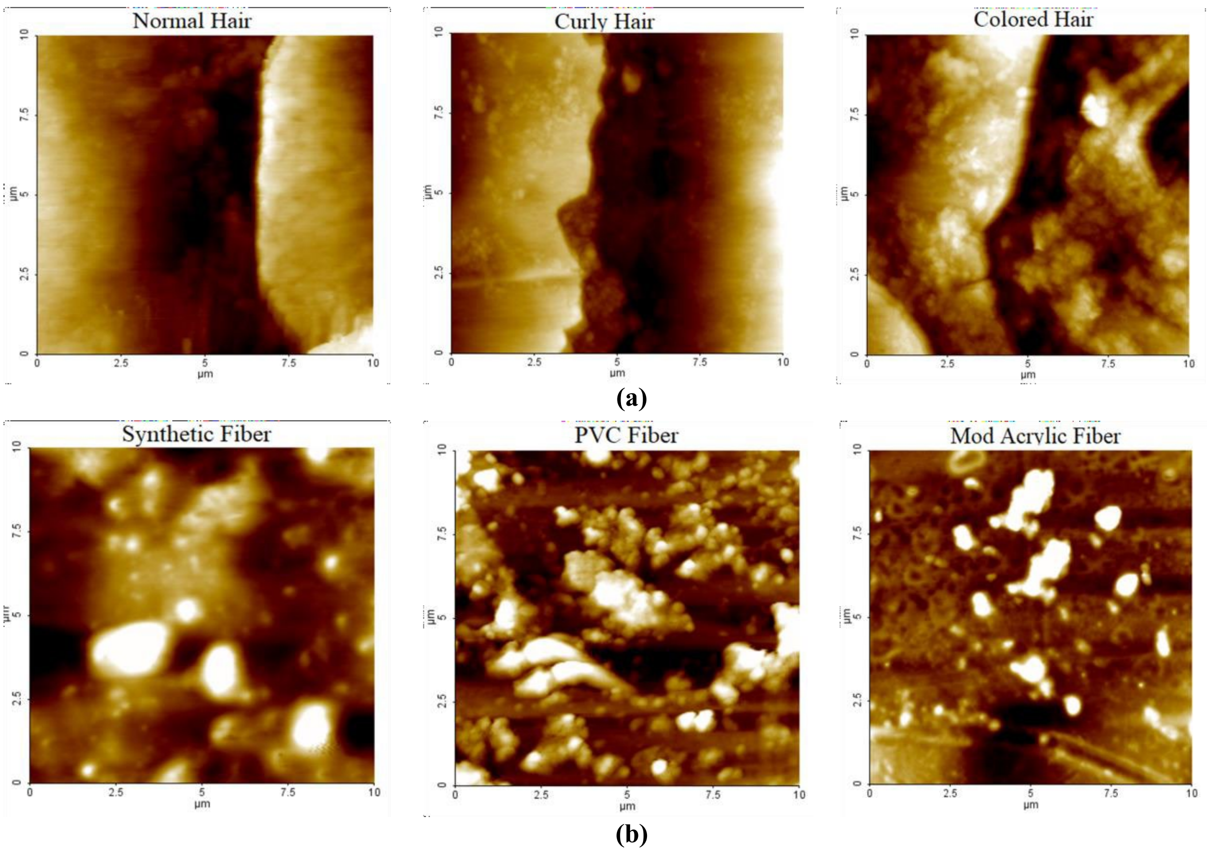

Fig. 1- (a) Surface Roughness of Normal, Curly & Colored Hair; (b) Surface Roughness of Synthetic Fiber, PVC Fiber, Mod Acrylic Fiber.

