

CAN CONTACT ANGLE BE AN INDICATOR OF FABRIC TYPE?

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ABSTRACT

Recycling of textiles is a major problem and identifying fabric is an important part of it. The aim of this exploratory study was to find out if contact angle can serve as an indicator of fabric type or not. Three samples were successfully identified as cotton-satin polyester blend, poplin, and polyester blend with contact angles 140.72° (almost superhydrophobic), 92.97° (hydrophobic) and 58.22° (hydrophilic) respectively, while the remaining two with fast water absorbency were identified as pure cotton and georgette. It appeared that functional groups, surface treatment, blended material and weave pattern can affect surface roughness enormously. So, contact angle together with FTIR and supported by FESEM can reveal the true identity of an unknown fabric in most cases. A library creation is being proposed for quick reference.

KEYWORDS: contact angle, FESEM, FTIR, identification, fibres, polymers

1. INTRODUCTION

Woven and non-woven textiles are two major categories of fabric with distinct manufacturing processes and characteristics. Woven fabric is made of two sets of perpendicularly interlacing yarns known as weft (widthwise) and warp (lengthwise), whereas non-woven fabric is made by creating bonds or entanglements directly without weaving, such as face masks [1]. Then there are knitted fabric and braided fabric, which involves interloping yarns and diagonal interlacing respectively. This study pertains to woven fabric only.

Woven fabric can be made of different types of fibers such as natural (cotton, silk, wool etc.) or man-made (polyester, acrylic, nylon etc.) or a combination of both. There are several physical and chemical tests by which fiber type can be determined such as burn test, touch test, drape/ring test, crease recovery test, solubility test etc. This paper will look only at the surface testing methods of polymer.

Near infrared (NIR) based fabric sorting and identification is not uncommon, NIR having a higher penetration depth than regular FTIR. With the help of chemometric method like multivariate analysis, composition in fabric blends can be determined, such handheld machines are already in the market.

Contact angle is the angle between a tangent to the liquid's surface and the solid surface at the point where the liquid meets the solid. Hydrophilic materials exhibit a contact angle less than 90°, hydrophobic and superhydrophobic materials have contact angle higher than 90° and 150° respectively. A superhydrophobic surface also exhibits a low sliding angle or low contact angle hysteresis. The aim of this study was to find out if static contact angle can be a quick indicator of fabric type or not.

The type of textile material significantly influences its contact angle, which is a measure of wettability. Surface roughness, weave structure, wicking, coating and surface treatment affect how a liquid interacts with the fabric, influencing the contact angle. The rougher the fabric surface, the greater the contact angle. Microcapsules [2] incorporated in various smart and technical textiles can also increase the surface roughness, in addition to the hydrophobic nature of the shell material (siloxane, fluoropolymer etc.) similar to the effect of a coating. The interlacing pattern and yarn density can be amazingly different from fabric to fabric offering different amounts of porosity that govern the liquid interaction. For example, twill has a more denser structure than plain weave whereas satin has more open spaces in between interlocked yarns. Intra-yarn porosity refers to the micro-pores between fibers within a single yarn influencing absorption of dyes and liquids, while inter-yarn porosity represents the macro-pores between adjacent yarns in a fabric structure governing air permeability and capillary transport. Researchers have used image analysis method to find out intra-yarn porosity [3], proving it a faster and reliable method than theoretical calculations based on fiber and yarn parameters. These pore structures are also crucial in identifying fabric types and correlating with contact angle. Wicking is the ability of a fabric to draw moisture (sweat) away from the skin through capillary action of the fabric, which reduces contact angle and improves wettability [4]. Surface treatments like mercerization which improves dyability of a cotton fabric actually reduces contact angle. Quaternization, which is needed for better dye uptake, hemostatic property and finish durability, significantly reduces contact angle as surface charge is changed from negative to positive attracting more water [5].

2. MATERIALS AND METHODS

Five remnant fabric samples of unknown origin were collected from a local tailoring shop. Figure 1 shows the fabric samples. The samples are named as checkered, cream, deep green, mehendi green and red, based on their visual appearance.

