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Effect of pile yarn properties and abrasion factor on thermal and sound absorption performance of carpets

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The study aims to examine the impact of long-term use on the thermal conductivity and sound absorption properties of carpets, with the broader goal of identifying pile-yarn production parameters that can be used to extend carpet lifespan and support sustainability. In this study, Wilton-type face-to-face carpets are produced using pile yarns with different filament fineness values and texturing parameters. The carpets are then subjected to an abrasion test, and their acoustic and thermal performances in both abraded and non-abraded states are evaluated. The results indicate that pile yarns produced with a filament fineness of 3.13 dpf, a ceramic disc type, and a 1-7-1 disc combination exhibit greater resistance to declines in thermal conductivity and sound absorption during prolonged use. These parameters are therefore suggested as preferable for enhancing carpet longevity and reducing environmental impact.

Keywords: Abrasion, Carpet pile, Disc combination, Disc type, Filament fineness, Thermal conductivity

1 Introduction

Sound pollution is recognised as a significant environmental problem that impairs human well-being by causing physiological and psychological stress[1]. Humans generally perceive sound between 20 and 20,000 Hz, with maximum sensitivity at 2,500–4,000 Hz[1,2]. Sound-absorbing materials are therefore essential for reducing noise levels, and porous materials are widely used due to their lightweight nature and broad absorption range. Their performance is commonly described by the sound absorption coefficient, measured as the ratio of absorbed to incident sound energy[3-6].

Textile materials, particularly carpets, play an important role in acoustic insulation. Softer floorings allow sound to penetrate rather than reflect, reducing noise transmission[7]. Numerous studies have examined the sound-absorbing properties of textile structures, including corduroy, nonwovens, drapery fabrics, composites, woven fabrics and carpets, produced from fibres such as kapok, polyacrylonitrile (PAN), Kevlar, acrylic, polypropylene and wool. For example, Tang *et al.* reported that increasing wale width in corduroy fabrics improves air permeability and decreases airflow resistance, thereby enhancing acoustic absorption[8]. Yang *et al*. analysed that Struto nonwovens with greater thickness, finer fibres and higher mass per unit area exhibit improved sound absorption, with porosity strongly correlating with airflow resistance and thermal properties[9]. Several other studies highlighted the influence of fibre composition, structural parameters and multi-layered configurations on the acoustic performance of nonwoven and woven textiles[10-15].

Thermal properties are another key performance feature of textile products. Thermal conductivity, thermal resistance and thermal absorption determine heat transfer and insulation capabilities[16-19]. Numerous studies have explored how fibre characteristics and fabric construction parameters influence thermal behaviour in woven, nonwoven and composite structures[20-23]. Increasingly, research has also considered recycled sources, such as work on nonwovens made from cotton/polyester selvedge waste, where both thermal insulating and sound absorption characteristics have been examined[24].

Carpets, which consist of a ground and a pile layer, are widely used for both aesthetic and functional purposes. Their thermal and acoustic performances depend on pile height, density, pile configuration, and fibre type[25]. Studies have shown that finer filaments, higher pile density and specific weaving parameters improve carpet sound absorption and insulation[6-8, 26-29].

In textured yarn production, disc type and disc combination are critical factors influencing twist and

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crimp. Ceramic (hard) and polyurethane (soft) discs differ in frictional behaviour, affecting yarn bulk, softness and strength[30]. While previous work has examined their effects on carpet recovery performance[31], their influence on thermal and acoustic properties remains largely unaddressed.

Given growing concerns regarding global warming and the contribution of building-related heating to carbon emissions, thermal insulation and heat loss reduction have become increasingly important. At the same time, carpet recycling remains challenging because carpets frequently incorporate multiple incompatible fibre types, making effective recycling difficult. Extending the life of carpet is, therefore, a crucial strategy for supporting sustainability.

In the present study, polyester pile yarns produced using different filament fineness levels and various disc types and disc combinations during the texturing process are used to manufacture Wilton-type face-to-face carpets. The carpets are subsequently exposed to an abrasion test, enabling the acoustic and thermal properties of abraded and non-abraded samples to be compared. The primary objective of this work is to investigate the impact of long-term use on the acoustic and thermal performance of carpets—properties that not only influence comfort but also contribute to energy efficiency and noise reduction. In addition, the study addresses a notable gap in the literature by evaluating the influence of filament fineness, disc type and disc combination on carpet insulation performance. By doing so, it contributes new insights into carpet design parameters that support both functional performance and sustainability.

