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A review of the functional properties of textile carpets

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Abstract
The article comprehensively reviews some significant research trends in textile carpets with regard to functional areas of applications. Antibacterial and antifungal properties of tufting carpets containing metal/texturized polyester composite yarns were investigated. Carpet contains different yarn groups such as pile yarns, ground warps and wefts. Backing fabric's warp and weft yarns are suitable for gaining antimicrobial activity because of their placement and low usage amount. Thus, textured polyester yarns were commingled with copper, stainless steel metal wires and silver metalized polyamide yarn. Backing fabrics were produced with four different placements by composite yarns. Tufted carpets with electromagnetic shielding (EMSE) effectiveness have been developed. For this purpose, stainless steel, copper, silver wires, and metalized silver PA filaments were commingled with textured polyester yarn to produce composite yarn. Composite yarns were used in tufted carpet backing fabric with different densities and directions. The EMSE of carpet samples was measured in the frequency range of 0.8–5.2GHz by free space technique. The effects of metal type, composite yarn density, and placement direction on the EMSE were statistically analyzed in 0.8–3.0 and 3.0–5.2GHz frequency ranges separately.
Key words: *Tufting carpets, Antibacterial properties, composite yarns, metalized filaments, electromagnetic shielding.*

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I. INTRODUCTION

Production of carpet is a branch of weaving art based on the previous century BC. It is believed that the first produced carpets are inspired by the structure of animal fur [1]. Nowadays, carpets have wide usage area in daily life such as houses, work places, hotels, kindergartens, nursing homes, mosques, bus floors, etc. Carpets provide several benefits in this areas as follows; contribution to thermal comfort, safety against falling and slippage, decrease in noise and esthetics. Particle retention is another important feature of the carpet. This feature helps to improve the air quality of environment [2,3]. According to the data of the year 2015; world carpet exports amounted to \$14.6 billion, and world carpet imports amounted to \$13.7 billion. \$6.9 billion of total exports were tufting carpets [4]. This is equivalent to 47.6% of total carpet exports of world. When the export data are examined, it is seen that the tufting carpets have an important role in world carpet production. Electrical and electronic devices are nearly used in all areas of daily life. Various devices emit electromagnetic waves when they running such as modems, computers, mobile phones, radio, microwave ovens, and AC motors. Due to this extensive emitting, people are exposed of electromagnetic waves coming from different angles [5]. It is known that the electromagnetic waves emitted by electrical and electronic tools have adverse effects on health of living organisms. Reducing the damage caused by the electromagnetic radiation has become extremely important for the environment and human health. Electromagnetic shielding is the basic method for protection of electromagnetic radiation. Shield is a barrier that can be used to prevent the emitting of electromagnetic waves from one point to environment. Metal and metal-containing conductive textile surfaces can be used for providing electromagnetic shielding [6].

II. ANTIFUNGAL AND ANTIBACTERIAL PROPERTIES OF TUFTED CARPETS WITH METAL COMPOSITE YARNS

Bacteria and mold basically need moisture, oxygen, a nutrient source and surface for growing. So, structure of standard carpets provides a suitable surface to bacterial and fungal growth. This paves the way for the spread of infectious diseases in public areas. This situation prepares the substructure of infections and illness. The carpet industry has lost market share in commercial settings due to perceived relationships between carpeted areas and an increase in asthma and allergies. The use of soft floor coverings in schools, hospitals and other health care facilities has long been controversial as carpet is thought to contribute to the presence of microorganisms in the indoor environment. One of the reasons for which antimicrobial agents is applied on textiles is to prevent antimicrobial attack against degradation of the textile. Others can be listed as follows: Esthetic functions (suppressing or killing bacteria causing odor), hygienic functions (preventing skin infections and related infections usually caused by dermatophyte fungi) and medical functions (suppressing or killing pathogenic and/or parasitic microorganisms) [7]. It is known that silver and copper coated areas reduce risk of bacterial growth considerably. Their bactericidal activity was well known even since the time of ancient civilizations. Today, copper is utilized as an agent for purification of water and inactivation of some microorganisms and bacteria.

