# Graphene-based advanced adhesives with high thermal and electrical conductivity

S. Tsantzalis[1], C. Kostagiannakopoulou[1], K. Kouravelou[2], A. Vavouliotis[2], A. Baltopoulos[2], V. Kostopoulos[1] and Ugo Lafont[3]

[1]Applied Mechanics Laboratory, Department of Mechanical Engineering and Aeronautics, University of Patras University Campus, 26500, Patras, GREECE
[2]Adamant Composites, Agias Lavras & Stadiou Str., Platani-Patras, 26504, GREECE
[3]ESTEC, European Space Agency (ESA), Keplerlaan 1, 2201 AZ Noordwijk, Netherlands

In recent years, graphene and graphene-based materials have been under investigation since they combine the intermediate level cost and layered structure of nanoclays with the superior mechanical, thermal and electrical properties of carbon nanotubes. The layered structure of such materials provides reinforcement in two directions and a 2-D path for phonon transport which is expected to be more effective compared to the 1-D offered by CNTs in improving mainly the thermal properties. In addition, due to its high aspect ratio and surface area, is promising conductive filler in producing electrically conductive polymer composites with low percolation threshold. Graphene-based polymers possess many potential applications in radiation, EMI shielding, antistatic, packaging, sensors, fuel cells and other various fields. Toward this direction, the most widely used graphene nano-species are graphene nano-platelets (GNPs). In particular, GNPs are disk-shaped graphite particles which are usually obtained by rapid heating of a graphite intercalation compounds (GICs). The resulting material is composed of two or more layers of graphene planes, with a platelet thickness ranging from 0.34 to 100nm.

As the multifunctional performance of adhesives is of great importance for aerospace applications, an extensive study was carried out with the purpose of enhancing thermal and electrical conductivity of insulating adhesives by using GNPs. The most important key to gain the desired material properties is to obtain well dispersed nano-reinforced adhesives with separated nano-particles. In order to fully utilize the unique properties of GNPs, appropriate dispersion procedure has to be applied. In this case, 3-Roll Milling/Calander was preferred in order to incorporate different contents of GNPs in the adhesives and achieve the desired dispersion. More specifically, this study presents the results of the production and testing of graphene nano-enhanced epoxy and silicon adhesives. Several parameters were tested targeting to the best nano-modified adhesive materials performance, in terms of balanced thermal, electrical and mechanical properties, and the best formulations for each matrix is highlighted.

The results indicate, as it can be seen in Tables 1 and 2, that GNPs proved beneficial for the improvement of thermal and electrical conductivity of the used adhesives. Quantitatively, 450% and 500% increase of thermal conductivity was achieved in nano-reinforced epoxy and silicon adhesives, respectively, with the addition of GNPs into the reference material. Furthermore, the presence of GNPs enhanced 10 and 11 orders of magnitude the through thickness electrical conductivity of epoxy and silicone adhesives, respectively. Finally, it should be mentioned that thermal and electrical properties of the reference materials improved without diminishing the mechanical behavior of the adhesives.

**Table 1:Thermal, electrical and mechanical properties of epoxy adhesive system**

| EPOXY ADHESIVE SYSTEM | | | |
|---|---|---|---|
| **PROPERTY** | **REFERENCE MATERIAL** | **GRAPHENE-REINFORCED MATERIAL** | **INCREASE** |
| Thermal Conductivity (W/mK) | 0.29 | 1.60 | 450% |
| Electrical Conductivity (S/m) | <1.00E-12 | 2.32E-02 | 10 orders of magnitude |
| Shear Strength (MPa) | 13 | ~9 | - |

**Table 2: Thermal, electrical and mechanical properties of silicone adhesive system**

| SILICON ADHESIVE SYSTEM | | | |
|---|---|---|---|
| **PROPERTY** | **REFERENCE MATERIAL** | **GRAPHENE-REINFORCED MATERIAL** | **INCREASE** |
| Thermal Conductivity (W/mK) | 0.14 | 0.84 | 500% |
| Electrical Conductivity (S/m) | 1.00E-12 | 1.12E-01 | 11 orders of magnitude |
| Tear Strength (MPa) | 11 | 10 | - |