2 Materials and Methods

2.1 Materials

Drawn textured polyester filament yarns (DTY) with a final linear density of 1200 denier were used as pile yarns. These yarns were produced by combining four partially oriented yarns (POY) and were manufactured with either 384 or 768 filaments. During texturing, 1–6–1 and 1–7–1 disc combinations were employed with both polyurethane and ceramic disc types, while all other texturing parameters were kept constant. The DTY polyester pile yarns were produced at Korteks Mensucat Sanayi ve Ticaret A.Ş. in Turkey. The yarn specifications are presented in Table 1.

All carpet samples were woven on a Wilton-type face-to-face weaving machine (Van de Wiele RCI02 model). Eight carpet samples were produced using a 1/1 V ground weave, with all weaving parameters kept constant. Carpets were manufactured with a pile height of 12 mm and a pile density of 915,200 piles/m². The weft sett was 143 picks/dm with 1.3 Nm jute yarn, and the warp sett was 32 ends/dm using 1600 denier stuffer warp yarn and 800 denier chain warp yarn. After weaving, the carpet backs were coated with latex at 115 ºC.

Table 1 — DTY polyester pile yarn properties

Sample code	Treatment	Filament number	Filament fineness, dpf	Disc type	Disc combination
313.P6.BA		384	3.13	Polyurethane	1-6-1
313.P7.BA		384	3.13	Polyurethane	1-7-1
313.C6.BA	Before abrasion	384	3.13	Ceramic	1-6-1
313.C7.BA		384	3.13	Ceramic	1-7-1
313.P6.AA		384	3.13	Polyurethane	1-6-1
313.P7.AA		384	3.13	Polyurethane	1-7-1
313.C6.AA	After abrasion	384	3.13	Ceramic	1-6-1
313.C7.AA		384	3.13	Ceramic	1-7-1
156.P6.BA		768	1.56	Polyurethane	1-6-1
156.P7.BA		768	1.56	Polyurethane	1-7-1
156.C6.BA	Before abrasion	768	1.56	Ceramic	1-6-1
156.C7.BA		768	1.56	Ceramic	1-7-1
156.P6.AA		768	1.56	Polyurethane	1-6-1
156.P7.AA		768	1.56	Polyurethane	1-7-1
156.C6.AA	After abrasion	768	1.56	Ceramic	1-6-1
156.C7.AA		768	1.56	Ceramic	1-7-1

2.2 Methods

Abrasion and texture deformation were evaluated using the hexapod appearance retention test in accordance with TS ISO 10361. Carpet specimens measuring 940 × 200 mm were placed inside the hexapod drum and subjected to 12,000 rotations, with cleaning performed every 2,000 rotations. Visual grading was carried out by three assessors using CRI reference scales, scoring from 1 (most distorted) to 5 (least distorted).

Thermal conductivity was measured according to ASTM C1113-09. Carpet specimens of 100 × 100 mm were placed between two plates under controlled temperature conditions, and thermal conductivity values were recorded.

Sound absorption measurements were conducted using a Brüel & Kjaer impedance tube following ISO 10534-2 standard. Tests were performed using 100 mm and 30 mm diameter samples, with large and small tubes, to cover frequency ranges of 0.05–1.6 kHz and 0.5–6.4 kHz, respectively. Data from both tubes were combined to obtain absorption coefficients across the full range of 0.05–6.4 kHz.

A multiple comparison ANOVA was applied to determine the significance of filament fineness, disc type, and disc combination on the performance of abraded and non-abraded carpets. Statistical analyses were conducted using SPSS 21.0, and all results were evaluated at a 95% confidence interval.

