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Thermophysiological Performance of Sheep Wool, Goat Wool and Their Hybrid Composite Fabrics

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Abstract- Wool's ability to easily absorb sweat and not feel damp, keep you warm, protect against radiation, and its antibacterial properties have always been very appealing to humanity. In this study, three different fabrics were produced using two different natural fibers: goat and sheep wool. The thermal conductivity, thermal absorptivity and diffusion values of the fabrics obtained were measured. The results showed that sheep wool has the highest moisture absorption property. The measured thermal absorptivity values were 121 W·s$^{1/2}$/m^{2}K for sheep wool, 113 W·s$^{1/2}$/m^{2}K for goat wool, and 73 W·s$^{1/2}$/m^{2}K for the composite structure. The maximum heat flows of sheep, goat, and sheep-goat composite fabrics were measured, and the sheep-goat composite fabric, with the lowest value of 166W/m^2, was the fabric that felt the warmest upon first contact. The results showed that sheep -goat composite fabric showed very good thermo-physiological performance that can be sustainable alternative compare to synthetic fabrics.

Keywords: Fabric, natural fibers, thermal, thermal garment, thermal comfort.

I. INTRODUCTION

Thermophysiological comfort is the capacity of clothing systems to preserve the human body's thermal equilibrium under varying environmental conditions1. That is closely related to physiological mechanisms of the human body, the heat and moisture transfer characteristics of fabrics2. A key element affecting thermophysiological performance is the air layer trapped between the skin and the fabric surface, referred to as the microclimate3-4 .

The thermal properties of clothing are related to the user's thermal comfort 1and encompass the heat and moisture transfer between the environment and the garment. Physiological or thermal comfort is defined in ISO 7730 as the state of being in harmony with the thermal environment in which one feels comfortably. It is known that wool was being used as early as 4000–3000 BCE, Silk manufacturing flourished in ancient China, and cotton was grown in the Indus Valley more than 5,000 years ago. These examples demonstrate how deeply people depended on natural fibers textile clothes5-6-7.

Thermal absorption, thermal resistance, thermal diffusion, and heat flow provide important insights into the thermal comfort 8 of wool fibers. These properties related with the intrinsic characteristics of the fibers, such as hygroscopicity, but are also strongly affected by structural factors including porosity, density, fiber arrangement, and air entrapment.

Wool has two essential properties9. The first is its ability to trap air between its wool because of their natural structure and crimp. This trapped air behaves as an insulating layer, which allows wool garments to keep body heat and one can feel warm with this property. The second important property of wool is its high moisture absorption capacity. Wool fabric keeps you warm and prevents your skin from feeling wet by binding with the fabric when you sweat for outdoor wearing.

Sheep wool is known as a natural insulating material10-11. The thermal properties of sheep wool have been investigated by Zach et al.12 who compared it with conventional insulation materials such as mineral wool. In addition, sheep wool is suggested more environmentally sustainable thermal insulation materials.

In this study, a novel sheep–goat wool composite textile structure was improved and its maximum heat flow, thermal diffusion, and thermal absorption

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values was investigated in order to investigate thermal comfort of the garment.

II. EXPERIMENTAL PART

Materials

In this study, sheep wool and goat wool were used as the primary raw materials for fabric production. The fibers were blended in equal proportions, consisting of 50% sheep wool and 50% goat wool by weight. The blended yarns were then produced and used in a traditional double-layer weaving machine.

Method

In this article, Alambeta test (ISO 11092 standard test) was carried out that provides with the measurement of the following thermal parameters: thermal conductivity, thermal absorptivity, thermal resistance, and thermal diffusivity.

III. RESULTS AND DISCUSSION

Thermal Absorption Behavior of the Sheep–Goat Wool Composite

The degree of heat absorption depends on the difference between the fabric and skin temperatures and the measurement duration. This parameter is also related to the fabric surface properties that affect the area of heat transfer between the fabric and skin. If the thermal absorption value is low, it gives a feeling of warmth; if it is high, it gives a feeling of coldness. The most of textile fibers have a significant degree of moisture absorption capability (called hygroscopicity). It is known that wool fiber can absorb 38% of moisture relative to its own weight13.

When humidity increases, thermal conductivity increases, density increases because it absorbs moisture, and since water has a high specific heat capacity, specific heat capacity also increases as humidity increases. Since water absorption increases in these three terms, thermal absorptivity increases when the amount of moisture taken into fabric.

Table 1. Thermal parameters of sheep wool, goat wool, and sheep–goat layered woven fabric samples

Fabric	**Isıl iletkenlik, mW/mK**	***Isı Direnci, R* değeri, K.m^2/W**	**Thermal absorptivity (b), $W{\cdot}s^{1/2}{\cdot}m^{-2}{\cdot}K^{-1}$**
Sheep wool	46.18	0.053	121
Goat	49.35	0.087	113
Sheep wool/Goat	46.35	0.093	73

This hygroscopic behavior leads to microclimate stabilization and cold-weather comfort. The ability of sheep and goat fibers to absorb without feeling wet that supports thermal regulation and decreases sudden temperature changes at the skin–textile interface. Interestingly, the sheep–goat composite structure showed a lower thermal absorption value, indicating a moderated moisture uptake behavior (in Table1). This reduced moisture absorption capacity suggests that the sheep and goat fibers composite controls excessive moisture accumulation.

