Robust Design of Multifunctional Nanocomposites suitable for Additive Manufacturing of Electrical Devices

P. Lamberti[1,*], **M. La Mura**[1], **V. Tucci**[1]
[1]*Dept. of Information and Electrical Eng. and Applied Math., University of Salerno, via Giovanni Paolo II 132, Fisciano (SA) – ITALY*
[*]*plamberti@unisa.it*

1. Summary

A robust design approach for the selection of the best nanofilled polylactic acid (PLA) filament for the Fused Deposition Modeling (FDM) additive manufacturing of electrical devices will be reported. The use of two nanofillers to modify the electrical and thermal properties of the hosting material has been considered in order to realize a three phase nanocomposite, i.e. PLA matrix, electrically conductive multiwall carbon nanotubes (CNT) and graphene-based nanoparticles (GNP), expecting to have different effects [1-3]. According to the customer requirements, the PLA filament with the best combination of fillers amount respecting the physical constraints is selected among those realized following a Design of Experiment (DoE) pre-planning-phase.

2. Description of the problem and proposed approaches

The production and use of conductive polymeric composites is in continuous development due to the opportunity to combine the advantages of plastic materials (low cost, low weight, easy workability) with the possibility of modulating the thermal and electrical conductivity as the filler concentration varies [4-6]. It has been demonstrated that the electrical behaviour of a nanocomposite changes from insulator to conductor following the addition of electrically conductive nanoparticles, such as CNT and GNP, when their concentration reaches the percolation threshold [7,8]. Moreover, the introduction of nanoparticles influences also the mechanical and thermal properties. In case of multiphase nanocomposites, it is crucial to define the amount of a specific filler and to understand the role of each one on specific features. In order to reduce the samples and to exploit as much as possible the experimental measurements, specific points in the parameter space have been selected, avoiding the classical trial and error experimental analysis. By expressing the material formulation in terms of two parameters, i.e the GNP wt% concentration, x_1, and the CNT wt% concentration, x_2, the array of the input parameters to use in the analysis is $x = (x_1,x_2) \epsilon \mathbb{R}^2$. The values considered for both parameters are chosen by uniformly discretizing the interval $x_1,x_2 \in [0,12]$, defined according to possible percolation threshold, with the constraint on the total wt% concentration of $0 \le x_1 + x_2 \le 12$ addressed for rheological constraint. The last constraint reduces the region of variation of the parameter space, the x_1-x_2 plane, to the triangle described by the red dots in Figure 1, sampled with 15 sets in the 5-level full-factorial design.

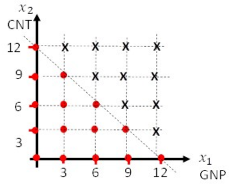

Figure 1. Discretized 5 level parameter space used to define the required experimental samples according to the constraint.

The experimental analyses are then performed on these selected configurations. The same points are used to derive an interpolation of the experimental data, with Response Surface Methodology (RSM), and exploited in the optimization procedure. For example, if the main goal is the maximization of the electrical conductivity σ, the optimization algorithm is applied to the RSM interpolation of the measured DC conductivity $f_1(x_1,x_2)$, suggesting the solution $x_1=0$ and $x_2=12$.

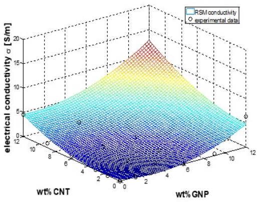

Figure 2. RSM interpolation of σ as a function of fillers percentage (colour-map) together with the experimental data (black circles).

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4. References

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