In spite of the negligible responsiveness of human tissues to copper, microorganisms show high sensitivity to copper. For instance, silver nanoparticles and nanostructures with a high bactericidal activity have been widely applied in medicine to inhibit colonization by the bacteria on prostheses, dental materials, and wound dressing, and to reduce infections in burn treatments [8-10]. Biocides which can be used in the textile industry belong to biocidal compounds category II. Category II includes eight groups of chemical compounds: inorganic compounds, compounds of nitrogen, phenol and their derivatives, compounds of halogens and their derivatives, oxidizing compounds, alcohols, aldehydes, organic acids and their derivatives. Silver and copper that used for antimicrobial protection are inorganic compounds. Their antimicrobial activity mechanisms have been determined [11]. Increasing economic constraints on the textile industry brought forward alternative and less expensive methods to conventional techniques. Intermingling is an alternative technique for yarn blending process. Yarns having different features can be combined by feeding the same intermingling jet. This process is defined as commingling. The commingling process diagram is given in Figure 1.

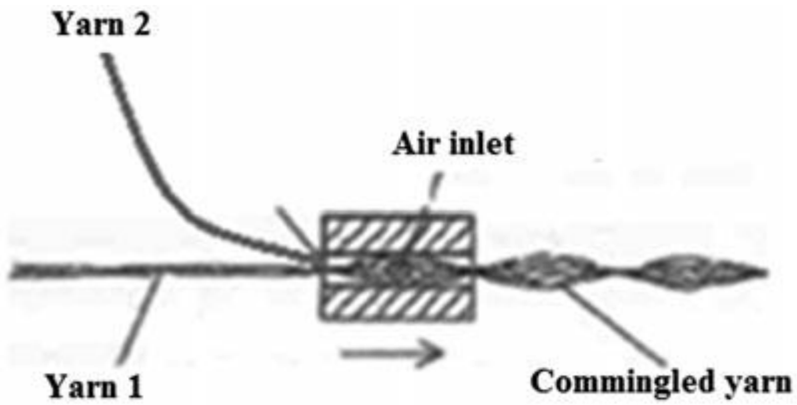

Figure 1 – Comingling process [20].

Commingling technique has been preferred in this research because of its ease of application, speed and cost effectiveness. Studies about antimicrobial textile applications related to our research are summarized below.

The effect of a metallic salt treatment on the antibacterial activity of cellulosic fabrics against three kinds of bacteria: *S. Aureus, K. Pneumonia* and methicillin resistant *S. Aureus* has been studied [12]. It is noted that after 10 laundering cycles, treatments that used in study are very effective in providing antibacterial activities to cellulose fabrics. The antibacterial efficacy of nanosized (2–5 nm) silver colloidal solution on the cellulosic and synthetic fabrics against *S. Aureus* and *K. Pneumonia* bacteria has been studied [13]. The studies showed that the antibacterial treatment of the textile fabrics was easily achieved by padding them with nanosized silver colloidal solution and antibacterial efficacy of the fabrics was maintained after many times laundering. Polypropylene has been compounded with micro and nano sized silver powders [14]. The mechanical properties of these materials have been measured using a universal tensile tester and evaluated the antibacterial activities of these compounds by performing quantitative antibacterial tests using the AATCC-100 test method. Researchers concluded that the compounds incorporating the silver nanoparticles exhibited superior antibacterial activity relative to the samples containing micron-sized particles. Work has been reported on the antibacterial effectiveness of BAC solutions on acrylic fibers used in machinery carpet. In the study, an acrylic pile carpets laid in a public place for 30 days and the antimicrobial effect of different BAC solutions were assessed [15]. The results in the studies showed that amount of colony growth on treated carpet reduced considerably moreover there is no significant difference between treated and untreated sample's mechanical properties.

