Multi-layered Cellulosic Material as a Leather Alternate in the Footwear Industry

Changhyun Nam and Young-A Lee
Iowa State University, USA

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The footwear industry has negatively impacted to the environment and workers' health and safety for the past few decades. Shoes are commonly made of various types of materials (e.g., synthetic textiles, leather), which take approximately 50 years or more to fully decompose without being recycled or reused (Grahame, 2014). Because of the increasing sustainability awareness from various stakeholders in our society, the footwear industry has been actively developing and incorporating eco-friendly materials into their new product development process.

Several academic studies (e.g., Lee et al., 2014) have been conducted to develop a new material (e.g., cellulose fiber mat) as a leather alternate, which is biodegradable and compostable without contributing to landfills. Lee et al. (2014) examined the material properties of the cellulose fiber mat and reported one major issue with this material, easy moisture regains from the atmosphere or human body, which result in a softening of the material and a loss of tensile strength. This implies that the single layer of cellulose fiber mat may not be effective to use as a leather alternative material in the current footwear industry. Therefore, in this study, we aimed to develop a multi-layered cellulosic material (MCM) and examine its properties – thermal comfort, air permeability, tensile strength, and wettability – compared with those of commercially available leathers using experimental research design. We hypothesized that these two materials would have similar properties.

The selected materials for this experiment were the cellulosic fiber mat we developed, denim (100% cotton), 100% hemp, and calf and pig skins; the first three materials for MCM we proposed as a leather alternate and the last two for commercially available leathers often used when making shoes. Properties of each material were first examined separately, followed by two separately combined materials – MCM (cellulosic fiber mat + denim + hemp) and two-layered leather (calf skin + pig skin) (see Figure 1).

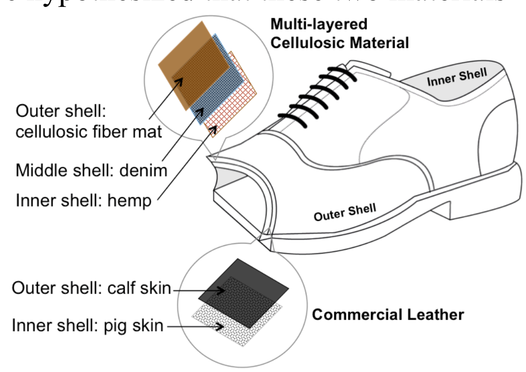

Figure 1. Material structures.

The material properties we chose to examine were related to wearers' comfort of a product, here shoes. Heat and moisture transfer properties, the material's thermal resistance (R_{ct}) and evaporative resistance (R_{et}), have a crucial influence on the comfort of wearable products (McQuerry et al., 2016). R_{ct} and R_{et} were measured using a sweating guarded hotplate with the ASTM F1868-14 method. Air permeability (AP; cfm) was measured in the test area of $38cm^2$ at a test pressure of 125Pa, using an air permeability tester based on the ASTM D737-04 method. For examining the tensile strength, determining the maximum force required to break a material, the breaking strength (N) and elongation (%) of each sample were determined by averaging the

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measured values using a tensile testing equipment followed by the ASTM D5034-11 method. Contact angle (CA; º) for wettability was measured with a deionized water droplet of 2.00μL on each sample surface using a dataphysics system OCA 20 machine based on the Sessile drop-method. Before the property testing, all material samples were put into a chamber for three days at a specified temperature (21ºC) and relative humidity (64ºC) and examined three times. SPSS 21 was used to analyze statistically significant differences between the two materials with *t*-test.

The results of the *t*-test showed statistically significant differences in the air permeability (AP) between MCM (2.1cfm) and two-layered leather (0cfm) ($p < 0.05$), because the latter was perfectly impermeable. The different textile structures (e.g., woven hemp, nonwoven leather) lead to possible influence on the material's properties. MCM had a higher R_{ct} (0.12m^{2}ºC /W) and a lower R_{et} (117.7m^{2}Pa/W) than two-layered leather, R_{ct} (0.11m^{2}ºC /W) and R_{et} (180.9m^{2}Pa/W). Total heat loss (THL) (McQuerry et al., 2016) and permeability index (i_m) (Woodcock, 1962) were calculated from the values of R_{ct} and R_{et} to examine the heat and moisture transfer properties of thermal comfort. MCM had slightly lower THL (153.9 W/m^2) than two-layered leather (THL=158.4W/m^2); however, the first had a bit higher i_m (0.1) than the latter (0.04 of i_m), indicating that both are somewhat water vapor permeable. No statistically significant value differences of THL and i_m between two materials were identified; therefore, it can be stated that MCM can perform similarly to two-layered leather in terms of thermal comfort. Two-layered leather had the higher values in break force (3591N) and elongation (55%) than those of MCM, 3486N and 27%, respectively, but no statistically significant differences were found between two materials. The CA of two-layered leather (84.6°) was much higher than that of MCM (38.6°).

This experimental study presented the effectiveness of MCM to be used as a leather alternate when developing shoes, due to its properties to maintain wearers' feet in a thermal equilibrium compared to two-layered leather. The results also provided a better understanding of the influence of MCM on the wearers' thermal comfort. Further research is suggested identifying solutions to reduce water absorbency of MCM. This study also urges to develop a shoe prototype using MCM and perform users' wear testing by comparing shoes made of leathers.

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