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Characterization of natural and synthetic fiber for forensic purposes

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Abstract
Fragments of cloth and fibers may become evidence in a wide variety of crimes. Whenever personal contact is involved, the exchange of fabrics or fiber may occur between the clothing of the suspect, the victim and or the weapon of offences. Therefore, the current study provides useful methods of fiber analysis which can further utilized by forensic expert dealing with such cases. In present study 6 natural and 6 synthetic fiber samples (cotton fiber, coconut fiber, wool fiber, jute fiber, silk fiber, flax fiber, polyester fiber, glass fiber, nylon fiber, rayon fiber, acetate fiber, acrylic fiber) were taken and analyzed by subjecting them to various examination such as burning test, microscopic examination, physical examination, solubility examination, tensile strength, refractive index and density examination. After analysis, characteristics features of different fibers were noted.

Keywords: Natural fiber, synthetic fiber, forensics, locard's principle, trace evidence, physical examination

Introduction
Fibers are a class of hair-like materials that are continuous filaments or are in disserted elongated pieces, similar to pieces of thread (Needles, 1986) [23]. They can be spun into filaments, thread or rope and is used as a component of compound materials. They are further matted into sheets to make products such as paper.

Fibers are mainly of two types- natural fiber and man-made fiber. Natural fibers are hair-like raw material directly obtained naturally from plants; animals and geological processes (John, 2008) [11]. They are further classified as- plant, animal and mineral fiber. They are biodegradable over a time. Plant fibers like cotton and jute are obtained from the plant sources. Bamboo, coconut trees, flax seeds, hemp, vegetable fiber, Nettle, Ramie, wood grains are different sources of plant fibers. Animal fibers like wool and silk are fibers obtained from the animal sources consist exclusively of proteins and form the protective epidermal covering of animals. Sheep, camel, cashmere and mohair goats, rabbits, yak, silkworms, vicuna are the different sources of animal fibers. Mineral fibers are the inorganic materials shaped into fibers such as asbestos. These fibers are resistant to fire and acid and are used for industrial applications.

Man-made fibers are artificially synthesized in the industries in which the polymers are designed to make fabrics by the application of simple chemicals. These fibers generally come from synthetic materials such as petrochemicals but some types of synthetic fibers are manufactured from natural cellulose, including rayon, modal, and more recently developed Lyon cell (George, 1993) [10]. The polymers are macromolecules, which are composed by joining small, repeated subunits together. Rayon, nylon, acrylic polyester and acetate are some examples of these fiber types. Man-made fibers are further classified as: regenerated fibers, synthetic fibers and inorganic fibers.

Regenerated fibers like viscose rayon, bamboo are also known as semi-synthetic fibers. These are made of long-chain polymers which are modified by a chemical process to enable polymerization to form fibers. Synthetic fibers like polyester, acrylic, nylon are formed by the polymerization of monomers. Once a polymer is formed, it is converted into a fluid form.
The dissolved or molten polymer is extruded through narrow holes to give filaments. Inorganic fibers are also known as metallic fibers. They are obtained from copper, silver, gold, and can be extruded from nickel, iron, etc.

Locard's exchange principle states that every contact leaves a trace implying that a criminal will leave trace and take away trace evidence when at a crime scene. Trace evidence often refers to minute samples found at a crime scene which particularly include fibers, hairs, glass fragments and paint chips. Trace evidences commonly present at crime scene are often created by the perpetrator unconsciously coming in to contact with surfaces and leaving behind or picking up particulates. Various methods are employed in the collection of trace evidence, the method used depend on the type and nature of evidence and often larger objects, such as long fiber, may be collected by hand or tweezers. One of the common methods for recovery of the samples from fire scene is to shake the item over a sheet of paper or container. However this does not allow to know the exact location of the evidence on the item to be documented. Some particles might not be dislodged by shaking the item; therefore brushing the item may be necessary.

Fibers are all around us in form of thousands of products including clothing, upholstery, carpet, ropes and building components. When a person comes in contact with these products, some part of their fibers get lodged onto his/her body and/or clothes. The fibers evidence can therefore often provide information about where people have been.

