Polymeric composites with improved thermal conductivity for AM applications

D. Mirabile Gattia*, G. Corallo, A. Di Schiavi, C. Giuliani, R. Mancini
Department for Sustainability (SSPT), ENEA, CR Casaccia, Via Anguillarese 301, 00123 Rome, Italy
* Corresponding author: daniele.mirabile@enea.it

Polymeric materials have interesting properties as low density and corrosion resistance. On the other side, they have very low thermal conductivity (≈ 0.2 W/mK). Nevertheless, these materials are used to realize heat exchangers for specific applications with reduced heat loads and when lightening is necessary. In previous work, we realized plate heat exchangers by Stereolithography (SLA) 3D printing using photocurable resins in order to prototype a new heat exchanger with improved internal geometry. Once the geometry has been optimised, the thermo-fluid dynamic results have shown how with small increases in thermal conductivity it is possible to significantly implement the heat exchanged. In our case, with a thermal conductivity of few W/mK it would be possible to reach about 80% of the heat exchanged with a similar heat exchanger in stainless steel.

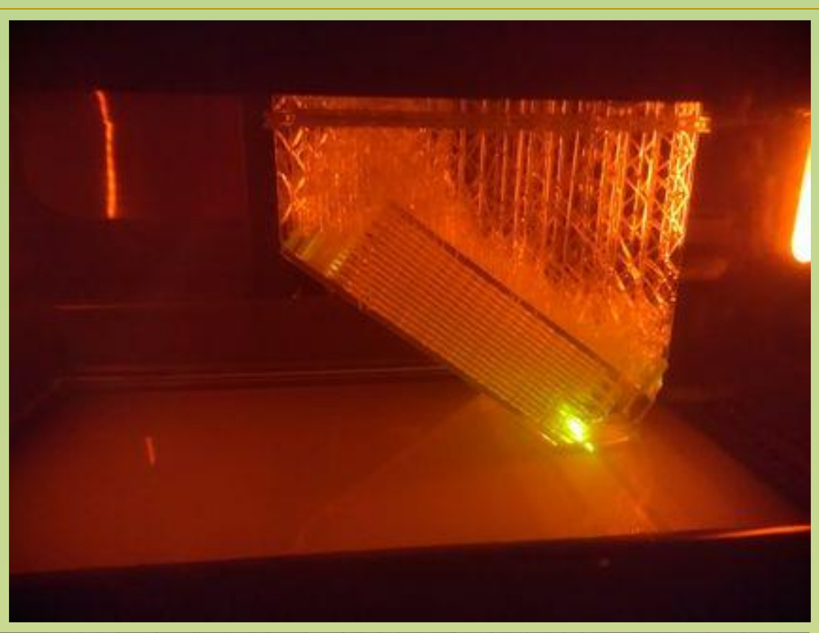
In this work we report about the attempts to increase the thermal conductivity of photo-curable resins by the mean of different inorganic fillers in the form of particles with even sub-micrometric dimensions. The presence of fillers in the resin alters its absorption of UV radiation, generally used in these machines, and consequently also the photopolymerization reaction. These preliminary results will be at the base of the development of a modified resin for SLA process for heat exchanger 3D printing. The activity is funded by the Program Agreements with the Italian Ministry of Economic Development "Advanced materials for energy".