3.1.2 Adhesive Force Measurement

The adhesive force was carried out with the F/D (force-distance) curve mode. The customized probe (spring constant 0.78 N/m) with microsphere was used to measure the adhesive force. The probe was brought to contact with the sample surface by the horizontal movement of the piezo. It could not measure the adhesive force of the whole scan size sample surface. Therefore, we added every three specimens to calculate the average $F_{adhesion}$ of those points to evaluate the sample's $F_{adhesion}$. According to specimens, the microsphere tested the $F_{adhesion}$ of those points in turn[12-17].

Before the measurement of $F_{adhesion}$, the velocity and the normal load (set-point force) of F/D curve mode need to resolve. When the microsphere contacted the sample hairs, the down and up speed could affect the shape of the force-distance curve and the amount of the $F_{adhesion}$. Hence the best velocity of both contact and split up from the sample surface is important to apply in this mode. In Fig. 2, the force-distance retracting curves are indicated the range of different leading speed from 0.1 μm/s to 1.5 μm/s. Most curves are concordant at 0.1 μm/s and the $F_{adhesion}$ is not reaching a normal value at 0.2 μm/s. Therefore, it could be seen that, when the microsphere measured the sample hairs, the force-distance curve at 0.5 μm/s being mostly correct (the circle part) and velocity fixed at0.5 μm/s.

In the case of set-point, some fixed forces (1 ~25nN) were used in a force-distance test. In other words, the set-point force is the force of the probe which added on the hairs. So, different set-point force has an influence on the force-distance curves. In Fig. 3, the force-distance retracting curves are indicated. To compare the F/D curves under different set-point forces [8-9,12-17] random six set-points were used in tests on the same position of an identical sample hair. The highest set-point value applied at 25 nN which is fixed. When the set-point force is 1 nN, the distance is not reaching a normal value and the other curves are concordant at the same distance. While setting point at 5 nN, the $F_{adhesion}$ is highest, and this set-point force is best for the hair test. Hence, we fixed the force load at 5nN.

