Indian Journal of Fibre & Textile Research
Vol. 43, March 2018, pp. 126-131

Relationship between morphology and tensile properties of pig hair fibre

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Received 8 September 2015; revised received and accepted 11 April 2016

The surface and cross-sectional features of hair fibres from four different breeds of pigs has been evaluated using scanning electron microscopy. The cross-section of the pig hair is modelled into an ellipse and the elliptical features of the fibre are correlated with its tensile properties. Surface scales in pig hair are arranged in imbricate type, crenate pattern and spaced at a mean distance of 4.58±0.24µm. Overall mean eccentricity, flattening, focus, area and angular eccentricity of pig hair fibre is found to be 0.60±0.09, 0.25±0.07, 195.16±33.68µm, and 0.06±0.01mm^2 and 38.24±6.61 ° respectively. The ellipticity parameters are positively correlated with tensile properties (tenacity, extensibility, initial modulus and work of rupture) of the fibre. The specific flexural rigidity is negatively correlated with the ellipticity of the fibre, suggesting that the elliptical fibres may be more flexible than the fibres with circular cross-section.

Keywords: Fibre ellipticity, Fibre cross-section, Pig hair, Tensile property

Hair fibres are by-products of humane slaughter of pigs with significant commercial value. The value addition and extensive utilisation of pig hair fibre is limited by incomplete characterisation of physical properties of this natural fibre[1]. The extent of value-addition in pig hair fibres is meagre as compared to the quantity of fibres available for manufacturing of utility products. Our previous study[2] has shown that tensile properties of pig hair fibre are comparable to wool. The annual global trade of pig hair fibre is about 110.35 million US dollars[3], indicating commercial value of these fibres.

Pig hair fibre is made of mostly keratin, and the keratin fibres of animal origin have cuticular scales on the surface, arranged in a distinct pattern that varies between animal species[4]. The scales are made up of keratin proteins, high sulphur keratin associated proteins (KAPs) and structural lipids[5]. The surface features of fibres contribute towards improved adhesion between fibres and matrix, hence to the strength of the composite[6]. The surface properties of the fibre are quite often modified for improving the quality of products developed from the fibres.

The animal fibres are elliptical in cross-section rather than circular even though the term diameter generally implies that the fibre has a circular cross-section[7]. The variation in microscopic features such as diameter, ellipticity, and cross-sectional shape can influence both physical and chemical properties of the fibre[5]. The term ellipticity is referred to describe the deviation from the circular shape and is measured as the ratio of major axis to minor axis of the fibre cross-section[8]. The fibre ellipticity is one of the parameters that can provide an estimate of intrinsic material strength of the fibres[9]. Previous studies[5,10,11] have established variation in the cross-sectional features keratin fibres. Several studies have also shown that the shape of fibre cross-section such as ellipticity can influence properties of fibre based products[12-14]. Elliptical fibres are reported to have lower moment of inertia and can flex preferentially towards minor axis[8,15,16]. Earlier studies using human hair[17] and wool[8] have established relationship between cross-sectional features of the fibre and its tensile properties. Therefore, it will be of practical value to examine the relationship between cross-sectional features of the pig hair fibre and its tensile properties.

In the present study, the cross-sectional morphology of the pig hair fibres has been analysed in relation with tensile properties of the fibre. We also describe the surface features of pig hair fibre for the first time as revealed by scanning electron microscopic study.

Experimental

The hair fibres obtained from four different breeds of pigs (Duroc, Hampshire, Ghungroo and Niang Megha, aged 12-18 months) maintained in the institutional farm of National Research Centre on Pig,

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Indian Council of Agricultural Research, Guwahati, Assam, India were used for the study. The fibre was extracted from apparently healthy pigs (n=6/breed, female) maintained under standard feeding and management practices. The animal experiments were approved by the Institutional Animal Ethics Committee. Hair fibres were clipped using scissors close to the skin after properly restraining the animal. All the properties of fibres were evaluated in their natural form without any processing at room temperature (22-25ºC) and a relative humidity of 65±2%. The fibres were conditioned for 72 h before tensile studies as per standard methods[18].