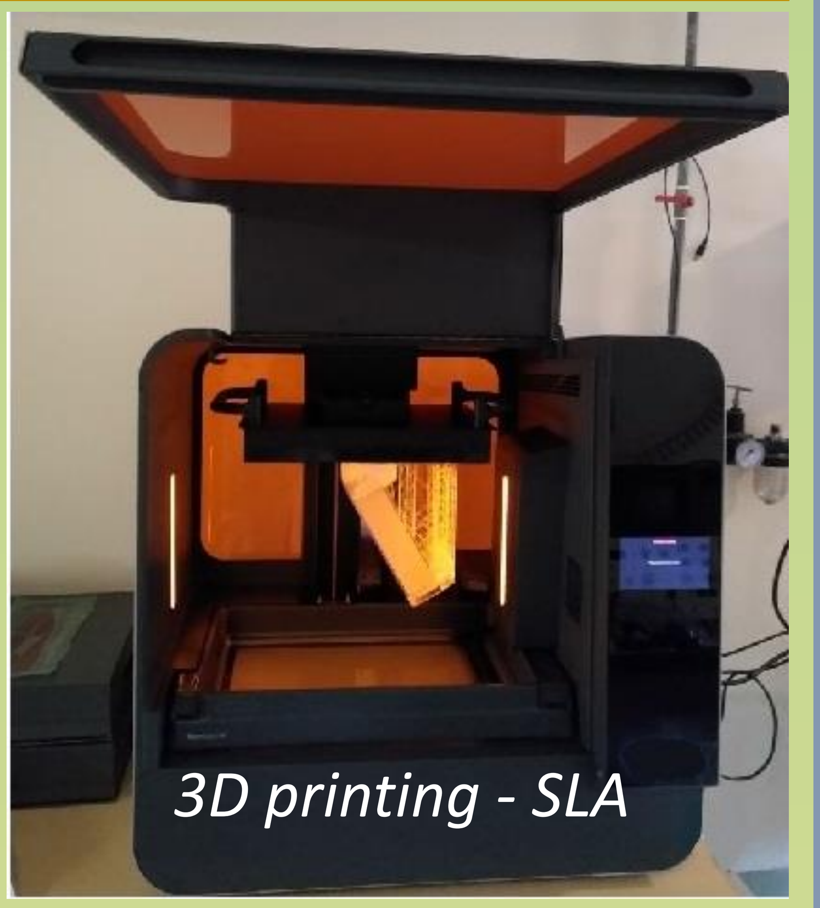
Heat exchanger realized by 3D printing

- Highly convoluted geometries;
- Improved heat exchange efficiency;
- Customization: modification of internal geometry and dimensions by simply modifying a CAD model;
- Computer Aided Design optimization also by means of software simulating liquid flow and thermal behaviour;
- Useful for different applications;
- Rapid testing

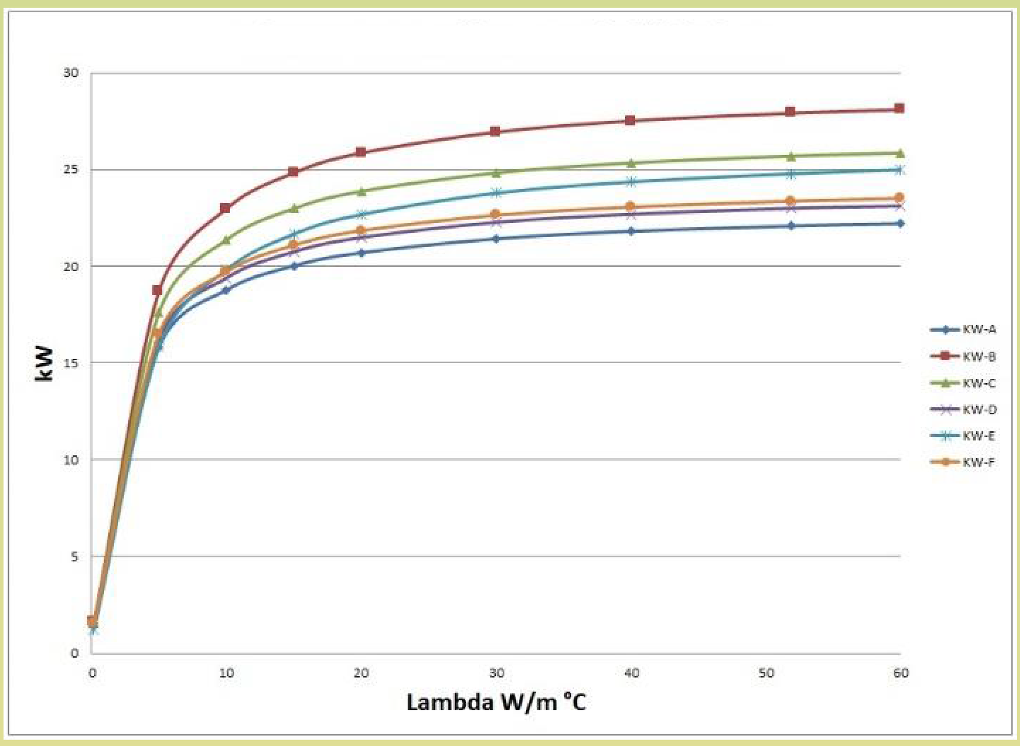
Heat exchanger testing

- Use of a dedicated test bench;
- Determination of global heat transfer coefficient;
- Determination of pressure drops;