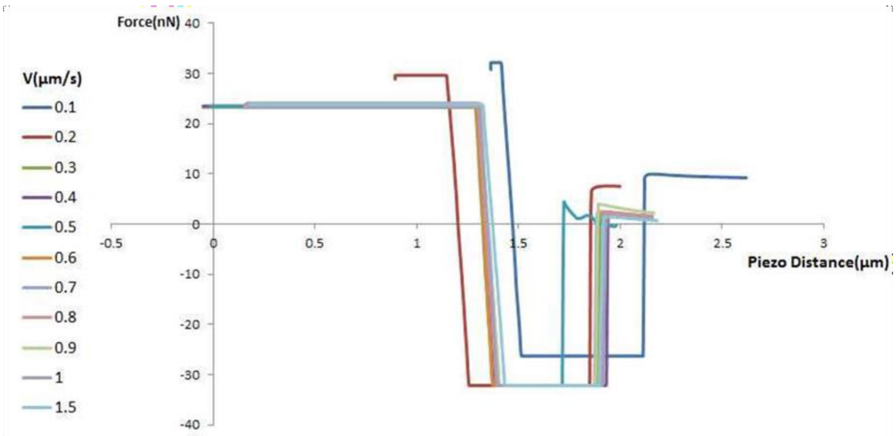

Fig. 2 - Force distance curve with different separate velocity

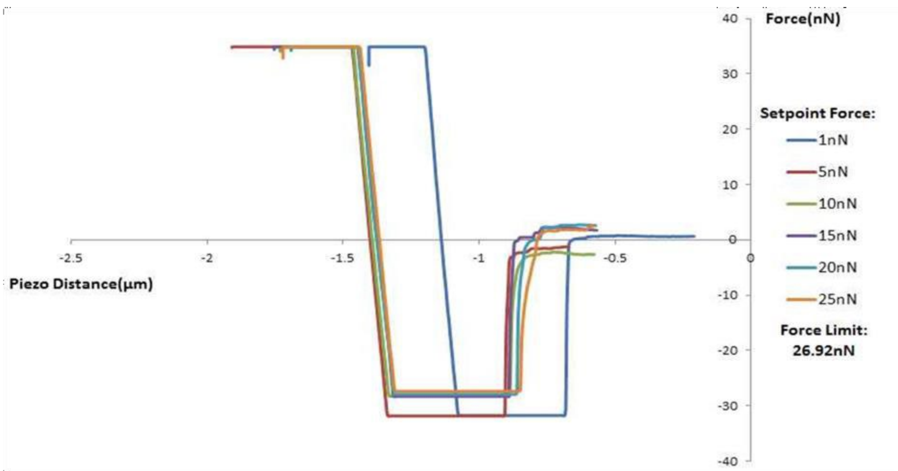

Fig. 3 - Force distance curve with different set point

Using the F/D curve we have taken a total of 9 tests of each three specimens of Group A and Group B samples. From the line curve of adhesive distribution, both human and artificial hair was shown to be comparable with PVC fiber. In terms of mod-acrylic, the curve line went down when the PVC fiber increased significantly. For synthetic fiber, it was slightly up, but the difference with normal hair was higher. A trivial similarity was found with PVC fiber adhesion distribution is shown in Fig. 4.

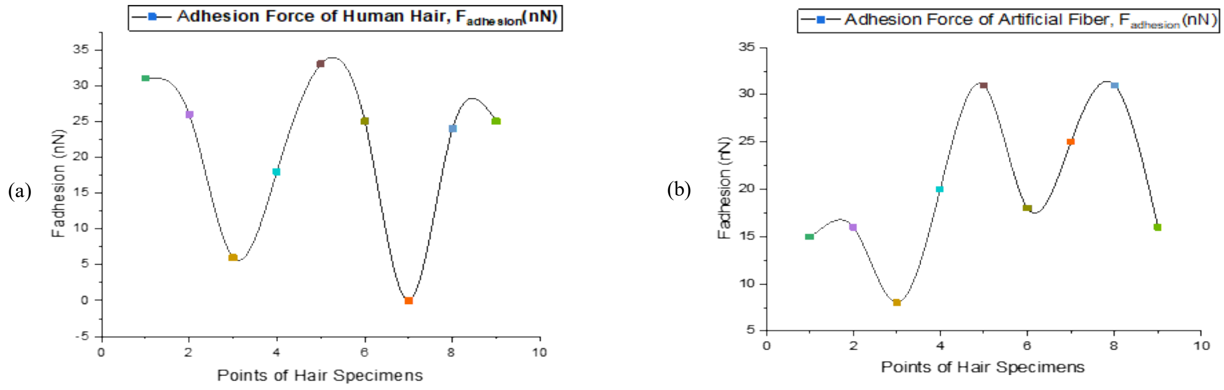

Fig. 4 - (a) Adhesive force of Human Hair (b) Adhesive Force of Artificial hair

3.1.3 Friction Force Measurement

Friction force measurements can be done at the same time with R_a. Its scan size, normal load and scan rate are also set as 10×10 μm², 5 nN, 1 Hz. The average coefficient of friction can be determined from the slope of the least-squares fit line of the data termed estimated value. While the calibration of friction force has done by the relationship below:

$$F_{friction} = \mu(F_{load} + F_{adhesion}) \quad (1)$$

This method supplied a relationship for friction force with the coefficient of friction, normal load, and adhesive force. Where μ is the coefficient of friction, F_{load} Pis the applied normal load, and $F_{adhesive}$ is the adhesive force. Then adhesive force can also be calculated by this method [1-3,17-20].