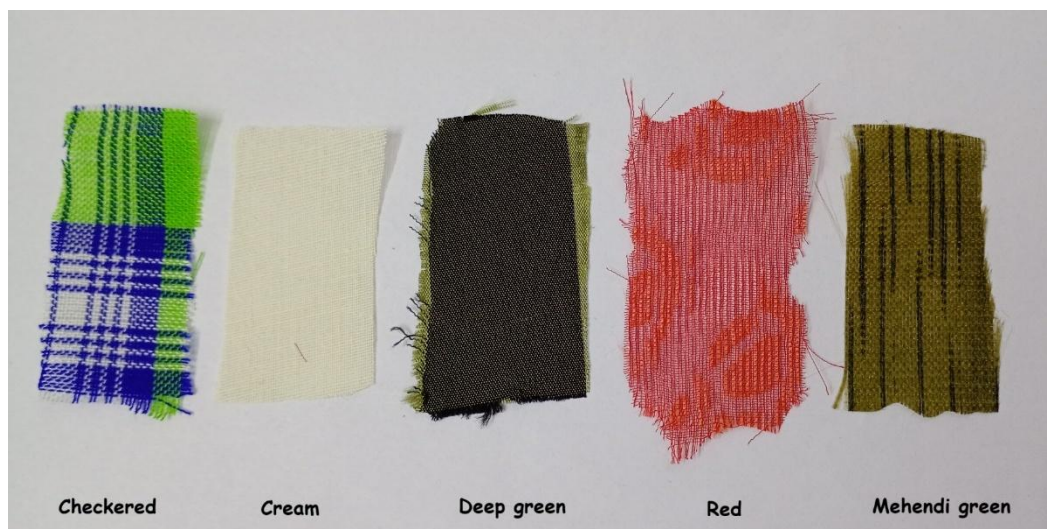


Figure 1: Five unknown fabric samples under this study.

Theta Lite Optical Tensiometer along with OneAttension software from Biolin Scientific AB, Sweden was used in ‘sessile drop’ mode for measuring static contact angle (CA) of water on fabric surfaces and P-20 micropipette was used for dispensing the water droplet. The instrument was calibrated with 1 μm tungsten carbide ball. Fabric samples were attached to glass slides using double sided adhesive tape prior to measurement. Each measurement was done with 2 μL of dispensed water droplet and repeated five times for each sample.

A Zeiss Sigma VP Field Emission Scanning Electron Microscope (FESEM), Germany was used to obtain the microstructures of fibers, voids and weaving patterns in the fabric samples (SE2 detector, EHT 2 kV). Prior to analysis, the samples were sputter coated with gold using Quorum Sputter Coater, UK using 20 mA current for 150 sec (tooling factor 2.5). Each sample was analyzed in five different spots.

Alpha II FTIR Spectrometer from Bruker, Germany equipped with Platinum ATR (monolithic diamond crystal), was used in 16 scan mode, 4 cm^{-1} spectral resolution and 4000-400 cm^{-1} range, for qualitative identification of the samples. Each sample was analyzed in three different spots.

3. RESULTS AND DISCUSSIONS

Contact angle measurement was not possible for the checkered and red samples, as the water droplet was immediately getting absorbed due to high levels of porosity. This was further confirmed from the FESEM images (Figure 2). Figure 2-A2 shows average strand thickness of $13.42 \pm 0.71 \mu\text{m}$ and Figure 2-A3 shows open spaces of average dimension $175.42 \pm 44.47 \mu\text{m}$ in checkered sample, which explains the instant water absorbance due to porosity. Figure 2-B1 shows presence of rectangular pores of average dimension $288.68 \mu\text{m} \times 151.54 \mu\text{m}$ in the red sample and a unique combination of two weave patterns where the interlacing twisted yarn thickness was $88.07 \pm 14.81 \mu\text{m}$ (Figure 2-B2) which was intercepted by a bunch of loose strands of average thickness $20.45 \pm 1.77 \mu\text{m}$ (Figure 2-B3). These void spaces clearly explain the instant water absorbance. This is further supported by literature where scoured and bleached pure untreated cotton fabric as well as with easy care finish showed no contact angle due to water penetration into porous structures [6].