Heat exchanger realized by SLA



Power heat exchanged vs thermal conductivity

Considerations

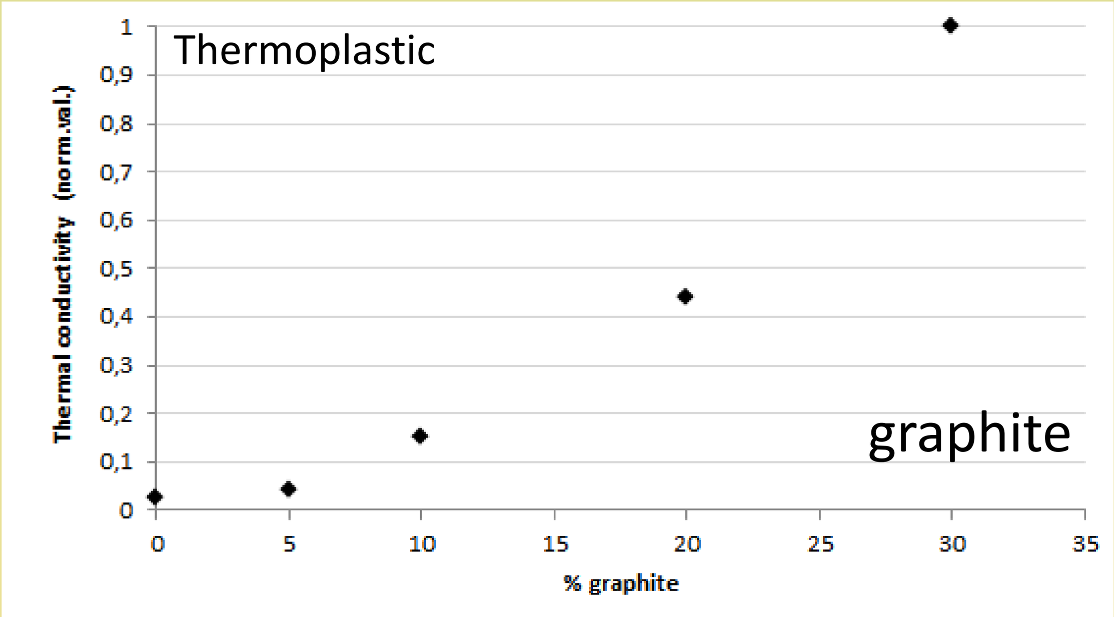
- Polymeric materials have low thermal conductivity (≈ 0.2 W/m/K);
- From Heat Exchangers testing: low increases in thermal conductivity allow high increases in heat transferred;

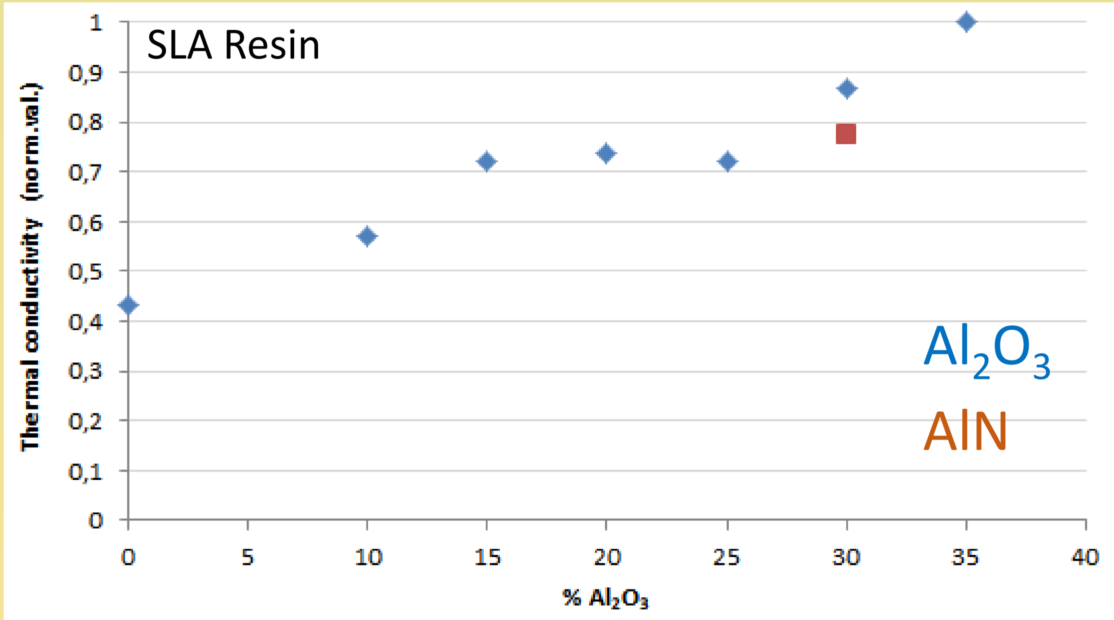
$$\frac{1}{Ud} = \frac{1}{h_1} + \frac{s}{k} + \frac{1}{h_2} \qquad \frac{1}{Ud} \cong \frac{s}{k}$$