Fiber's analysis is very important for forensic purposes. Fragments of cloth and fibers may become evidence in a wide variety of crimes. Whenever personal contact is involved, the exchange of fabrics or fiber may occur between the clothing of the suspect, the victim and/or the weapon of offences. Torn fabrics have been observed and collected as evidences in homicides cases, where the victim was tied and gagged with some ligature or cloth. In burglary cases, the culprit often left a small torn piece of clothing or a thread from his clothing at the point of entry and exit. In hit and run cases torn clothing usually left under carriage of the suspect vehicle. In suicide cases, tensile strength of the ligature material can be examined to check whether the material could bear the weight of the victim or not. In this way, fiber can be used as an evidence to link the criminal, crime scene and the victim with each other and hence even though they are trace in amount, they become important piece of evidence from forensic point of view.

Materials and Methods

The present study entitled "Characterization of Natural and Synthetic Fibers for Forensic Purposes" was carried out at the Department of Forensic Science, Sam Higginbottom University of Agriculture Technology & Sciences, Prayagraj. A total of 60 samples, which comprised of 5 samples from each fiber type, were subjected to analysis. Cotton fiber, coconut fiber, wool fiber, jute fiber, silk fiber, linen fiber, polyester fiber, glass fiber, nylon fiber, rayon fiber, acrylic fiber and acetate fiber samples were used for the study. These sample fibers were collected from local shops of Prayagraj. After collection, the samples were preserved in alcohol to remove contaminants like dirt particles. Samples were then subjected to different tests for the characterization of fiber sample.

Naked Eye Examination/Physical Analysis

All samples were examined by naked eye and touch examination by hands.

1. **Microscopic Examination:** Samples were twizzled and placed on a slide, covered with a cover slip and observed under microscope. The characterization of each fiber was observed and recorded.
2. **Burning Test:** Sample of each fiber was held using forceps and burned using in a spirit lamp. Behavior of each sample was observed and recorded.
3. **Solubility Examination:** Each sample fiber was dipped in different solvents for overnight. The observations were recorded the next day. Sodium hydroxide; ethanol, conc. sulfuric acid, conc. nitric acid and chloroform were used as solvents for performing this experiment (Abir *et al.*, 2017) [14].
4. **Refractive Index:** Each fiber sample was taken on different microscope slide and fluids of different refractive index were added dropwise on it and then observed under microscope. The behavior of each sample was observed and recorded. If the refractive index of fiber matched with the refractive index of liquid, the Becke line (the halo-effect seen around certain substance under a microscope) did not appear which meant refractive index of fiber matched with liquid's refractive index. If Becke line appeared, it meant the fiber's refractive index was higher than the liquid's refractive index (Faust, 1955) [7]. The fluids used in this test were:

Fluids	Refractive Index
N-butyl alcohol	1.402
Olive oil	1.467
Castor oil	1.482
Clove oil	1.543
Bromoform	1.597

5. **Density Examination**

In this method, a density tube was filled with mixture of solutions mixed in different ratios. Solution with high density (Bromoform) was present at the bottom of the tube and at the top was a solution with low density (Bromobenzene); densities gradually decrease in between as they ascend the tube. Each fiber sample was put into different density gradient tubes and kept undisturbed for 24 hours. The fibers sank through the solution mixtures of lighter density until they reached a point where the solution mixture density matched the respective fiber density. Thus, fibers represent various densities (Mark, 1946) [19]. The observations were recorded.

Results

Table 1: Below describes the solubility of the different fibers in different reagents- sodium hydroxide, conc. Sulfuric acid, conc. Nitric acid, chloroform and ethanol.

Table 1: Comparative chart for solubility of different fibers by using different reagents

Reagents Samples	NaOH	Conc. H_2SO_4	Conc. HNO_3	$CHCl_3$	C_2H_5OH
Cotton fiber	Not Soluble	Soluble	Soluble	Not Soluble	Not Soluble
Coconut fiber	Not Soluble	Not Soluble	Soluble	Not Soluble	Not Soluble
Wool fiber	Not Soluble	Not Soluble	Soluble	Not Soluble	Not Soluble
Jute fiber	Not Soluble	Soluble	Soluble	Soluble	Not Soluble