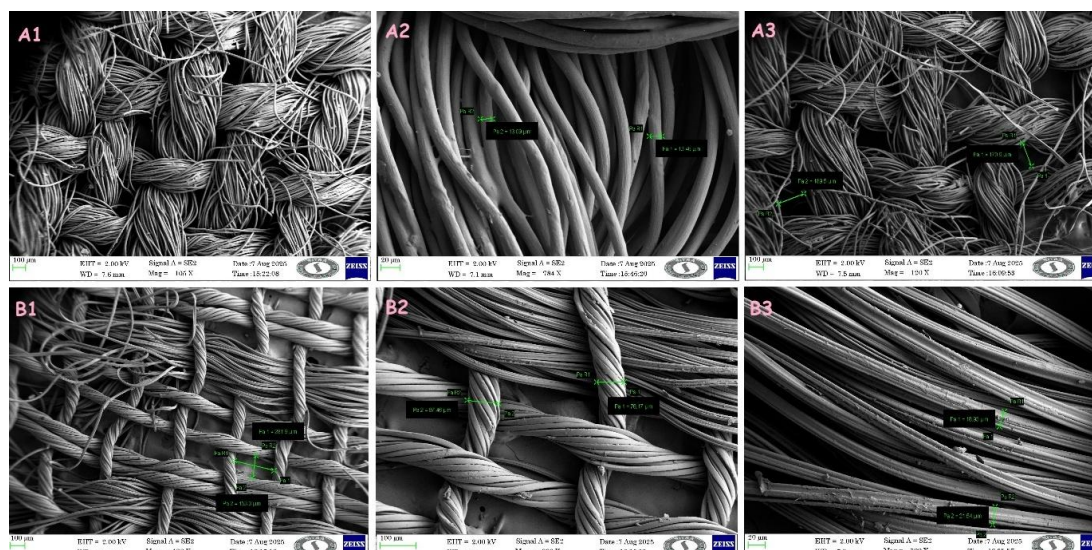


Figure 2: FESEM images of fast water absorbing fabric samples: (A) Checkered (B) Red.

The contact angles (Figure 3) of deep green sample were almost superhydrophobic ($140.72^{\circ} \pm 18.5$), whereas the cream sample was slightly hydrophobic ($92.97^{\circ} \pm 11.7$) and the mehendi green sample was in the hydrophilic regime ($58.22^{\circ} \pm 9.56$). Contact angle values are correlated to surface free energy [7], higher surface energy indicating higher wetting and strong cohesion of the probe liquid and hence lower contact angle.

Under FESEM (Figure 4), all of these three samples showed densely knit structures with smaller gap areas, $71.25 \pm 16.67 \mu\text{m}$ for mehendi green (Figure 4-C1) and $\sim 100 \mu\text{m}$ for deep green and cream samples. Slightly twisted bunch of loose strands of average diameter $9.91 \mu\text{m}$ (Figure 4-A2) constituted the interlacing in perpendicular directions in the cream sample. Mehendi green sample has similar weave structure with average strand diameter of $13.55 \pm 0.67 \mu\text{m}$ (Figure 4-C2), but bunch of untwisted square strands in the perpendicular direction. The deep green sample had a unique pattern of three or four thick rounded strands of average diameter $45.62 \pm 1.4 \mu\text{m}$ (Figure 4-B2) in one direction and bunch of untwisted loose strands of average diameter $23.61 \pm 0.84 \mu\text{m}$ (Figure 4-B3) in the perpendicular direction.