SEM of Fibres

SEM studies of the mid-shaft region of the fibres were carried out with Zeiss Evo-Maio scanning electron microscope (Carl Zeiss, Germany) at 3kV and 10 Pa after 24 nm thick palladium coating following standard methods[19] at Network Project on Insect Biosystematics, Division of Entomology, Indian Agricultural Research Institute, New Delhi, India. The SEM images were analysed using Analyzing Digital Images software (version 2012, Global Systems Science, University of California, Berkeley, California, USA).

Elliptical Modelling of Fibre Cross-section

The SEM cross-section of the pig hair fibre was modelled into an ellipse (Fig. 1) and various parameters that define an ellipse to describe cross-section of fibres were calculated. The ellipse is defined as a two dimensional closed curve that satisfies the equation $\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$, where a and b are the longer (semi-major) and shorter (semi-minor) axis respectively. The eccentricity, flattening, focus, area and angular eccentricities were calculated from a and b values measured from the SEM pictures as follows:

Ellipticity $(E) = a/b$
Eccentricity $(e) = \sqrt{1-(b^2/a^2)}$
Focus, $(f) = 1-(b/a)$
Area, $(A) = \pi ab$,

Angular eccentricity (α), representing the angle whose sine is eccentricity (e) was calculated as $\cos^{-1}(b/a)$ and flatness as ratio of longer and shorter axis of the ellipse.

The scale index was calculated by dividing scale interval (free proximo-distal diameter) of a cuticle scale divided by the shaft diameter[5].

Tensile Properties and their Correlation with Fibre Ellipticity

The tensile properties (breaking tenacity, extension at break, initial modulus and work of rupture) of pig hair fibres were estimated using a Universal tensile tester (Tinius Olsen Inc, USA, Model H50KS). The flexural rigidity, specific flexural rigidity and coefficient of static friction were measured as described previously[2]. The detailed study on tensile properties published earlier[2], was used for this study. The Pearson`s correlation coefficients were calculated between various ellipticity parameters and tensile properties. The correlation between scale index and fibre diameter was also calculated.

Statistical Analysis

The data on hair fibre characteristics were analysed using Graphpad Prism software (v5.0, Graph Pad Software, San Diego, USA).

Results and Discussion

In the present study, surface features of fibres obtained from different breeds of pig have been characterised. The cross-sectional features of the fibre were correlated with its tensile, flexural and frictional properties.

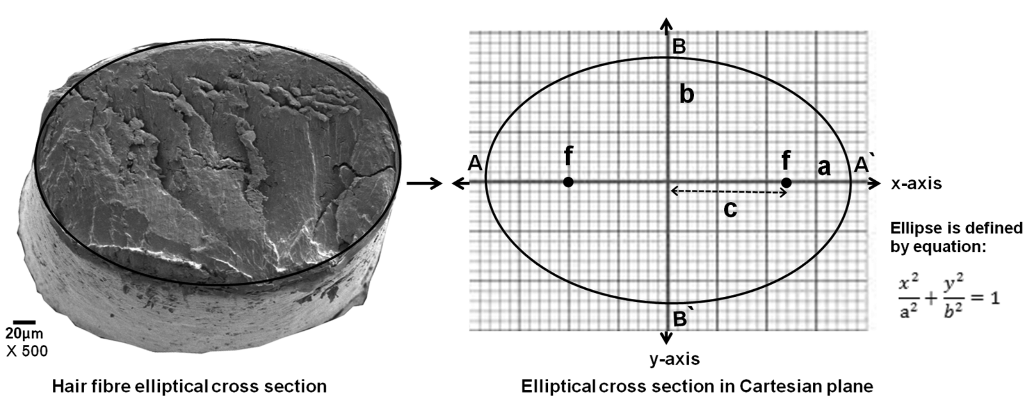

Fig. 1 — Elliptical modelling of cross-section of pig hair

Surface Features of Fibres

The surface of pig hairs reveals the presence of scales (Figs 2, 3A and 3B) similar to wool[20,21], human[5], rabbit hair[22], horse and feline hair fibres[3,23]. The scales are found arranged as layers, one overlapping the other, separated by an average distance (scale interval) of 4.58±0.24µm. The mean scale thickness is found 0.39±0.02µm and the number of scales per 100µm is between 14.76 and 20.42 (mean 17.19±1.65). The mean scale thickness of pig hair fibre is found similar to cashmere (0.35µm), but was lower than wool from Merino sheep (0.48µm)