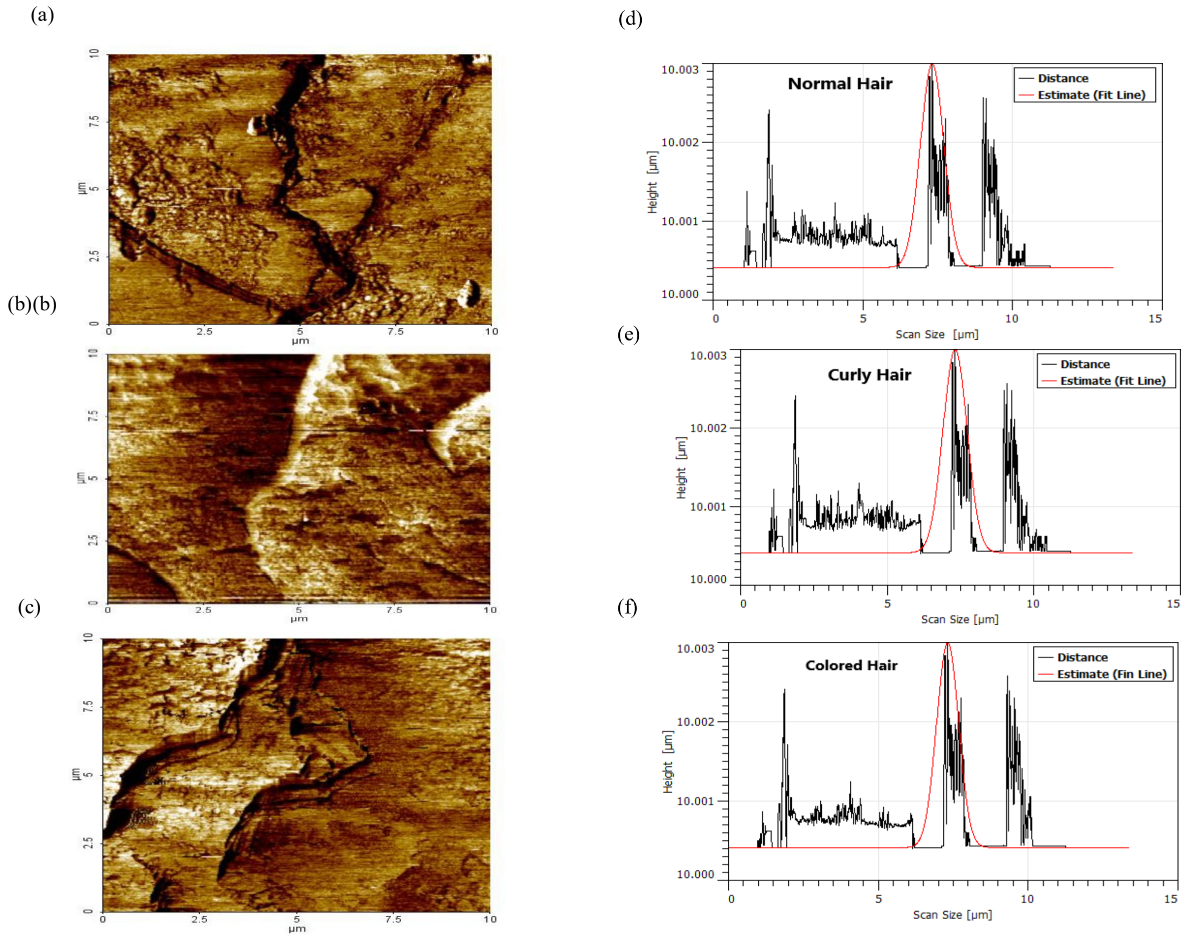

Fig. 5 - Friction images for, (a) Normal Hair, (b) Curly Hair, (c) Colored Hair. Line curves of friction coefficient for, (d) Normal Hair, (e) Curly Hair, (f) Colored Hair