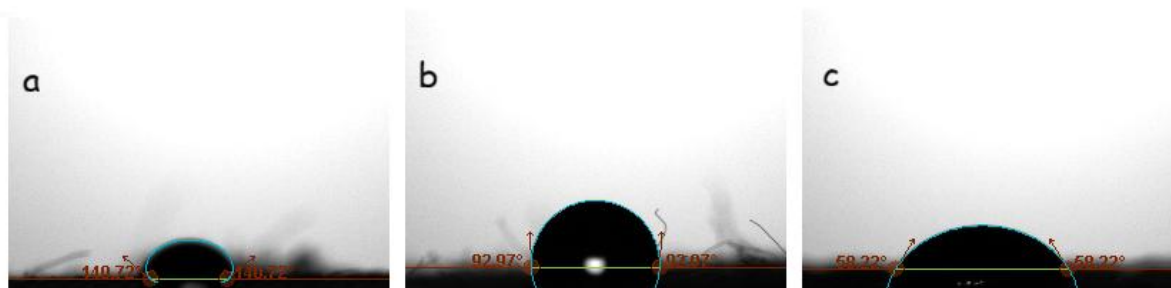


Figure 3: Contact angle measurement of fabric samples: (a) Deep green (b) Cream (c) Mehendi green.

Attempt was made to find out if there is any apparent correlation between pore size and contact angle from the FESEM data by further quantifying the data with the help of ImageJ software. The percentage porosity found from ImageJ results in checkered, red, cream, deep green and mehendi green samples were 63.85%, 54.84%, 24.85%, 20.69% and 7.51% respectively. No linear relationship was noted, this is because wettability can be influenced by multiple factors, not only just pore size, but fibre surface energy, cross-section, yarn twist, capillary continuity, surface finish, surface tension, and ambient temperature/humidity. However, the results strongly supported why contact angle was unmeasurable in the checkered and red samples.

