ANTIMICROBIAL ACTIVITY OF FIR FUNCTIONALIZED TEXTILE MATERIALS AGAINST PATHOGENIC FUNGI STRAINS

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Far infrared (FIR) functional textiles are a new category of functional textiles that have the potential to improve well-being and health. At the molecular level, FIR exerts strong rotational and vibrational effects with potential biological benefits. The majority of textiles with antimicrobial functionalization are based on synthetic products, and there is a need to link current end-user demands with both efficient products and low environmental impact, promoting natural antimicrobial treatments as viable solutions. Two structures of knitwear were obtained, with functional inorganic particles with antimicrobial, anti-UV and IR emission properties: variant 1: 100% BBC gauze ground yarn plated with functionalized polyamide yarn; variant 2: 85% wool/15% cashmere blend ground yarn plated with functionalized polyamide yarn. The antimicrobial efficiency of two types of functionalized materials was tested against six pathogenic microbial strains: *Tricoderma viride* (laboratory strain), *Aspergillus flavus* (laboratory strain), *Candida albicans* (ATCC 90028), *Epidermophyton floccosum* (CCM 8339), *Trichophyton interdigitale* (ATCC 9533) and *Aspergillus niger* (IMI 45551), highlighting various degrees of microbial reduction, depending on both the material and the tested strain, with lowest percentage microbial reduction of 9.67&, against *Aspergillus niger* strain, and highest of 86.65%, against *Candida albicans*.

Keywords: Antimicrobial, fungi, textile materials.

INTRODUCTION

Pyroelectric materials are functional materials that can generate an electrical response following a temperature change (Best *et al*., 2008). Modern solutions often include a combination of polypropylene and special lead-free bio-ceramics to create functional FIR (Far Infrared) garments, which are materialized in commercially available products such as socks, pillows, underwear, knee pads, trousers, bed covers, bed linen, shoulder pads etc. The functionalization materials of FIR functional products consist of a wide range of inorganic bio-ceramic compounds, such as: bamboo charcoal, pearl powder, tourmaline, carbide-based materials (ZrC, SiC), oxide-based materials (magnesium, zirconium, alumina, iron, germanium), photocatalytic compounds (TiO_2), which impart controlled infrared radiation (Wang and Li, 2010).

Currently, the synthetic fibers generating pyroelectric effects are obtained by introducing minerals (e.g., superfine tourmaline powder) into melted polymers before spinning or by dispersing the minerals into the spinning solution (Taekyung *et al*., 2020). Regarding the current state of the art level, regarding FIR functionalized materials, emerging technologies, like PRTM (Personal Radiant Thermal Management), are being widely adopted for manufacturing advance clothing materials, that can promote thermal comfort to the wearer, while reducing energy consumption (Zhu and Feng, 2021).

Processing methods for anionic fibers and functional textiles can be divided into two main categories. In the first category, the anionic additive is integrated into the anionic fibers, and in the second category, the textiles are functionalized with negative ion generating materials during the finishing process. The main method of manufacturing anionic fibers is coating and surface modification, melt spinning and copolymerization.

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MATERIALS AND METHODS

Functionalization Masterbatches

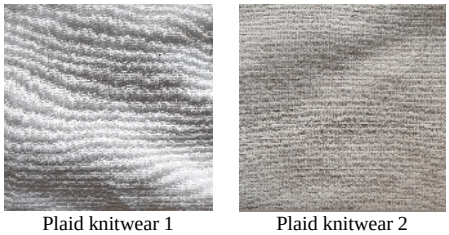
The functionalization masterbatches, used for the development of the textile structures used in the antimicrobial testing, were developed by Clavis Corporation (Korea) by blending functional inorganic particles (Fig. 1) into PET and PA. In order to impart multiple functional properties, inorganic particles with antimicrobial, anti-UV and IR emission properties were used. Extrusion characteristics between PET polymer and inorganic particles were considered, taking into account particle size, specific gravity, color and accounting with other additives.