3 Results and Discussion

3.1 Thermal Conductivity Test Results

Thermal conductivity and thermal resistance are key indicators of the heat-transfer behaviour of textile materials. Lower thermal conductivity corresponds to improved insulation performance. In this study, the thermal conductivity of abraded and non-abraded carpet samples produced with two filament fineness values (3.13 and 1.56 dpf), two disc types (polyurethane and ceramic), and two disc combinations (1–6–1 and 1–7–1) is examined. The results are presented in Fig. 1.

Across all samples, thermal conductivity increases after abrasion, indicating that long-term use reduces the thermal insulation of carpets. When filament fineness is considered, finer filaments (1.56 dpf) consistently exhibit lower thermal conductivity than coarser filaments in both abraded and non-abraded samples. This outcome aligns with earlier findings that finer filaments provide greater filament surface area and increased inter-filament friction, thereby contributing to higher thermal resistance[32]. With finer filaments, the greater number of fibres in the cross-section restricts heat transfer and contributes to improved insulation performance.

Regarding disc type, it is observed that it also affects thermal conductivity. Samples textured with polyurethane discs display higher thermal conductivity, and therefore poorer insulation, compared with samples textured using ceramic discs. The stiffer surface of ceramic discs increases fibre friction during texturing and tends to produce yarns with higher crimp stability, which leads to increased fabric cover and lower conductivity[30].

Disc combination further affects thermal behaviour. Carpets produced using the 1–6–1 disc combination exhibit higher thermal conductivity than those made with 1–7–1. The additional working disc in the 1–7–1 configuration increases yarn twist and

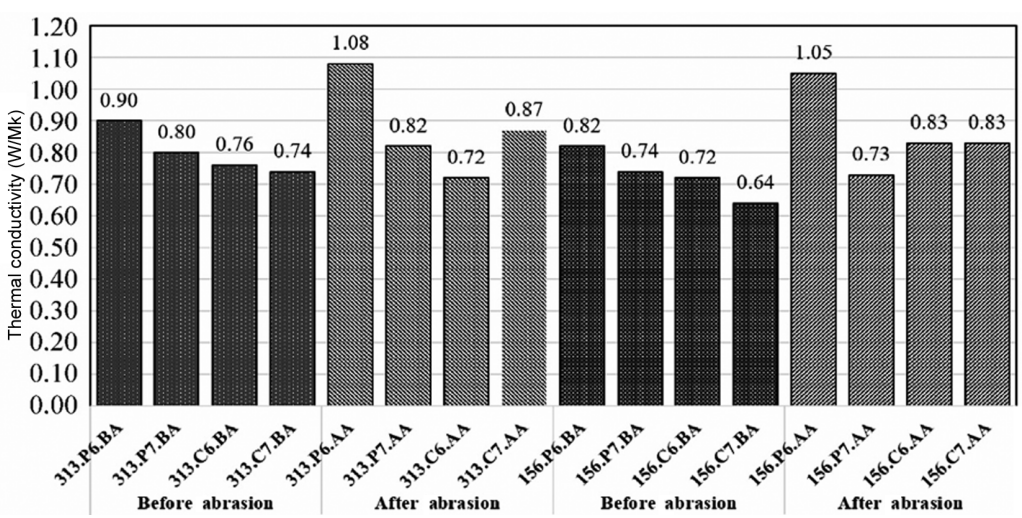

Fig. 1 — Thermal conductivity of abraded and non-abraded carpets

crimp, resulting in greater elasticity and bulk, which reduces thermal conductivity by increasing the entrapped air within the structure.

Multiple comparison ANOVA results (Table 2) show that abrasion, disc type and disc combination have statistically significant effects on thermal conductivity ($p < 0.05$). Filament fineness does not show a statistically significant main effect ($p = 0.296 > 0.05$) despite its visible influence in the descriptive results. Two interactions—disc type × disc combination ($p = 0.014$) and abrasion × disc type × disc combination ($p = 0.039$)—are statistically significant, demonstrating that thermal conductivity is governed by combined processing parameters. It indicates that finer filaments, ceramic disc type and the 1–7–1 disc combination yield the most favourable thermal insulation performance, particularly in the non-abraded state.

3.2 Sound Absorption Test Results

Carpets are widely used for improving indoor acoustics, and their sound absorption behaviour is influenced by structural and material parameters. However, long-term use and abrasion may alter their acoustic performance. In this study, sound absorption coefficients between 0.05 and 6.4 kHz are measured for all carpet samples, with results presented in Fig. 2. The discussion is organised according to filament fineness, disc type and disc combination.