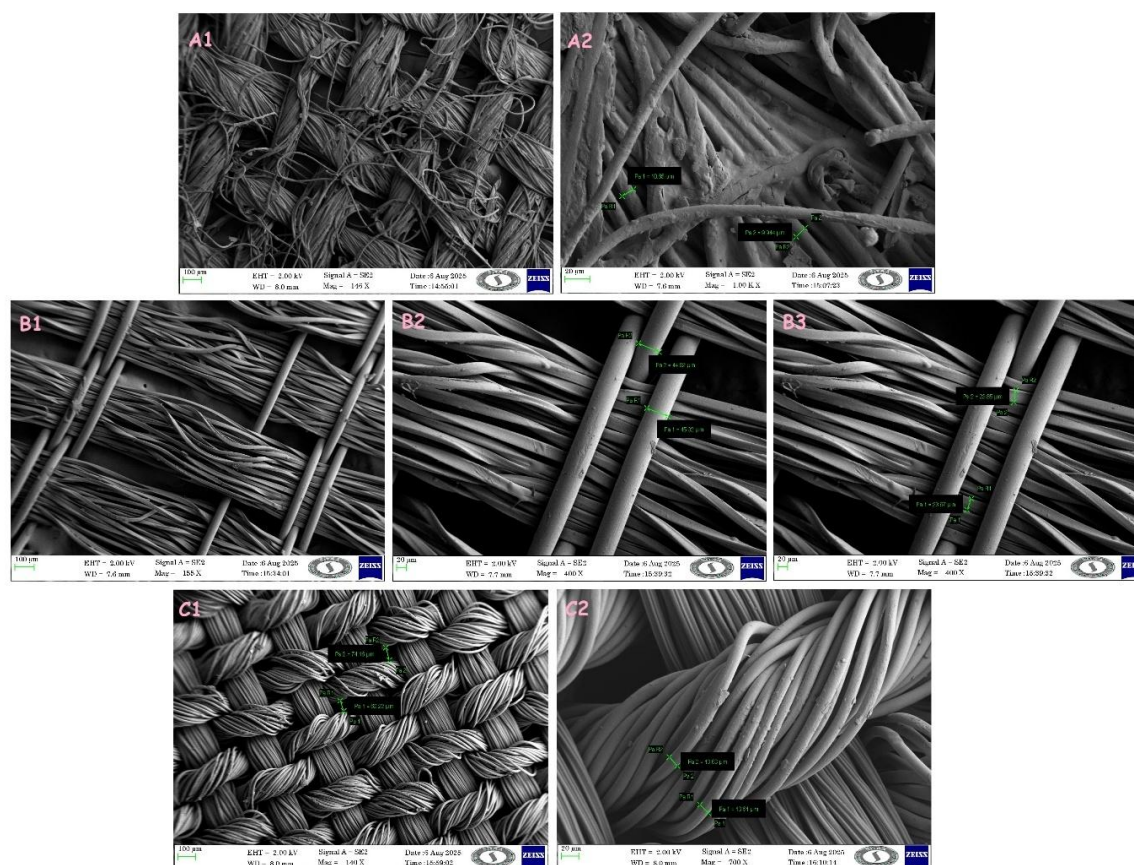


Figure 4: FESEM images of densely knit fabric samples: (A) Cream (B) Deep green (C) Mehendi green.

FTIR spectrum (Figure 5) revealed that all samples had -CH stretching frequency in the range of $2854\text{--}2922\text{ cm}^{-1}$ and C-O-C stretching frequency in the range of $1235\text{--}1241\text{ cm}^{-1}$. The cream sample had prominent broad -OH stretching band at $3050\text{--}3640\text{ cm}^{-1}$ and the deep green sample had the -OH stretching band too. Other samples did not have this band. All samples had carbonyl (C=O) peak at 1707.6 cm^{-1} , out-of-plane C-H bending at 719.2 cm^{-1} and C-H rocking band at 860.9 cm^{-1} , except the checkered sample indicating that the checkered sample was pure cotton made up of cellulose.

Ideally a systematic study should involve white, untreated and unblended samples of known manufacturing history, because the above mentioned functional groups may be present in dyes, finishing agents, auxiliaries and coatings. Therefore in the following paragraphs attempts have been made to correlate the FTIR results with other properties and reported data, to rule out the interference as much as possible. A more systematic study can also help in establishing contact angle as a standalone identification tool rather than a characterization method. This study was more exploratory in nature and there is certainly room for improvisation.

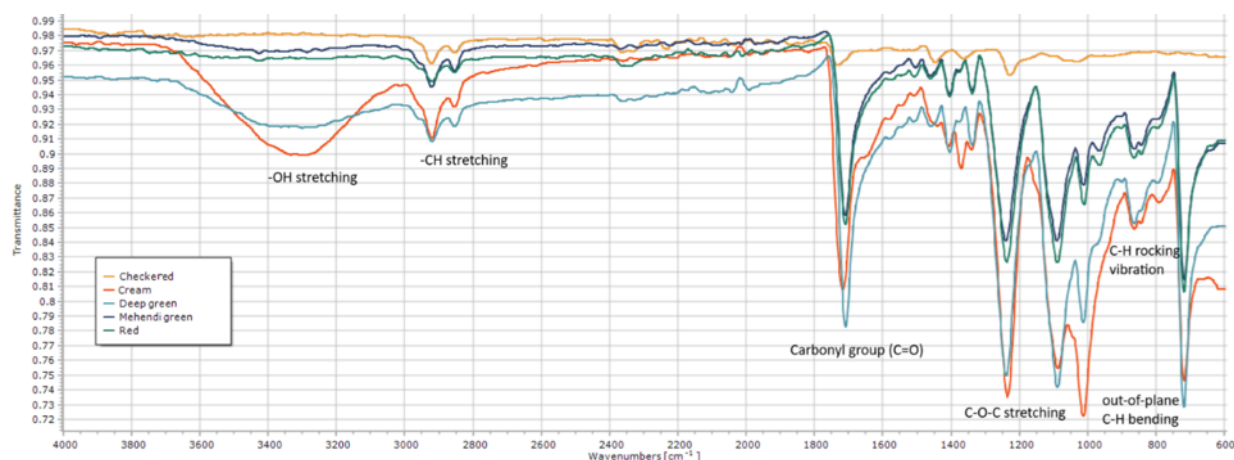


Figure 5: FTIR spectra of fabric samples under this study.

