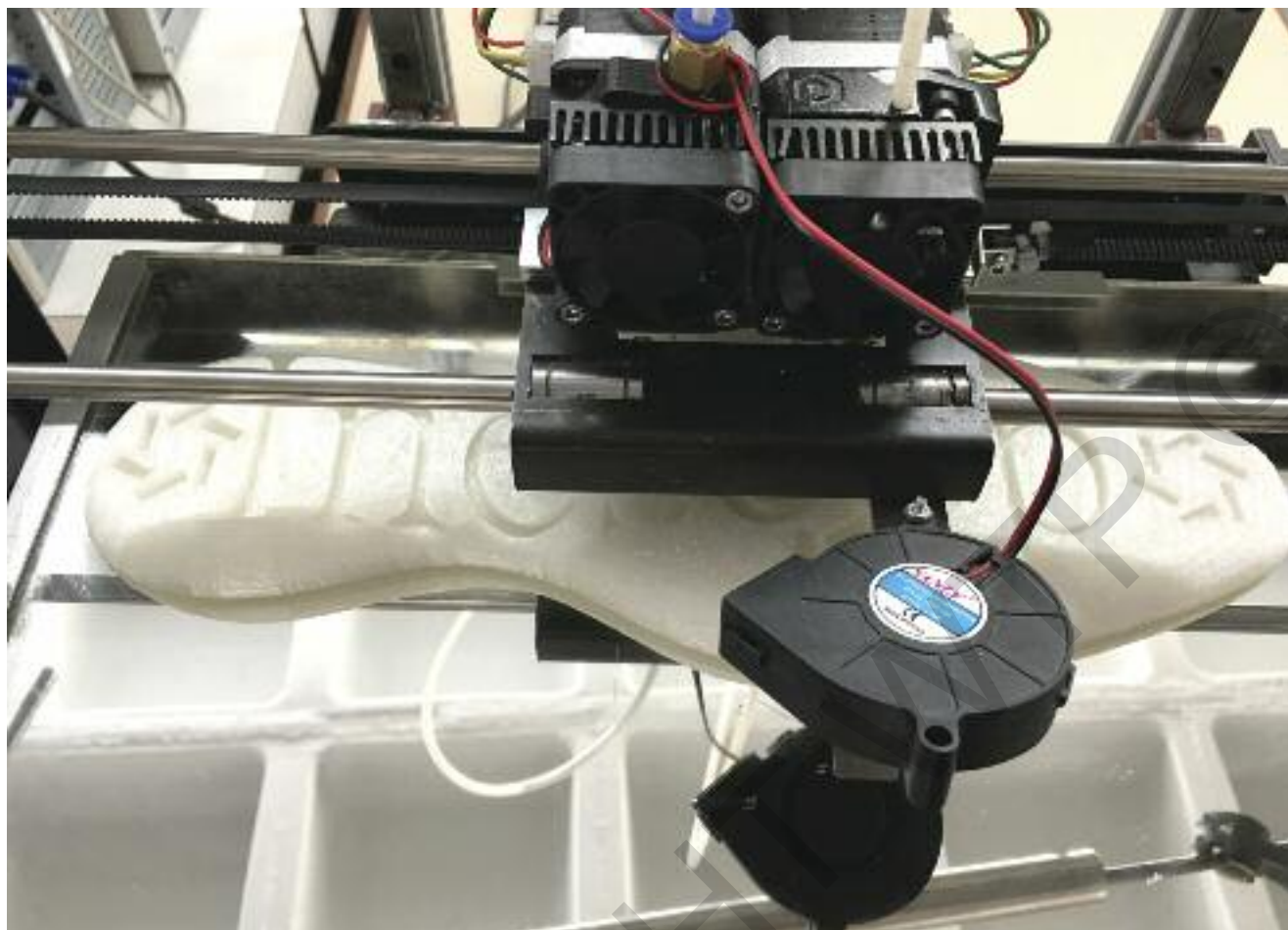




3D impression of sole functionalised with silver nanoparticles.

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Preventing microbial contamination

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Preventing the risk of microbial contamination is an issue of major importance in various industrial sectors. It is especially so in some production areas closely related to human health as in the case of the healthcare sector, where maximum rigour in the implementation of control systems has to be ensured. In Spain, risks related to exposure to biological agents are dealt with in Spanish Royal Decree 664/1997, Regulation (EC) No. 852/2004, which lays down a series of principles based on general and specific hygiene rules, the main objective of which is to

ensure a high level of protection for consumers and workers with regard to health security.