3.2.1 Effect of Filament Fineness

Higher sound absorption coefficients are observed with finer filament fineness in both abraded and non-abraded carpets. Before abrasion, carpets produced with 1.56 dpf filaments show better sound absorption than those produced with 3.13 dpf filaments. After abrasion, carpets with 1.56 dpf filaments continue to show higher absorption values up to approximately 3000 Hz. Above this frequency, both filament fineness levels exhibit similar behaviour.

Samples produced with 3.13 dpf filaments show almost identical absorption curves before and after abrasion, indicating that coarser filaments are less affected by mechanical wear. In contrast, the 1.56 dpf samples present a noticeable decrease after abrasion, although they still perform better than the 3.13 dpf samples at most frequencies. According to Fig. 2, finer filaments consistently produce higher sound absorption coefficients before abrasion and up to around 4000 Hz after abrasion; beyond this point, both fineness values yield similar results.

The superior performance of finer filaments is expected, as they create a larger surface area and a denser coverage over the carpet surface. This improved surface coverage enhances the dissipation of acoustic energy within the pile. These findings align with earlier studies: Çelik and Kaynak stated that carpet pile yarns with finer filaments provide

Table 2 — Multiple comparison results of thermal conductivity

Source	*F*-value	*p*-value
Corrected model	2.249	0.017
Intercept	1769.940	0.000
Abrasion	6.525	0.014
Filament fineness	1.114	0.296
Disc type	7.374	0.009
Disc combination	5.054	0.029
Abrasion x filament fineness	0.562	0.457
Abrasion x disc type	0.011	0.917
Abrasion x disc combination	0.196	0.660
Filament fineness x disc type	0.365	0.548
Filament fineness x disc combination	0.586	0.448
Disc type x disc combination	6.443	0.014
Abrasion x filament fineness x disc type	0.405	0.527
Abrasion x filament fineness x disc combination	0.327	0.570
Abrasion x disc type x disc combination	4.491	0.039
Filament fineness x disc type x disc combination	0.274	0.603
Abrasion x filament fineness x disc type x disc combination	0.002	0.968

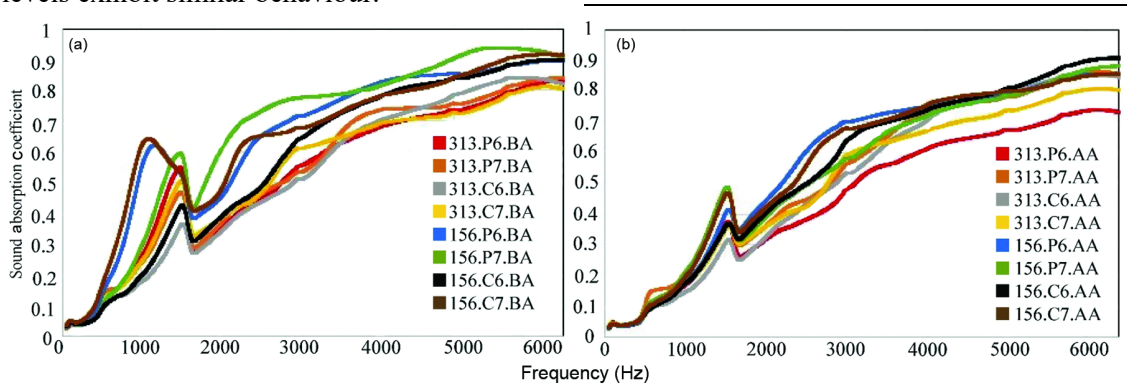

Fig. 2 — Sound absorption coefficient of carpet samples (a) before abrasion and (b) after abrasion

better sound absorption coefficients than coarser ones[7], and research on Struto nonwovens similarly indicates that finer fibres improve sound absorption performance[9]. Thus, it can be concluded that 1.56 dpf filaments deliver better acoustic performance before and after abrasion. However, because the reduction after abrasion is greater in fine-filament carpets, coarser 3.13 dpf filaments may be more suitable for long-term use where stability of sound absorption is required.