The absence of carbonyl peak combined with fast water absorbance during contact angle measurement indicates that the checkered sample was pure cotton. However, the absence of hydroxyl band at 3050-3640 cm^{-1} in FTIR results implies that the fabric underwent surface modification like acetylation or etherification that removes -OH groups.

A thorough comparison of different fabric types is needed at this point. Pure cotton is made of natural cellulose fiber which has significant amount of hydroxyl (-OH) groups on its surface, giving rise to extreme hydrophilic behavior (low contact angle). Art silk or artificial silk has even lower contact angle, as it is made of rayon (regenerated cellulose fiber) which renders more hydroxyl groups during its chemical processing. Although silk has similar shine and smoothness as art silk, its contact angle is higher than rayon because of its constituent protein fiber.

Georgette is a lightweight crinkled fabric typically made from polyester or nylon and may show high contact angle due to rough surface, but the porous fabric may absorb water quickly and may not be suitable for contact angle measurement. The presence of carbonyl group and fast water absorbance combined with porous rough appearance indicates that the red sample was georgette.

Poplin is a fabric primarily made of cotton, but blended with polyester, rayon or even wool. It has a characteristics tight plain weave that creates a smooth crisp texture, making it ideal for uniforms and aprons. The presence of a prominent hydroxyl band and a sharp carbonyl peak in FTIR results along with the over-and-under warp and weft interlacing pattern with less gaps and the tight weaved look clearly indicates that cream sample was poplin. Untreated poplin is reported to have a contact angle of 129.89°, which after coloration and finishing by starch de-sizing using atmospheric plasma treatment, resulted in a contact angle of 38° in 30 sec [8]. This explains the observed contact angle of 92.97° in this study, which might have undergone partial de-sizing.

The almost superhydrophobic contact angle of 140.72°, the presence of -OH and C=O groups in FTIR results, the glossy look on one side and the wrinkle resistance indicates that the deep green sample was a blend of cotton and satin-polyester. Satin weave is a special weaving technique where some yarns float over several others, creating a fabric that reflects light uniformly. This is further supported by the unique SEM microstructure image (Figure 4-B). Fabric construction such as the weft count greatly affects the drop impact. An increase of weft count causes a decrease in penetration and increase in the water spreading [9]. This explains the glossy look and SEM microstructure of the deep green sample. The Cassie-Baxter model describes how water droplets sit on air pockets, creating a high contact angle and a highly hydrophobic state, while the Wenzel model describes how a liquid can penetrate into the roughness, leading to a lower contact angle and increased wettability [10, 11]. The deep green sample with hierarchical micro/nano-structures is an example of Cassie-Baxter model with nearly superhydrophobic contact angle.

Untreated polyester is naturally hydrophobic and repels water with a contact angle of 102° [12, 13]. However, a hydrophilic poly fabric can be achieved either by chemical surface finish or by polymer blending. The presence of carbonyl group in FTIR spectra, the combination of loose and twisted yarn and the low contact angle of 58.22° indicates the mehendi green sample was a polyester blend.

NIR spectroscopy combined with chemometric analysis can offer the ultimate answer in fabric sorting and identification, which can complement this study.

4. CONCLUSION

In nutshell, the contact angle serves as a powerful indicator of how a textile material will interact with liquids. Understanding this relationship is vital for various applications, including textile design, performance assessment, and product development. However, as the contact angle measurement relies on image processing, the method suffers from optical limitation especially in the hydrophobic regime due to proper positioning of baseline [14]. Besides contact angle value can be affected by a wide range of factors such as functional groups, surface treatment, blended material, weave pattern and dye interaction. A library creation of contact angle database is being proposed, at least for all types of pure undyed fabrics, for quick referencing.

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STATEMENTS AND DECLARATION

DATA AVAILABILITY

No datasets were generated or analysed during the current study.

COMPETING INTEREST

The author declares that there is no competing interest.

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