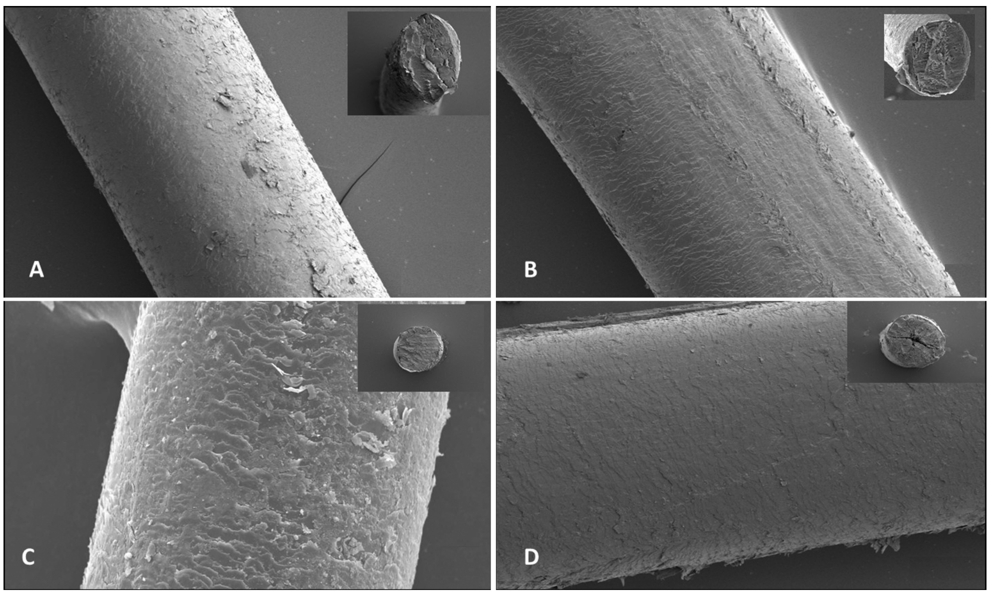

Fig. 2 — SEM images showing surface features of pig hair fibre from different breeds (×500). The inset shows cross-section of mid-shaft of the fibre (×250). [A — Hampshire, B — Duroc, C — Ghungroo and D — Niang Megha]