Silk fiber	Not Soluble	Not Soluble	Soluble	Not Soluble	Not Soluble
Linen fiber	Not Soluble	Soluble	Soluble	Not Soluble	Not Soluble
Polyester fiber	Not Soluble	Not Soluble	Not Soluble	Not Soluble	Not Soluble
Glass fiber	Not Soluble	Not Soluble	Not Soluble	Not Soluble	Not Soluble
Nylon fiber	Not Soluble	Not Soluble	Not Soluble	Not Soluble	Not Soluble
Rayon fiber	Not Soluble	Not Soluble	Not Soluble	Not Soluble	Not Soluble
Acrylic fiber	Not Soluble	Not Soluble	Not Soluble	Not Soluble	Not Soluble
Acetate fiber	Not Soluble	Not Soluble	Not Soluble	Not Soluble	Not Soluble

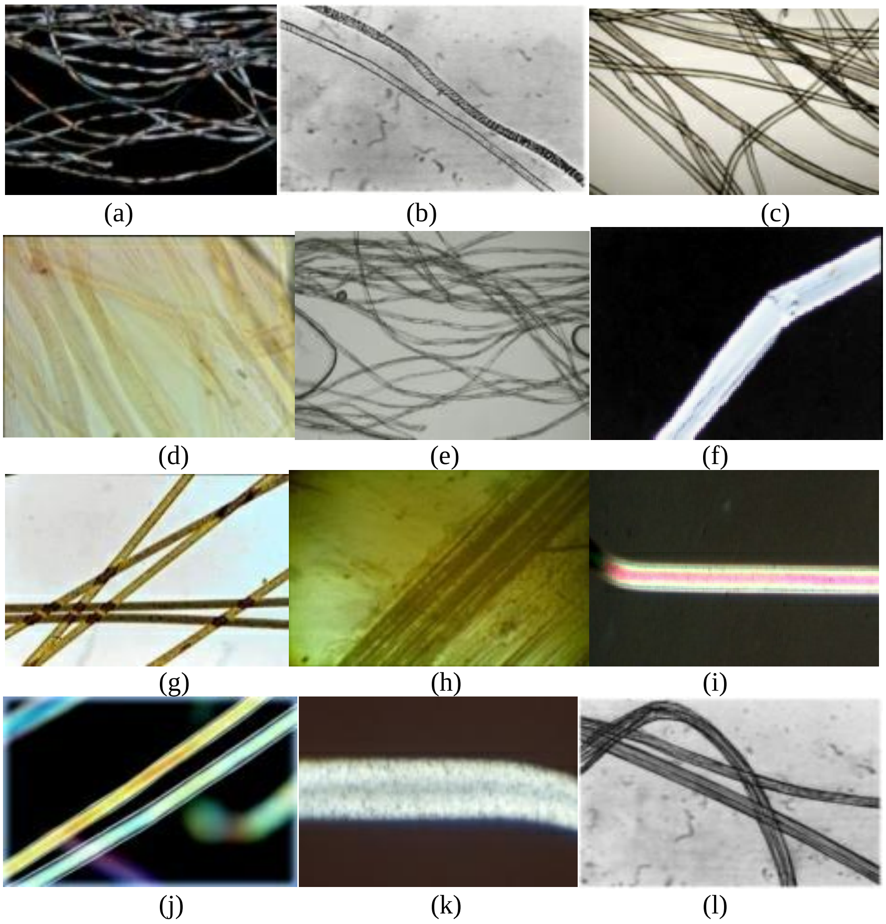

Fig 1: Microscopic images of different fibers under compound microscope (at 45X)- a) Cotton fiber, b) Coconut fiber, c) Wool fiber, d) Jute fiber, e) Silk fiber, f) Linen fiber, g) Polyester fiber, h) Glass fiber, i) Nylon fiber, j) Rayon fiber, k) Acrylic fiber, l) Acetate fiber

Table 2: Given below describes the density and Refractive Index of different fibers. Linen fiber shows maximum refractive index and minimum refractive index is seen in acetate fiber. Glass fiber shows maximum density whereas acrylic fiber shows minimum density.

Table 2: Comparative chart for density and Refractive Index of different fibers

Fiber samples	**Density**	**Refractive Index**
Cotton fiber	1.5g/cm^3	1.53
Coconut fiber	1.15g/cm^3	1.46
Wool fiber	1.30g/cm^3	1.54
Jute fiber	1.50g/cm^3	1.57
Silk fiber	1.25g/cm^3	1.54
Linen fiber	1.42g/cm^3	1.59
Polyester fiber	1.40g/cm^3	1.58
Glass fiber	2.44g/cm^3	1.53
Nylon fiber	1.2g/cm^3	1.54
Rayon fiber	1.50g/cm^3	1.53
Acrylic fiber	0.95g/cm^3	1.51
Acetate fiber	1.30g/cm^3	1.48

Table 3 below describes the characteristic features of fibers when examined under microscope and their physical appearances as observed by naked eye.