IR emission Antimicrobial properties Anti-UV

Figure 1. Inorganic particles with dedicated functional properties

Textile Materials

For the antimicrobial testing, two knitted textile structures were executed, with a plated glazed structure: knit 1: 100% BBC gauze ground yarn plated with functionalized polyamide yarn; knit 2: 85% wool/15% cashmere blend ground yarn plated with functionalized polyamide yarn (Fig. 2).



Plaid knitwear 1 Plaid knitwear 2

Figure 2. Knitted textile materials

Testing Method and Microbial Strains

The antimicrobial efficacy testing was done according to ISO 20743:2007, a method applicable to all textile products, including canvas, wadding, yarns and materials for clothing, home furnishings and various products, regardless of the type of antibacterial agent used (organic, inorganic, natural or synthetic) or the method of application (incorporated, post-treatment or grafting). The absorption method was used, in which the microbial suspension is inoculated directly onto the samples, with previous sample sterilization. The samples were inoculated with 50µL of the last dilution performed for each strain tested in the step (in pre-sterilized tubes) and incubated for 24 hours at 28°C for filamentous fungal strains and 37°C for *Candida albicans* strain. After the

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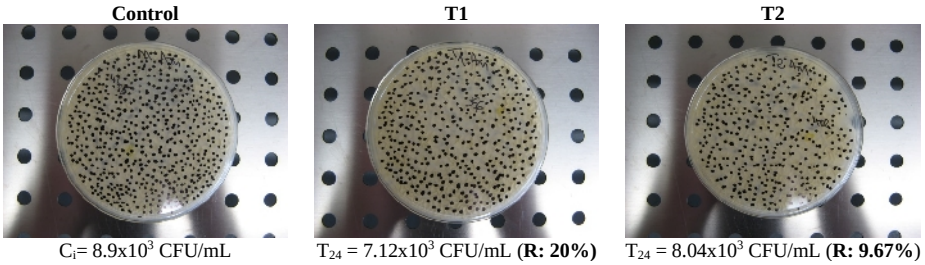
incubation period, each sample was vortexed for approx. 20" in 1mL sterile distilled water and inoculated on specific nutrient medium (Czapek-Dox and Sabouraud-Agar), followed by an incubation period of 2-3 days. To quantify the results, the CFU (Colony Forming Units) counting technique was used on the incubated plates and the strain as a control was used to report the antimicrobial efficacy.

Antimicrobial evaluation was performed on the 2 functionalized materials, compared to a 0 control (single control, from each strain, taken as microbial inoculum), against six microbial strains: *Trichoderma viride* (laboratory strain), *Aspergillus flavus* (laboratory strain), *Candida albicans* (ATCC 90028), *Epidermophyton floccosum* (CCM 8339), *Trichophyton interdigitale* (ATCC 9533) and *Aspergillus niger* (IMI 45551).

RESULTS AND DISCUSSION

Fungi are ubiquitous microorganisms with representative species that have a high pathogenic potential for human hosts, especially for immunocompromised and immunocompetent individuals. Pathogenicity is the ability of an organism to affect a living host by deregulating homeostatic parameters, triggering an immunological response or mechanical action at the tissue level (Siscar-Lewin *et al*., 2022).

Testing against *Aspergillus niger* (Fig. 3) indicates a low efficiency of functionalized materials against the strain, with a maximum of 20% (T1 material), which is more than twice as efficient as T2 material (9.67%). *Aspergillus niger* is a highly resistant strain to the action of certain antimicrobial agents, combined with the high microbial concentration of the inoculum (8.9x103 CFU/mL), leading to low microbial reduction rates.



$C_i = 8.9x10^3$ CFU/mL $T_{24} = 7.12x10^3$ CFU/mL (**R: 20%**) $T_{24} = 8.04x10^3$ CFU/mL (**R: 9.67%**)

Figure 3. Antimicrobial activity against *Aspergillus niger* strain

The results of the antimicrobial test against *Candida albicans* (Fig. 4) highlighted better degrees of microbial reduction than against *Aspergillus niger*. The T1 material showed better antimicrobial efficacy (86.65%) compared to the T2 material (65.48%). This may also be due to the higher cotton composition, correlated with a higher mechanical retention, T2 also having polyester in its composition.