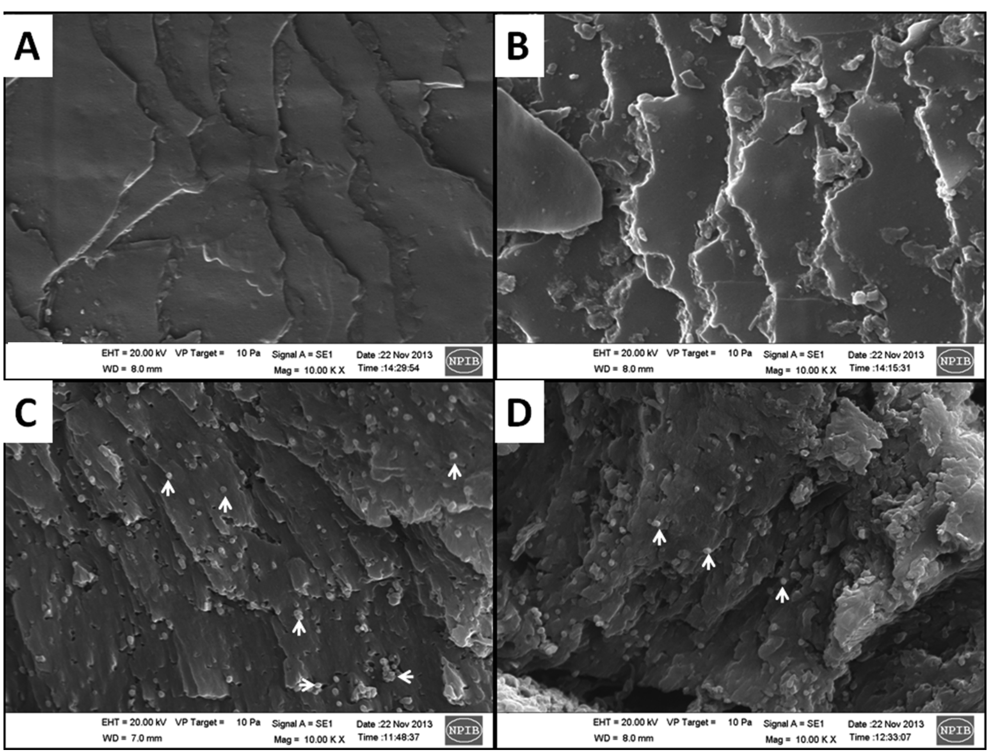

Fig. 3 — SEM images showing surface features of pig hair fibre (×10000, A and B at different locations); and the cross-section of the fibre shows macrofibrils (white arrows) (×10000, C and D at different locations)

and Chinese local sheep (0.53μm). The pig hair has more number of scales than both wool and cashmere[24]. The number of scales on the surface per unit length is found similar to wool and alpaca fibre, but lower than cashmere and fine wool[8]. A lower scale interval and higher mean scale thickness supports higher coefficient of static friction for the pig hair fibre observed earlier[2].

The distribution of scales on the surface of pig hair fibres follows an imbricate type, crenate pattern, similar to wool, human hair[5] and fibres from other domestic species such as cattle, horse and goat[23]. The mean scale index is 0.22. The fibre diameter is negatively correlated to scale index and scale interval (Fig. 4). Several studies examined the surface features of mammalian hairs, especially that of human hair[25,26] and wool[8]. The surface features of the fibre contribute to friction and hence are one of the factors determining the properties of product. The relationship between the surface features with felting capacity, binding and amenability of the fibre for nonwoven applications needs further study. Some of the observed surface features of pig hair fibre reported in the study might have also resulted from frictional wear and the chipping away of the hair surface scale as suggested earlier for human hair[27].

Elliptical Features of Fibre Cross-section

The elliptical features of hair fibre cross-section (Table 1) show a variation with respect to breed of pigs. The mean semi-major and semi-minor axis lengths are 316.15±23.24 and 236.71±27.31μm respectively. The overall mean eccentricity, flattening, focus, area and angular eccentricity of pig hair fibre are 0.60±0.09, 0.25±0.07, 195.16±33.68μm, 0.06±0.01mm^2 and 38.24±6.61° respectively. The results of present study indicate that the pig hair fibre has an elliptical outline, similar to other protein fibres. The ellipticity of fibres from Hampshire and Duroc breeds of pig is more than the fibres from indigenous breeds (Ghungroo and Niang Megha). There is significant difference ($P<0.05$) in angular eccentricity and flattening of the hair fibres among different breeds of pigs. The elliptical features of pig hair are found similar to wool[9] and human hair[28]. The ellipticity of the fibre is influenced by fibre diameter, which, in turn, is influenced by season, nutrition, breed and genetic makeup of the animal[29]. The present study confirms our earlier findings suggesting a breed-wise variation in the physical characteristics of pig hair fibre[2].

Higher magnifications (x10000) of hair fibre cross-section (Figs 3C and 3D*)* show granular structures with a diameter of 274.43±10.15nm. The granular

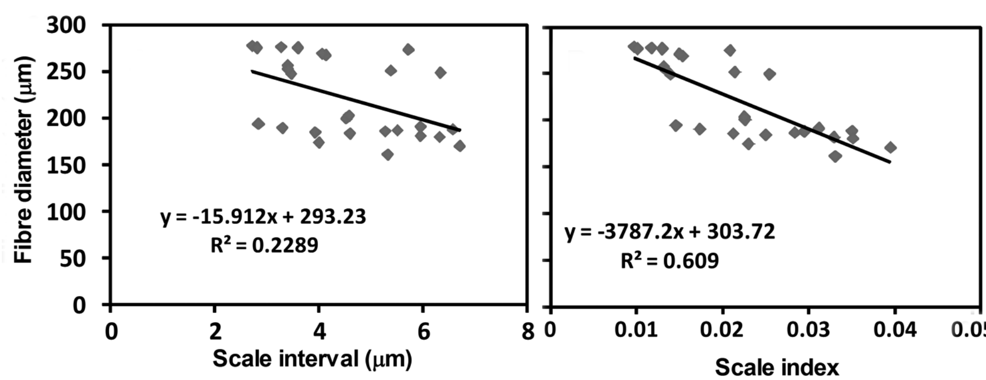

Fig 4 — Relationship between diameter with scale interval and scale index of pig hair fibre

