Report on the outcomes of a Short-Term Scientific Mission[1]

Action number: CA17107

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Details of the STSM

Title: Plasma treatment of textile surfaces to improve adhesion of printed flexible electronics

Start and end date: 01/03/2022 to 31/03/2022

Description of the work carried out during the STSM

Description of the activities carried out during the STSM. Any deviations from the initial working plan shall also be described in this section.

The work plan presented in the application form was successfully implemented.

In WP1, about 20 different commercially available woven fabrics for technical applications made of glass and carbon fibers were tested. An initial selection was made by basic tests of the main constructional parameters and the most suitable fabric surfaces, namely six fabrics made of glass fibers, were selected for further experiments, because the surfaces of all carbon fabrics were too loose. The construction properties of the fabrics were investigated and the surfaces of the materials were inspected to define a range of fabrics with optimal surface properties as substrates for screen printing samples. Mainly all woven fabrics for technical applications are woven in plain weave, therefore 5 samples were in plain weave (B: 300 g/m^2, 52 warp/10 cm, 50 weft/10 cm, the thread density does not guarantee a closed compact surface; L: 160 g/m^2, 120 warp/10 cm, 118 weft/10 cm, fine threads in higher density provide smooth surface; T: 500 g/m^2 , 110 warp/10 cm, 110 weft/10 cm, a closed surface with a rougher surface due to the dense interlacing; S 400 g/m^2 , 140 warp/10 cm, 130 weft/10, a closed, smooth surface). One sample was twill 2/2Z, K : 160 g/m^2, 120 warp/10 cm, 120 weft/10, characteristic twill surface with diagonal rays.

In WP2 was to determine the correct plasma parameters. Optimization of plasma parameters for selected surfaces was performed by studying plasma parameters such as pressure, power, operating mode (H-mode, E-mode), gas type, and treatment time. Once the optimization was established (vacuum plasma, gas: oxygen - 300sccm O2, 44KPa vacuum, base 1Pa. The changes in mechanical properties of the untreated and treated materials were studied and analyzed. The tensile strength of the samples treated for 30 seconds decreased by about 23% in the warp direction, while the tensile strength in the weft

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.

direction remained almost unchanged. The elongation at break of the plasma-treated samples decreased by 20% in the warp direction and by 0.1% in the weft direction.

In WP3, the conductive flexible circuits were printed directly on untreated and treated fabrics using two different conductive pastes (Mateprincs SSAG001 - silver ink and carbon-based DuPont 7292 PCT cardon resistor) for screen printing to test the printing capabilities in a test setup using hand screen printing technique. The optimal fixation parameters were determined according to the ink manufacturer's instructions (130 °C, 20 minutes in a box oven) to achieve satisfactory adhesion of the printed conductive circuits to the fabrics and to ensure the required properties for further applications. Next, the electrical properties (electrical resistance in Ω) and adhesion strength were measured according the adhesive tape test IPC-TM -650 test methods manual, but performed with Instron at constant speed rate 50 mm/min). The abrasion resistance of the printed samples was tested with the SDL Atlantis electronic crockmeter at 10 cycles (rubbing fastness). Finally, everything was examined with the scanning electron microscope (SEM, JSM-6060 LV, JEOL, Japan) and the Leica S9i stereomicroscope. At the end, all results were analysed, compared and verified.

Description of the STSM main achievements and planned follow-up activities

Description and assessment of whether the STSM achieved its planned goals and expected outcomes, including specific contribution to Action objective and deliverables, or publications resulting from the STSM. Agreed plans for future follow-up collaborations shall also be described in this section.

The main objective was to develop new lightweight printed electroactive components for electromechanical devices to facilitate the development of new aerospace and automotive applications that can be widely used. The use of the novel screen printing technique in combination with plasma treatment is also expected to improve the functionality of these components.

The stereomicroscope observations of the untreated and the plasma-treated e-glass fabric printed with the conductive ink shows that with the duration of plasma treatment increases, the conductive ink Ag gradually spreads on the surface of the e-glass fibres. The conductive ink completely covers the fibres in the yarn after the e-glass fabric is treated with plasma for 10 s and 30 s, respectively. As the plasma treatment time increases, the droplets of the conductive ink are less round and flatter than ink droplets on the untreated e-glass fabric. The droplets of the conductive ink Ag form on the untreated fabric due to the dense fabric and the hydrophobic properties of the glass. Treatment of the fabric with oxygen plasma enables functionalization of the fabric surface with oxygen-rich functional groups, resulting in higher absorptivity of the substrate. Higher absorptivity leads to higher sorption of the conductive ink and consequently to less round printed droplets. The effect of plasma treatment is also evident after rubbing test. The conductive ink is completely rubbed off the fibres in almost all samples. For the samples with the lowest adhesion fastness, the removed ink is packed between the warp and weft threads. Good adhesion fastness of the conductive ink Ag is achieved on the sample after 30 seconds of plasma treatment. Here, the morphology of the flattened droplets of the conductive ink is clearly visible as the ink is firmly bonded to the fibres. The optical observations are confirmed by measuring the electrical resistance. It was difficult to ensure consistency by hand screen printing, so measurements of electrical resistance also varied widely. Nevertheless, the results show a sharp increase in conductivity with an 89.38% decrease in electrical resistivity for the samples treated with plasma for 30 s (Figure 1).

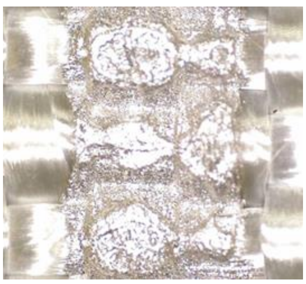

Figure 1: T30-Ag

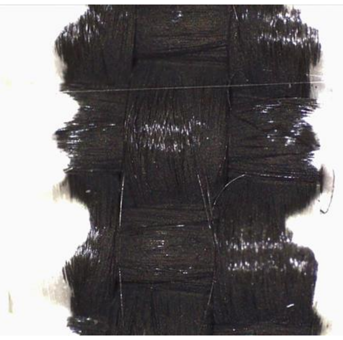

Figure 2. T30-C

The adsorption of the conductive ink C on the e-glass fabric is also higher after plasma treatment (Figure 2). Due to the different consistency and purpose of the ink (high electric resistance – heating applications) clear droplets of the ink can be seen on the surface. The longer the plasma treatment lasts, the more easily the conductive ink C spreads between the fibres and the yarn becomes uniformly covered with the ink. The ink C exhibits very poor rubbing fastness, as some of the ink was removed from all samples.

The proposed STSM addressed the main technological challenges in improving the adhesion of printed electronics on substrates made of glass fibres, which, to our knowledge, have not yet been systematically researched due to the hydrophobicity of glass fibres. Subsequent benchmarking of flexible electronics on untreated and plasma-treated woven fabrics indicated that there is potential for further systematic investigation using the Ekra screen printer to more uniformly printed plasma-treated samples.

The STSM results provided a solid knowledge base on the potential of printing smart textiles, including plasma surface treatment, for mobility and aerospace applications. The goal is to publish the STSM results as original scientific articles.