Friction force of Normal, Curly and Colored hairs are shown in Fig. 5 individually. Left image of Fig. 5 shows the structural semblance of friction force while the x and y-axis both represent a scan size of 10 µm. We can clearly determine the cuticle of Fig. 5 (a) & (b) while the cuticle of Fig. 5 (c) was more scattered. By the scatteration, we can also determine the range of $F_{friction}$. The higher scatter a cuticle has a higher $F_{friction}$ which was not required. To verify the condition, we need to achieve a lower $F_{friction}$. By the topography, we observed colored hair was more scatter than other hairs and hence it has the highest $F_{friction}$. To determine the exact amount of $F_{friction}$, we can analyze the right-side line curve of Fig. 5 (d), (e), and (f). Using the least square fit line we ascertained the estimated friction coefficient and force value. The coefficients were 0.07, 0.08 and 0.087 and forces are generally 0.961nN, 1.02 nN and 1.40 nN for normal, curly and colored hair while it is seen that more scratched cuticle surface has higher $F_{friction}$. Therefore, in terms of colored hair, the surface of the cuticle has high distortion, and its $F_{friction}$ was also seen higher. The red line shows the estimated value of $F_{friction}$ for each line curve.

Fig. 6 illustrates the $F_{friction}$ of chemical treated artificial fiber hairs. Left image of Fig. 6 shows the physical properties of $F_{friction}$ of artificial fibers. These fibers have no cuticle like human hair and hence we cannot determine the friction force using the distortion of the cuticle. While we can see the disturbance on them. Except for PVC fiber other two fibers have high disturbance and we can approximate; PVC fiber has low friction force compared to others.

Line graph of Fig. 6 (d), (e) and (f) shows, the mod-acrylic fiber has higher friction force with 1.8 nN which representing the high distortion of R_a. Hence, the synthetic fiber has damaged the surface with friction force 1.5 neighboring with mod-acrylic. Later it was observed that the friction force of PVC fiber was tiny of 0.76 nN which is joining the value of normal hair. Particularly, it was observed that the chemical treated fiber has similarity in magnitude with human hair however in terms of structure they were more biased.

3.2 Tribological Analysis

The results are focused on how artificial fibers were evaluated by nanotribological characterization using AFM. The human hairs were tested by choosing three types of samples: normal, curly and colored hair. Chosen sample types of artificial fibers were Synthetic, PVC (Polyvinyl chloride) and Mod-Acrylic fibers. Each of the samples was selected about