Table 3: Comparative chart for Microscopic Examination and Physical Examination by Naked eye of different fibers

Fiber Samples	Microscopic examination	Physical examination by naked eye
Cotton fiber	Single elongated cell, spirally twisted ribbon like tube, it looks like flat.	White colour, Feels cool and rough when touched.
Coconut fiber	Single elongated cell, spirally twisted ribbon like tube, it looks like flat.	Brown colour, Feels cool and rough when touched.
Wool fiber	Irregular, roughly cylindrical and multi cellular structure with tapered ends.	White and gray colour and feel warm rough to touch.
Jute fiber	Cylindrical with unevenness spread across diameter and nodes appear	Brown colour, Feels cool and rough when touched.
Silk fiber	Two fine and lustrous filaments are shown clearly looking like transparent rods with triangular shape.	White Shinning colour and feels sticky upon touching.
Linen fiber	Smooth and bamboo like with cross marking nodes, flat ribbons	White colour, It is soft in touch.
Polyester fiber	Generally, polyester fiber is smooth, straight. It looks round cross sectional.	Shining blue colour and feels sticky upon touching.
Glass fiber	The glass fiber looks smooth, round, translucent, shiny and flexible.	White in colour and smooth in touch.
Nylon fiber	Generally it appears fine, round, smooth and translucent. Sometimes it has shiny appearance it looks dull.	Orange in colour and smooth in touch.
Rayon fiber	Striation running parallel to fiber axis.	Smooth and orange in colour.
Acrylic fiber	Bone shape with apparent cut ends.	Lustrous appearance and light weighted
Acetate fiber	Striated surface and a lobed cross – section.	It is bright, shiny and smooth in touch.

The characteristic features of different fibers after subjecting them to flame and after their removal from flame, their odour while burning and ash left after burning fiber were examined. The observations are mentioned in Table 4 given below:

Table 4: Comparative chart for burning test of different fibers

Fiber samples	Burning Test
Cotton fiber	In Flame: Ignites immediately, Removed from Flame: Continues to burn, Odour: Characteristic Odour, Ash: Fine grey ash.
Coconut fiber	In flame: Ignites immediately , Removed from flame: Non-Self Extinguisher, Odour: Characteristic odour , Ash: Light ash
Wool fiber	In Flame: burns slowly (curls), Removed from Flame: Self extinguishing, Odour: Burning hair, Ash: Small beads.
Jute fiber	In Flame: Ignites immediately, Removed from Flame: Continuous to burn, Odour: Burning of paper, Ash: Light colored.
Silk fiber	In Flame: Burns slowly (curls), Removed from Flame: Self extinguishing, Odour: Burning hair, Ash: Dark bead.
Linen fiber	In Flame: Ignites immediately, Removed from Flame: continuous to burn, Odour: Burnt paper, Ash: fine gray ash.
Polyester fiber	In Flame: Melts slowly, Removed from Flame: Self extinguishes, Odour: Acidic odour, Ash: Brittle bead.
Glass fiber	In Flame: Does not burn, Removed from Flame: Flame can melt fabric slightly, Odour: Characteristic odour, Ash: Hard beads.
Nylon fiber	In Flame: Melts slowly, Removed From Flame: self extinguishing, Odour: unidentified odour, Ash: Plastic bead.
Rayon fiber	In Flame: slowly burns, Remove from Flame: Self – extinguisher, Odour: Burnt paper, Ash: Light, white ash.
Acrylic fiber	In Flame: Rapidly melts, Remove from Flame: Self – Extinguisher, Odour: Acidic odour, Ash: Hard black bead.
Acetate fiber	In Flame: Rapidly burn, Removed from Flame: Self – Extinguisher, Odour: Burned wood, Ash: Hard black bead.

Summary and conclusion

In this study, 60 fibers samples having different source of origin (5 samples from each category) were subjected to various physical and chemical tests such as- burning test, microscopic examination and solubility examination, refractive index examination, density examination and tensile strength examination.