Among the different possibilities of microbial contamination in healthcare settings, there is the so-called 'cross-contamination by people movement'. This type of contamination usually occurs as a result of the constant movement of workers across different areas in work facilities. This contributes to the dissemination of undesired and potentially pathogenic micro-organisms from one area to another inside the facilities and may result in health risks for workers,

consumers and, in the case of health centres, for the patients themselves.

One of the main vehicles for cross-contamination in the healthcare sector is occupational footwear worn by workers. The continuous movement of personnel around the facilities of any health centre favours the spread of potential pathogens. At present, contamination control procedures and biosafety schemes implemented in health centres are strict in that they limit personnel access or require the use of exclusive clothes and footwear such as overshoes for certain areas or the use of disinfecting shoe baths.

However, cross-contamination by people movement still constitutes a significant risk factor.

Accordingly, INESCOP is working on the development of a new line of research within the framework of a project by the Spanish Ministry of Economy, Industry and Competitiveness (DPI2016-80275-R) with financial support from the Spanish Research Agency (AEI) and the European Regional Development Fund (ERDF). The Antimicrosole3D project is based on the design and functionalisation of soles with antimicrobial properties through AM (additive manufacturing) technologies and is expected to be developed and industrially assessed over the course of the next three years.

SPECIAL SOLES

Nowadays, the most commonly used occupational footwear in the healthcare sector includes a wide range of materials for soling components or, in the case of clogs, making the entire article from thermoplastic polymer materials, such as SEBS, PUR or microporous EVA. Most of these materials have a porous structure to provide the footwear with comfort and lightness. Pore size may vary according to the manufacturing process involved.

The project approach is to preserve the individual features of the occupational footwear currently used in the healthcare sector, conferring added value by means of functionalised soles with antimicrobial properties, an anti-slip sole pattern and a special assembly system, thanks to CAD design and 3D printing. For the purpose of developing footwear materials with antimicrobial properties, it is intended to functionalise different types of thermoplastic polymer materials by incorporating silver nano-particles, i.e. by adding functional additives to a polymeric filament. Thanks to the previous experience of the research team on the subject, filaments complying with the necessary technical requirements in terms of thermal and mechanical properties, etc., have been selected for footwear materials. These include TPU, ABS, PLA, SBS, SEBS, and EVA, in terms of their material structure, design and

Polymer material abbreviations	
ABS:	acrylonitrile butadiene styrene
EVA:	ethylene vinyl acetate
PLA:	polylactic acid
PUR:	polyurethane
SEBS:	styrene ethylene butylene styrene
SBS:	styrene butadiene styrene
TPU:	thermoplastic polyurethane

processing, and taking into consideration that they were to be applied through AM technologies.

Once the optimal filament for 3D printing with regard to rheological, mechanical and comfort properties has been selected, the pursuit of additives is to be undertaken which, after being incorporated into the filaments, are able to provide footwear with the expected antimicrobial properties. Due to the wide range of functional additives currently available, it is necessary to select those that meet the relevant technical requirements. Additives to be incorporated may come in different physical forms including powder, micro-capsules, masterbatch,

nanoparticles, etc. Once the filament containing the antimicrobial properties has been developed, its antibacterial activity is to be assessed through standardised tests, such as footwear standard ISO 16187:2013 or the MIC (minimum inhibitory concentration) test, among others.

ADDITIVE MANUFACTURING

Given the complexity of the sole geometry, the 3D design of the sole and validation of its anti-slip properties will be carried out through CAD tools specifically tailored to this end. Once the sole has been designed, it will be produced using AM technologies. The main advantage of this system as regards the project's development is that it is possible to use complex materials that incorporate some additional functionality, e.g. antimicrobial properties. Furthermore, it allows any type of geometry to be built regardless of its complexity, as well as access to the inside of the object to be gained and different elements to be assembled into a sole piece. These features make AM suitable for sole manufacturing.

Among the various AM technologies, the one chosen is 3D printing by FDM (fused deposition modelling), by which the object is created by heating and extruding a thermoplastic filament. Manufacturing by FDM is regarded as the most convenient method for this purpose due to the recent development of low-cost machines by a large number of small-sized companies fostered by technology upgrading and the expiry of the relevant patent. This will allow sole printing to create the tread pattern, to be accomplished efficiently and cost-effectively.

The printing process begins with the CAD file processing via the printing software by properly positioning the digital object, slicing it into layers at different levels and calculating the path of the printing head. Subsequently, the material is melted and distributed throughout the extrusion path in droplets that solidify in a matter of seconds. In the last post-processing stage, when a water-soluble material has been used as scaffolding for the object to be manufactured, it is removed by dissolving it in water. 



Pellets and filament used in the preparation of the soles.