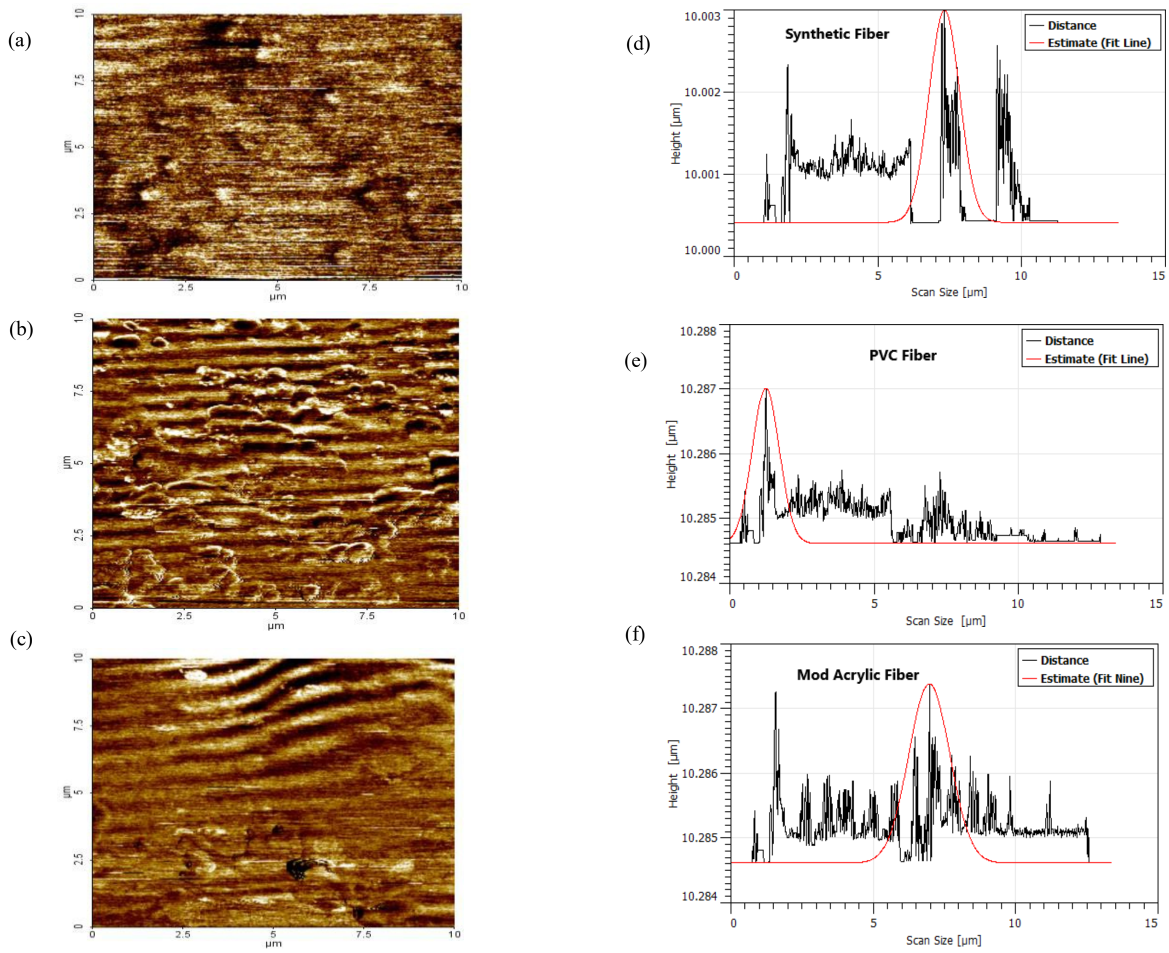

Fig. 6 - Friction images for, (a) Synthetic Fiber, (b) PVC Fiber, (c) Mod Acrylic Fiber. Line curves of friction coefficient for, (d) Synthetic Fiber, (e) PVC Fiber, (f) Mod Acrylic Fiber

1.0~1.5 cm of length for three specimens: Contiguous Part, Middle Part, and Distal Part. The tribology (R_a, $F_{Adhesion}$, and $F_{Friction}$) measurement of a total of nine groups of specimens was shown in Fig. 7. From the graphs in Fig.7, the brown, violet and purple lines were the group of human hair specimens and the brown, black & olive lines were the synthetic hair samples. It shows the variation of surface roughness, adhesion force and friction force of human hair and artificial fibers. Specimens of 1~3, 4~6 & 7~9 represent the normal, curly and colored hair respectively for human hair samples. Conversely, the points of specimens are the same as synthetic, PVC and mod-acrylic fiber individually. Some part of all curve line indicates the similarity between human and artificial hair. Fig. 7(a) shows the difference of R_a while for human