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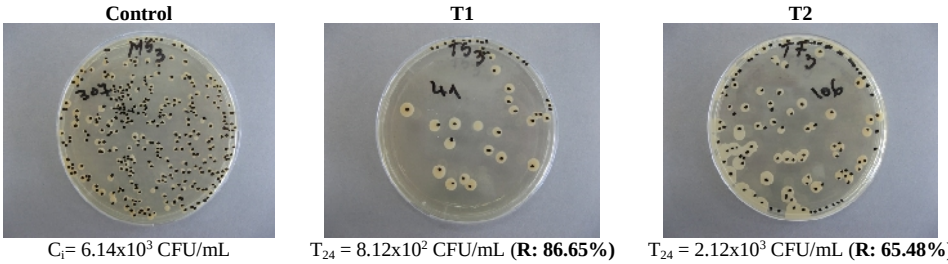
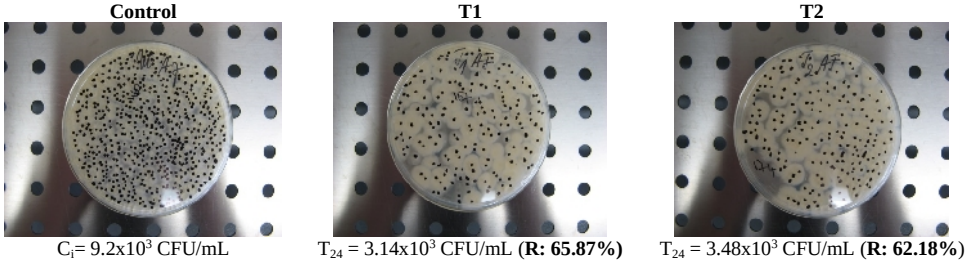


C_i= 6.14x10^3 CFU/mL T_{24} = 8.12x10^2 CFU/mL (**R: 86.65%**) T_{24} = 2.12x10^3 CFU/mL (**R: 65.48%**)

Figure 4. Antimicrobial activity against *Candida albicans* strain

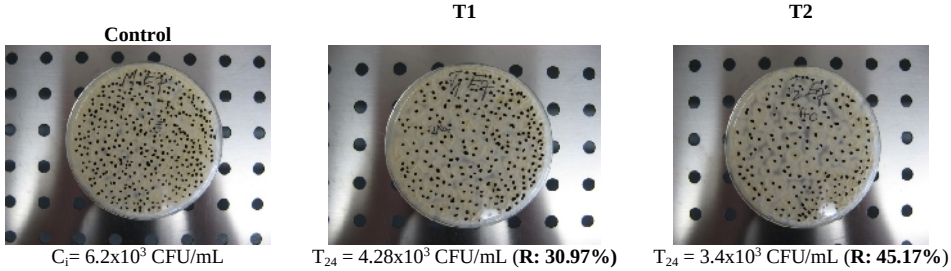
Antimicrobial analysis against *Aspergillus flavus* (Fig. 5) showed good degrees of microbial reduction, with very close values between the two materials (T1 and T2). Even if a slight similarity between inoculum concentration and *Aspergillus niger* is observed, the reduction rates are significantly higher against *A. flavus* strain, showing the difference in susceptibility to treatment of one strain versus another, even between species of the same genus.



C_i= 9.2x10^3 CFU/mL T_{24} = 3.14x10^3 CFU/mL (**R: 65.87%**) T_{24} = 3.48x10^3 CFU/mL (**R: 62.18%**)

Figure 5. Antimicrobial activity against *Aspergillus flavus* strain

Epidermophyton floccosum is an anthropophilic dermatophyte with a worldwide distribution and one of the most common causes of dermatophytosis in healthy individuals. The strains infect the skin (tinea corporis, tinea cruris, tinea pedis) and nails (onychomycosis). Infection is limited to the horny layers of the epidermis, as the microorganism does not have the ability to penetrate the viable tissues of the immunocompetent host. Antimicrobial testing against *E. floccosum* (Fig. 6) highlighted satisfactory degrees of microbial reduction, with 45.17% for T2 material, and 30.97% for T1.