3.2.2 Effect of Disc Type

In this section, filament fineness and disc combination are held constant to isolate the effect of disc type. For non-abraded carpets, polyurethane discs yield slightly higher sound absorption up to 4000 Hz, while ceramic discs provide marginally higher values above this frequency. After abrasion, ceramic disc-textured carpets demonstrate higher absorption than those textured with polyurethane discs, indicating greater resistance to performance loss.

For the ceramic disc samples, the curves before and after abrasion remain very similar, suggesting that ceramic discs produce carpets with acoustically stable structures. In contrast, polyurethane disc samples show a decrease after abrasion, particularly around 2500–3500 Hz. From Fig. 2, the differences between polyurethane and ceramic disc types are modest in the non-abraded state, but after abrasion, the ceramic samples maintain more consistent performance.

Below 5000 Hz, polyurethane disc samples generally show higher absorption both before and after abrasion, whereas at frequencies above 5000 Hz, ceramic discs perform better. When comparing the effect of abrasion, non-abraded polyurethane carpets have higher absorption than the abraded ones, whereas ceramic carpets show little difference. This indicates that ceramic disc texturing yields a more durable acoustic response.

In summary, polyurethane discs provide slightly better initial sound absorption, but carpets produced with ceramic discs maintain their acoustic performance more effectively after abrasion. Therefore, ceramic discs are more suitable when long-term sound absorption stability is required.

3.2.3 Effect of Disc Combination

Here, filament fineness and disc type are kept constant to evaluate the effect of disc combination. Before abrasion, both disc combinations show similar sound absorption behaviour, although the 1-7-1 combination generally produces higher absorption below 4000 Hz. Above this level, the 1-6-1 combination performs slightly better.

After abrasion, both combinations produce similar results up to around 3500 Hz. At higher frequencies, the 1-6-1 combination shows slightly higher absorption, though the difference is negligible. Overall, the curves for abraded and non-abraded carpets with both combinations are similar, indicating that the disc combination has a moderate effect on acoustic durability.

Non-abraded carpets textured with the 1-7-1 combination exhibit higher sound absorption across nearly all frequencies. After abrasion, both combinations display similar behaviour, except at 2000 and 4000 Hz, where the 1-7-1 combination shows slight advantages. The increased twist and crimp associated with the 1-7-1 configuration enhance pile bulk and air-trapping capacity, improving absorption in the unworn state.

In general, Fig. 2 confirms that non-abraded carpets always show higher sound absorption than abraded ones, consistent with the literature. For example, studies on nonwovens produced from virgin and recycled polyester fibres report that undamaged samples exhibit superior acoustic performance[10]. In the present study, the 1-7-1 combination provides marginally better absorption before abrasion, while both combinations behave similarly after abrasion. Therefore, the 1-7-1 disc combination is preferable for reducing the loss of sound absorption during long-term use.

4 Conclusion

The study demonstrates that filament fineness, disc type, and disc combination have a significant influence on the sound absorption performance of carpets. Finer filaments (1.56 dpf) consistently provide higher sound absorption coefficients than coarser filaments (3.13 dpf) due to their larger surface area and denser coverage of the carpet pile. However, finer filaments are more affected by abrasion, whereas coarser filaments maintain more stable acoustic properties over time, making them more suitable for long-term use. Carpets produced with polyurethane discs generally show higher sound absorption in the non-abraded state, particularly at low and mid frequencies, while ceramic discs maintain more consistent performance after abrasion. This suggests that ceramic disc-textured carpets are more durable in terms of long-term acoustic performance. Regarding disc combination, the 1-7-1 configuration provides

slightly better sound absorption before abrasion, especially at lower frequencies, whereas both 1-6-1 and 1-7-1 combinations exhibit similar behaviour after abrasion. This indicates that the 1-7-1 combination may be preferred to minimise loss of sound absorption over extended use. In conclusion, finer filaments enhance initial sound absorption, but durability considerations favour coarser filaments and ceramic discs for long-term performance. The study confirms that careful selection of filament fineness, disc type, and disc combination allows optimisation of both acoustic efficiency and durability in carpets.

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