Differences in results were observed in color of fiber samples, appearances of fiber under microscope, burning pattern of fibers- in presence of flame and after flame goes off and even color of ash residue**.** Cotton fiber is white colored single elongated cell which showed instant ignition when burned and would continue to burn even after the flame went off. Grey colored fine ash was left behind as a residue after burning cotton fiber. Coconut fibers are brown colored single elongated cell like structure and showed instant ignition when burned and stopped burning when the flame was put off. Minimal ash was left behind as a residue after burning coconut fiber. Wool fiber is white and grey colored cylindrical and multicellular structure with tapered ends which showed instant ignition when burned and would continue to burn even after the flame went off. Small bead was left behind as a residue after burning wool fiber. Jute fiber is brown colored cylindrical with unevenness spread across diameter and nodes appear which showed instant ignition when burned and continued to burn even after flame went off. Almost negligible ash was left behind as a residue after burning jute fiber. Silk fiber is white colored and consists of two fine lustrous filaments running parallel to each other and appears like transparent rods with triangular shape. It ignited slowly when burned and would continue to burn even after flame went off. Dark bead was left behind as a residue after burning silk fiber. Linen fiber is white colored flat ribbons and bamboo like with cross marking nodes which showed instant ignition when burned and would continue to burn even after flame went off. Grey colored fine ash was left behind as a residue after burning linen fiber. Polyester fiber is blue colored fiber which is round in shape in cross sectional view. It showed slow ignition and continued to burn even after the flame went off.

Brittle bead ash was left behind as a residue after burning. Glass fiber is white colored smooth, round, translucent, shiny and flexible which didn't show instant ignition when burned and would cease to burn after flame went off. Hard bead ash was left behind as a residue after burning glass fiber. Nylon fiber is orange colored appears fine round, smooth, translucent and showed instant ignition when burned and continued to burn even after flame went off. White ash was left behind as a residue after burning nylon fiber. Rayon fiber is orange colored appears fine round, smooth, translucent and showed instant ignition when burned and continued to burn even after flame went off. Plastic bead like ash was left behind as a residue after burning rayon fiber. Acrylic fiber is luxurious white appearance bone shaped with apparent cut ends which showed instant ignition when burned and continued to burn even flame went off. Hard black bead ash was left behind as a residue after burning. Acetate fiber is white shiny colored which showed instant ignition when burned and continued to burn even after flame went off. Hard black bead ash was left behind as a residue after burning acetate fiber.

In solubility test it was found that none of the sample fibers were soluble in strong base (NaOH) or ethanol or chloroform, except jute fiber which was soluble only in chloroform. However, fibers showed variable solubility in different types of acids. Fibers of cotton and jute were soluble in conc. H_2SO_4 where other fibers types were insoluble. Fibers of cotton, coconut, wool, jute, silk and linen were soluble in conc.HNO_3 whereas other remained insoluble. From these observations it can be safely concluded that synthetic fibers are resistant to solubility in strong acids, bases or organic solvents. On the other hand, natural fibers showed maximum solubility in conc. HNO_3. Jute fiber however showed different solubility pattern, i.e., it was the only fiber which was soluble in chloroform. Hence, it can be inferred from test results that chloroform stands out in testing the nature of jute fiber. Similarly, conc. H_2SO_4 can be used to test cotton and linen fibers as only these fibers are soluble in conc. H_2SO_4 while others are not.

When samples were subjected to density examination, it was found that glass fiber had maximum density, i.e. $2.44 g/cm^3$ whereas acrylic fiber was least dense with density $0.95 g/cm^3$ out of all fibers. Density of rest of fibers ranged from 1.15-$1.5 g/cm^3$.

None of fiber showed exceptional variation in terms of refractive index which fell in range 1.46 (coconut fiber) to 1.59 (linen fiber). Also, a definite relationship could not be established between density and refractive index of the fibers.

Conclusion

From present study it was concluded that natural and synthetic fiber can be successfully identified and differentiated from each other after their examination/test by subjecting them to various chemical and physical examinations like- Burning test, Microscopic examination, Refractive index, Density examination, Physical examination, Solubility test, etc. The study results can be useful for forensic scientist who are investigating arson cases or other cases like homicide, suicide, hit and run, burglary, kidnapping, wildlife crimes, etc. which include fibers as evidences. In this respect fiber can link the criminal, victim and crime scene with each other and hence even though they are trace in amount, they become important piece of evidence from forensic point of view. Other researchers or examiners working on fiber examination take the results from this study into their consideration.

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