C_i= 6.2x10^3 CFU/mL T_{24} = 4.28x10^3 CFU/mL (**R: 30.97%**) T_{24} = 3.4x10^3 CFU/mL (**R: 45.17%**)

Figure 6. Antimicrobial activity against *Epidermophyton floccosum* strain

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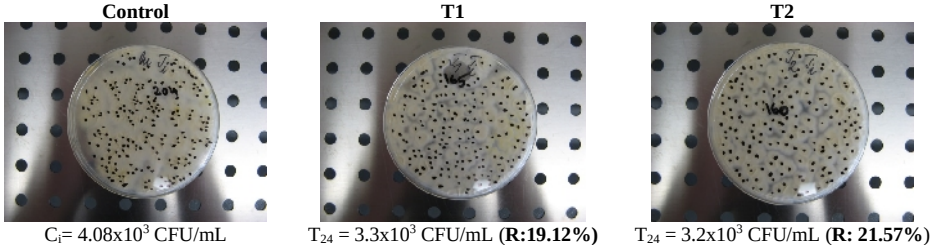
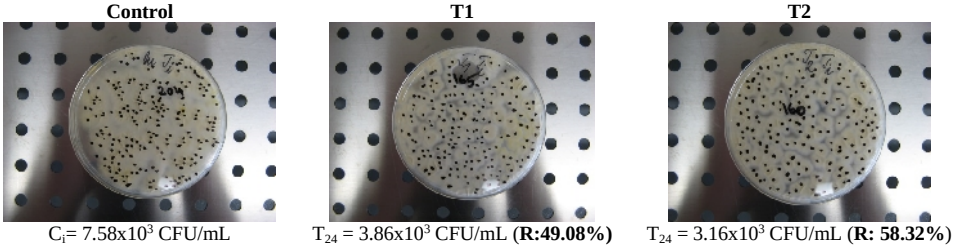
Tests carried out on the second dermatophyte strain, *Trichophyton interdigitale* (Fig. 7), showed sub-medium degrees of microbial reduction, with similar results for both treated materials: T1 = 19.12% and T2 = 21.57%. Compared to the other dermatophyte fungal strain, *Epidermophyton floccosum*, this one was found to be more resistant to the action of the antimicrobial agent.



C_i= 4.08x10^3 CFU/mL T_{24} = 3.3x10^3 CFU/mL (**R:19.12%**) T_{24} = 3.2x10^3 CFU/mL (**R: 21.57%**)

Figure 7. Antimicrobial activity against *Tricophyton interdigitale* strain

The results of the analysis against *Trichoderma viride* (Fig. 8) strain indicated a good antimicrobial efficiency of both materials, with very low variation (9.24%), thus promoting this type of functionalization as a biological barrier against *T. viride* strain.



C_i= 7.58x10^3 CFU/mL T_{24} = 3.86x10^3 CFU/mL (**R:49.08%**) T_{24} = 3.16x10^3 CFU/mL (**R: 58.32%**)

Figure 8. Antimicrobial activity against *Trichoderma viride* strain

CONCLUSIONS

Materials functionalized with FIR compounds are based on the principle of absorbing light energy and then radiating this energy back onto the body at specific wavelengths. Textiles are constantly exposed to the action of microorganisms, so their functionalization may prove to be an efficient method of obtaining antimicrobial active barriers, among other special properties. The antimicrobial evaluation performed on the 2 functionalized materials, compared to a 0 control, under static contact conditions (under agitation), against the six microbial strains showed good reduction rates, especially against *C. albicans* (max of 86.65%), *A. flavus* (max of 65.87%), *E. floccosum* (max of 45.17%) and *T. viride* (max of 58.32%), thus validating this type of functionalization treatment for inducing antimicrobial properties, beside FIR specific ones.

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