The antibacterial effectiveness of rodalon solutions on silken fibers has been investigated by spraying method used in silken carpet [16]. In the study, carpet was laid in a hotel for 30 days and bacteria that found on carpet were determined. Silken fibers were treated with antimicrobial solutions of Rodalon and the antimicrobial effectiveness was assessed. Results of study showed the presence of some pathogenic microbes on the laid carpet such as E. coli and *S. Aureus*. The amount of colony growth on treated carpet reduced considerably furthermore mechanical properties showed no significant deterioration effect of studied properties in comparison to the untreated yarn. The effect of silver on antibacterial properties of stainless steel has been studied [17]. In the research, AISI 304 stainless steels containing 0.1, 0.2 and 0.3 wt. % Ag, were prepared in an air induction furnace under a protective nitrogen atmosphere. Researchers noted that AISI 304 alloy do not possess antibacterial properties but the alloy contains about 0.3 wt. % Ag show excellent antibacterial property (nearly of 100%) against *E. Coli*. Study has been conducted on development of silver-containing austenite antibacterial stainless steels for biomedical applications [18]. In the research, AISI 316 stainless steels containing 0.1, 0.2 and 0.3 wt. % Ag, were prepared. Results showed that the AISI 316 alloy do not possess antibacterial properties but the alloy has an Ag content of 0.2 wt. % have excellent antibacterial properties against both *S. Aureus* and *E. Coli*, with an antibacterial rate of nearly 100%. The antibacterial and conductive effects of coatings containing metallic effect pigments onto textile materials have been studied [19]. It has been noted that application of coatings with copper or silver containing pigments show significant antibacterial properties against *E. Coli* and *S. Aureus* bacteria. It was not found a similar study related antimicrobial application for tufting carpets in the literature. So, this study is aimed to gain antibacterial and antifungal properties to tufting carpets' backing fabric. For this purpose, copper, stainless steel metal wires and silver metalized polyamide yarns were commingled with textured polyester yarns. Composite yarns were used in backing fabric's structure.

Carpet floor is suitable environment for growing of microorganism. Thus, it is aimed to gain antibacterial and antifungal properties to tufting carpets' backing fabric. For this purpose, copper, stainless steel metal wires and silver metalized polyamide yarns were used as antimicrobial content. According to antibacterial activity test results, AW construction provided high antibacterial activity for samples including metalized silver and copper composite yarns against *S. Aureus* and *K. Pneumoniae*. It is enough to use copper about 6% for antibacterial activity at 99% level. Approximately 1.5% of metalized silver is sufficient for that level. Metalized silver can be ionized more easily than copper so lower amounts are sufficient for high antibacterial activity. Metalized silver is a more expensive material than copper. However, it provides antibacterial activity in low quantities. Eventually, different bacterial species give specific reactions against different metal types [20]. But, generally antibacterial activity increases with increasing in the amount of metal composite yarn in unit area. Antifungal activity can be provided against A. Niger when copper and metalized silver (114 denier/30 filaments) composite yarn is used in all warps in the samples. In other constructions, amount of metal composite yarn was inadequate for antifungal activity, moreover *A. Niger* can be grow spaces between the metal composite yarns. Consequently, high antibacterial activity can be provided up to 99% with using composite yarns less than 7% level. However, it is necessary to have as small spaces as possible between the composite yarns in structure to improve antifungal activity. Otherwise the *A. Niger* can grow in those spaces.