Table 1 — Elliptical features of pig hair fibre cross-section

Elliptical parameter	Hampshire	Duroc	Ghungroo	Niang Megha	Overall mean
Ellipticity	1.48±0.1^a	1.51±0.1^a	1.10±0.1^b	1.25±0.1^b	1.34±0.10
Eccentricity	0.77±0.01^a	0.75±0.01^a	0.42±0.01^b	0.46±0.17^c	0.60±0.05
Flattening	0.37±0.01^a	0.34±0.01^b	0.09±0.01^c	0.18±0.09^d	0.25±0.01
Focus	228.3±25.9^a	273.9±23.3^b	143.7±21.5^c	134.7±56.6^c	195.2±31.83
Area,mm²	0.044±0.008^a	0.069±0.002^b	0.084±0.002^c	0.043±0.005^a	0.061±0.0.4
Angular eccentricity, deg	50.42±1.15^a	48.70±0.57^a	24.64±0.57^b	29.22±1.15^c	38.25±0.86

$^{a-d}$Values with similar superscript within a row do not differ significantly ($P<0.05$).

Table 2— Correlation between tensile and ellipticity parameters of the pig hair fibre

Tensile parameter	Ellipticity	Flattening	Focus	Eccentricity	Angular eccentricity
Linear density	0.44	0.38	0.25	0.40	0.39
Tenacity	0.49	0.54	0.58	0.55	0.54
Extension-at-break	0.37	0.38	0.42	0.39	0.39
Initial modulus	0.35	0.43	0.44	0.42	0.42
Work of rupture	0.51	0.54	0.56	0.55	0.55
Flexural rigidity	0.29	0.25	0.04	0.26	0.25
Specific flexural rigidity	-0.80	-0.71	-0.72	-0.74	-0.72
Coefficient of static Friction	-0.80	-0.11	-0.11	-0.08	-0.09

structures correspond to macrofibrils in the inter-macrofibrillar matrix confirming earlier findings in human hair[30,31] and wool[32].

Correlation between Tensile Properties and Fibre Ellipticity

The ellipticity parameters are found positively correlated with tensile properties (tenacity, extensibility, initial modulus and work of rupture) of the pig hair fibre (Table 2). Among the tensile characteristics of the fibre, tenacity and work of rupture show highest positive correlation (r^2=0.30) with ellipticity features of the fibre. The specific flexural rigidity is negatively correlated with the ellipticity of the fibre, suggesting that elliptical fibres are more flexible than the fibres with circular cross-section. Minor axis of elliptic is found to have a dominant effect on bending resistance of hair fibre[16]. Elliptical and ribbon shaped fibres are considered more flexible in twisting because their shape factor is less than one, leading to a lower torsional rigidity[8]. The coefficient of static friction shows a negative correlation with ellipticity of the fibre. The study falls in line with previous findings[33-35], indicating relationship between elliptical features of wool fibre and its diameter.

It has been inferred from the study that among the tensile characteristics of the fibre, tenacity and work of rupture showed positive correlation with the elliptical characteristics of the fibre. Variations in the elliptical cross-sectional features of pig hair fibres with respect to breeds could be observed. The surface features of pig hair fibres are similar to other protein fibres. Hence, pig hair fibre could be examined for manufacture of low cost, environment friendly industrial and domestic products similar to other natural protein fibres. Effect of various treatments on surface for improving fibre-matrix adhesion, abrasion resistance, and possible usefulness in species/breed identification using pig hair fibre also need further studies.

Acknowledgement

The authors are thankful to Indian Council of Agricultural Research, India for funding support to carry out this study.

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