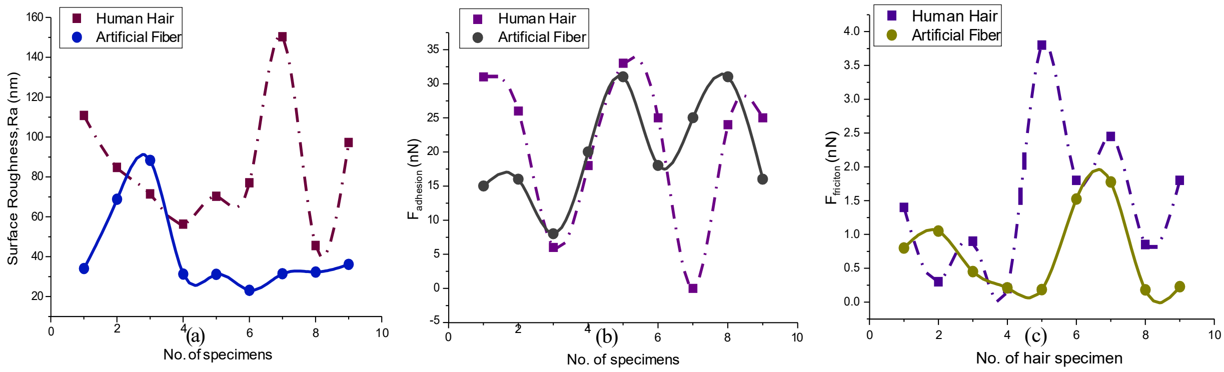

Fig. 7 - (a) Surface roughness, (b) Adhesion force and (c) Friction force curve lines of nine groups of hair specimens

hair, the variation was highly significant, and the only similarity can be seen for PVC fiber. For adhesion force, on PVC fiber resemblance with human hair. By the Comparison of friction force, only mod-acrylic fiber shows the similarity with hair while for surface roughness and adhesion force PVC fiber shows a trivial similarity with human hair.

Table 3 - Nanotribology Measurement of Human Hair

Group		R_a (nm)	Average (nm)	$F_{adhesion}$ (nN)	Average (nN)	$F_{friction}$ (nN)	Average (nN)
Normal Hair	**Contiguous Part**	110.7	88.97	31	21	1.4	0.87
	Middle Part	84.71		26		0.3	
	Distal part	71.43		6		0.9	
Curly Hair	**Contiguous Part**	56.28	67.82	18	25.3	0.2	1.9
	Middle Part	70.22		33		3.8	
	Distal part	76.97		25		1.8	
Colored Hair	**Contiguous Part**	150.2	97.64	0	16.33	2.45	1.7
	Middle Part	45.50		24		0.85	
	Distal part	97.19		25		1.8	

The results of the nanotribological characteristics of human and synthetic hair were illustrated in Table 3 & 4. From these results, it is testified that the tribology of nanocomposite fibers and human hair was relatively comparable. The average value of PVC fiber and curly hair were comparable with an average variation of 54.829~67.82 nm, 23~25.3 nN and 0.64~1.9 nN for R_a, $F_{adhesion}$ and $F_{friction}$ respectively. Therefore, under these solutions, the two properties of PVC synthetic fiber were treated heavier than others and we can conclude, the nanotribology of PVC synthetic hair are nearly similar human hair which can build in practice as a healthywig.

4. Conclusion

In this paper, we have evaluated the nanotribological characterization of human hair and nanocomposite synthetic fibers. The R_a, $F_{friction}$ and $F_{adhesion}$ of original human hairs and chemical treated synthetic fibers were assessed and compared. From the experimental results, a new artificial fiber, PVC is introduced by the evaluation of nanotribology. Through the validated range of the human hair and composite fiber, the synthetic hair meets the range of human hair, particularly the range of PVC synthetic fiber was the closest to compare with human hair. This means, the PVC fiber is suitable for people wearing, and it will not make side effects or some uncomfortable feeling with people skins or original hairs.

Acknowledgement

This work is supported by Research Center of Kumoh National Institute of Technology. South Korea.

Table 4-Nanotribology Measurement of Artificial Hair

Group		R_a *(nm)*	Average (nm)	$F_{adhesion}$ (nN)	Average (nN)	$F_{friction}$ (nN)	Average (nN)
Synthetic Hair	Contiguous Part	33.965	63.64	15	13	0.8	0.77
	Middle Part	68.749		16		1.05	
	Distal part	88.222		8		0.45	
PVC Synthetic Hair	Contiguous Part	76.279	54.829	20	23	0.21	0.64
	Middle Part	56.118		31		0.185	
	Distal part	32.09		18		1.524	
Mod Acrylic Synthetic Hair	Contiguous Part	63.387	43.92	25	24	1.776	0.72
	Middle Part	32.302		31		0.18	
	Distal part	36.075		16		0.228	

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