Heat Transfer behavior for sheep and goat wool composites

Maximum heat flux is the highest rate of heat transfer (Qmax) per unit area (W/m2) often means the sudden peak heat transfer upon initial contact of fabric with skin. If Qmax is high that means one can feel cool with initial contact, if that of Qmax is low, it denotes, one can fell very comfortably. Figure 2a indicated that sheep wool has the highest q_{max} value followed by goat wool, while the sheep–goat composite structure showed the lowest value. Since q_{max} represents the peak heat transfer14 occurring immediately upon contact, higher values correspond to a stronger initial cool sensation. Accordingly, sheep wool is expected to create the most pronounced cool feeling, whereas the sheep and goat composite structure bring about the warmest initial sensation.

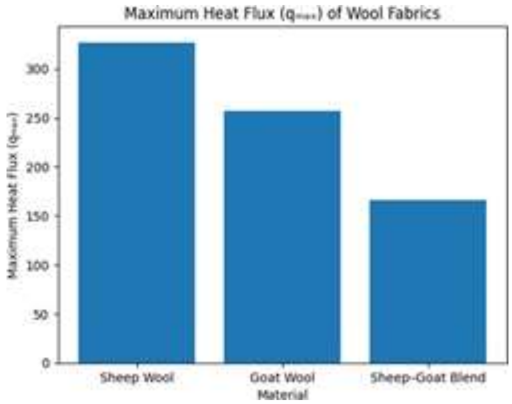

Figure2a.Maximum heat flux, q max of wool fiber

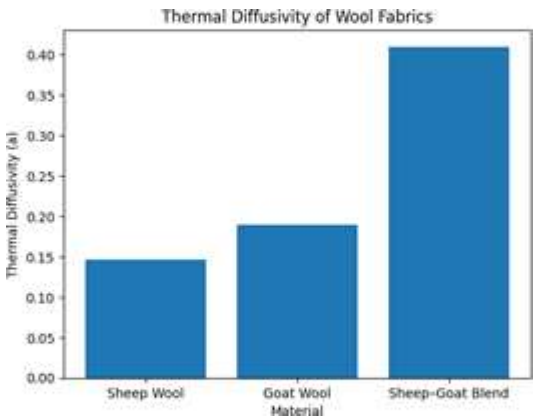

Figure 2b. Thermal diffusivity of wool fibers

Figure2. a) Maximum heat flux, q max of wool fiber, b) Thermal diffusivity of wool fibers

Thermal Diffusivity of Sheep and Goat Wool Fibers

Thermal diffusivity (a) in textiles measures how quickly a fabric transfers heat through a material when it has been absorbed. It reflects how quickly a fabric responds to temperature changes and is mathematically defined as the ratio of thermal conductivity to volumetric heat capacity ($a = \lambda/\rho c$). Higher thermal diffusivity15 values show faster internal heat distribution, whereas lower values suggest slower thermal response and greater thermal stability. In this study, the sheep–goat composite exhibited the highest thermal diffusivity, significantly exceeding that of sheep wool and goat wool (Figure 2b).

The most interesting result is the markedly increased diffusivity of the wool composite structure. Although, its lower maximum heat flux and thermal absorptivity, the composite fabric distributes absorbed heat more rapidly throughout its structure. This combination suggests that the wool composite redistributes heat internally, reducing localized temperature gradients. The enhanced diffusivity can be attributed to the layered weaving method that changes in effective density caused by blending.

IV. CONCLUSION

The feeling of comfort is the layer of air between the body and the garment, referred to as the microclimate. The microclimate is influenced by environmental factors, garment properties, and the person's active. A small change in fiber structure or weaving structure will affect microclimate and determine the person's comfort level. For a garment fabric to be considered thermally comfortable,

Garment should have high thermal resistance to protect the user from the cold; the natural fiber fabrics weaved in this study showed high thermal resistance provided with keeping warm. In addition, it is important that the fabric used does not lead to feel wetness on the skin when perspiring. Due to the high moisture retention capacity and hydrogen bonding of the sheep and goat natural fibers produced in the study, they do not feel wetness on the skin when perspiring.

Results indicated that natural sheep and goat wool fibers signifies promising hygrothermal activity. This behavior shows strong moisture retention ability bring about microclimate durability under cold-weather conditions. Accordingly, the composite denotes significantly higher thermal diffusivity, indicating high internal heat spread. This combination of low peak Qmax and high heat propagation suggests a structurally optimized architecture that decreases excessive surface cooling while preventing localized thermal gradients.

Therefore, the sheep–goat wool composite textile structure presents an innovative wool fiber-based system with controlled hygro-thermal performance. By optimizing moisture management while preserving the intrinsic comfort advantages of wool, the sheep and goat composite can be an alternative for advanced and outdoor textile applications.

Polyester garments, on the other hand, feel synthetic to the touch because polyester is not a natural material. However, natural wool fabrics provide a very comfortable sensation. In this regard, sheep and goat wool are advantageous, and their sustainability and reusability will also contribute to the circular economy.

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