III. ELECTROMAGNETIC SHIELDING PROPERTIES

The number of people living in the apartment is increasing day by day. These buildings contain devices that emit electromagnetic radiation in various floors. The adjacent floors are in an electromagnetic interaction with each other. Carpets with electromagnetic shielding effectiveness can be a useful and esthetic option to prevent electromagnetic interference between floors. Compared to widely used metal plates, textile materials are more suitable for EMSE because of their lightweight, cost effectiveness and flexible structure [21,22]. There are many studies in the literature about textile materials providing protection against electromagnetic radiation and the performance properties of these materials. Studies generally focused on woven fabrics, knitted fabrics and nonwoven surfaces. In the previous research studies, the main investigated parameters can be listed as metal density, metal wire diameter, yarn production type, surface structure, surface thickness, and relation between frequency and EMSE. In earlier studies, different techniques were preferred for metal composite yarn production such as core spun, plied, hollow spindle, and dref yarns [23-30]. It was determined that increasing in the metal content and density in fabric structure increased the EMSE [31]-. In terms of the weave types, it was stated that the woven fabrics with smaller mesh size showed better EMSE results [32]. In another study, lacoste type knitted fabrics showed higher EMSE than interlock, 1x1 plain and double pique types [33]. There are few studies about production of the carpets with electromagnetic shielding properties. In these studies, researchers noted that it was possible to give antibacterial and electromagnetic shielding properties to carpets by using metal composite yarns [34-36]. The aim of this research is to develop the tufted carpets with electromagnetic shielding effectiveness. There are few studies related to EMSE properties of the tufted carpets in the literature. Protective carpets may be a useful and esthetic alternative to prevent electromagnetic interference between floors. For this aim, stainless steel, copper, silver metal wires and metalized silver PA filament were commingled with textured polyester yarns. Produced composite yarns were used in tufted carpet's backing in four different placements. The EMSE of carpet samples was measured at vertical and horizontal by free space measurement technique. Effect of metal type, composite yarn placement and density on EMSE were analysed statistically in 0.8–3.0 GHz and 3.0–5.2 GHz. Frequency ranges. In this research, effects of composite yarn density, placement direction and metal type on EMSE of tufted carpet were investigated in the 0.8–3.0 GHz and 3.0–5.2 GHz frequency ranges separately. As a result, the tufted carpets which can provide electromagnetic shielding effectiveness up to 44 dB were produced successfully. EMSE performance was also analyzed statistically. Obtained results were summarized below.

Statistical analysis showed that the increasing in the amount of metal content generally increased the EMSE of carpet samples for both frequency ranges. The difference was not statistically significant in some samples whose metal density was close to each other. The relationship between 1X2W and 1X2WW revealed an interesting result that the increase in the amount of metal in the weft direction only increased the EMSE in that direction. Although 1X2WW contains two times more metal than 1X2W, there was no statistical difference between the warp direction EMSE values. On the other hand, 1X2WW exhibited a much better EMSE by the effect of composite yarns in the weft direction than 1X2W sample [37].

Only the samples (1X2WW) that include metal composite yarn in both warp and weft courses provided multiaxial shielding effectiveness at warp and weft directions. Carpet samples containing stainless steel and silver wires showed a better EMSE performance 0.8–3.0 GHz range. Multifilament conductive yarn came to the fore with its EMSE performance above 3 GHz frequency. In terms of metal type, it can be said that the stainless steel provided a better EMSE in lower frequencies than 3 GHz. In addition, it was found that the metallized silver was more effective in the frequencies above 3GHz. There was determined that a statistically significant negative correlation between EMSE and frequency for both frequency ranges. The correlation coefficient between 0.8 and 3.0 GHz range was at a moderate level but far from perfect association. This relation was weaker at frequencies above 3 GHz. Produced tufted carpets can provide electromagnetic shielding effectiveness at a very good level for daily use and a good level for professional use.

IV. CONCLUSION

Antibacterial activity tests were applied to carpet samples according to AATCC 100 standard against *K. Pneumoniae* and *S. Aureus* bacteria. AATCC 30 – Part 3 standard was used for determining antifungal activity against *A. Niger*. Results show that the antibacterial activity increases with increasing in the amount of metal composite yarn in unit area. Carpet samples which include copper or metalized silver composite yarn in all warps showed antibacterial activity about 99%. Moreover, antifungal activity can be provided against *A. Niger* when copper and metalized silver composite yarn is used in all warps of carpet samples. Stainless steel and silver wires provided better EMSE in the range of 0.8–3.0 GHz. Stainless steel showed better EMSE in lower frequencies than 3 GHz. The metallized silver was more effective above 3GHz. The increase in metal density significantly increased EMSE for all metal types. Carpets containing metal in two directions provided multidirectional shielding and maximum EMSE reached up to 44 dB level. As a result of the study, tufted carpets which can provide multi-axial protection were produced successfully.

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