Improvement of thermal conductivity of resins is necessary

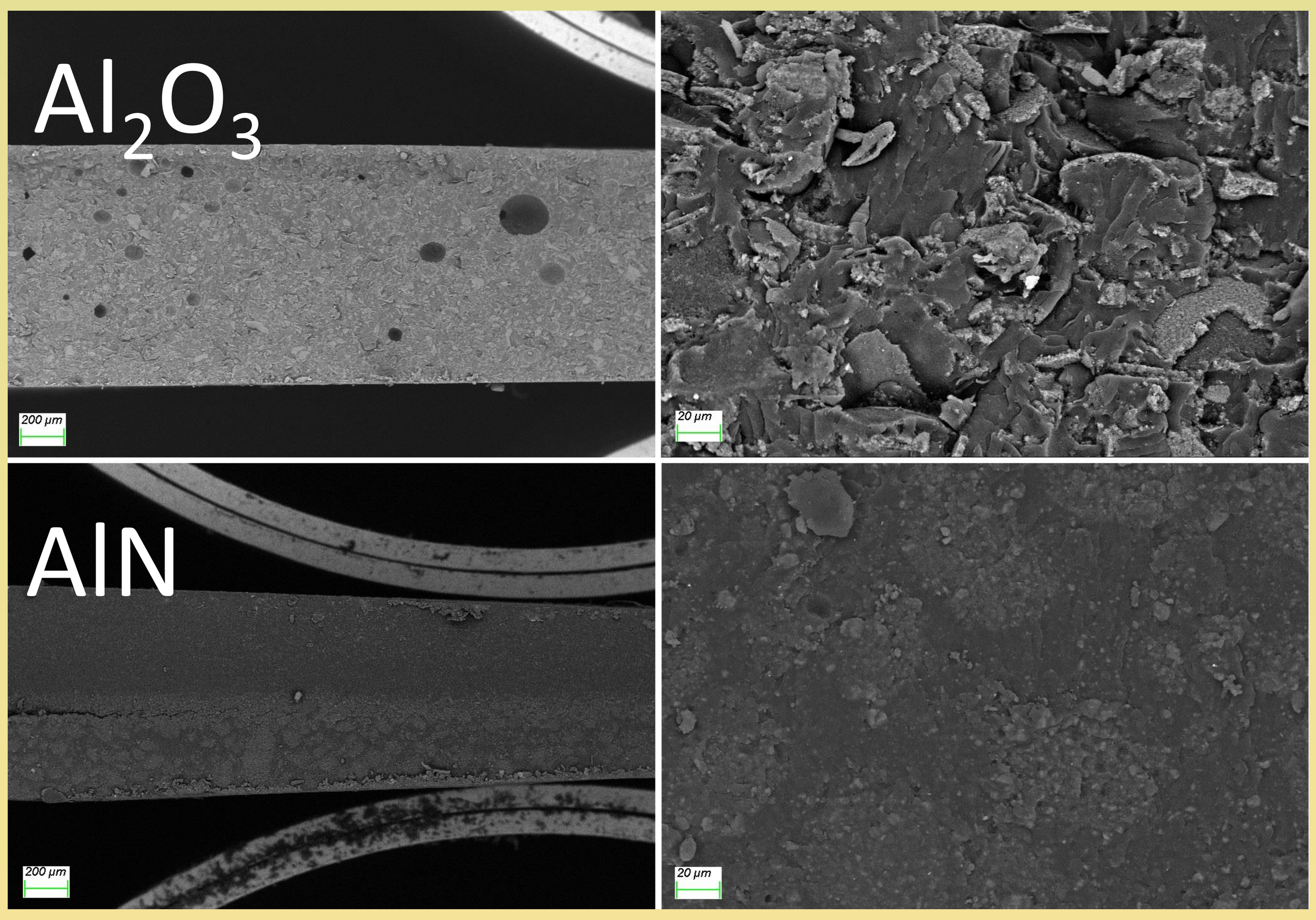
- It could be possible to reach about 80% of the heat exchanged with a similar heat exchanger in stainless steel;
- Possible approaches are:
  - use of high density and high conductivity particles (metals or metal alloys);
  - use of low density and medium conductivity particles (carbon nanostructures, ceramics: oxides, nitrides, borides [1,2])
- Main limitations are related to material dispersion and alteration of properties of photocurable resins

Material	k (W/mK)
Al_2O_3	20-30
AlN	130-260
graphite	25-470





Thermal conductivity vs filler content



SEM images:

- Presence of particles aggregates;
- Presence of porosities;
- Suitable dispersion of aggregates ;
- Photo-cured resin and no cracks;
- Suitable wettability of the filler

Conclusions: 3D printing allows to realize componens with highly convoluted internal geometries. Dramatic heat transfer improvements could be obtained by increasing thermal conductivity of polymeric materials of few W/mK. In this work diffferent approaches have been carried out to modify photo-curable resins' properties: dispersion of carbon nanomaterials and of ceramic materials. Work is in progress to: improve homogeneous particles dispersion, stability, and 3D printing processability.

Ref.: [1] S.-L. Chung, J.-S. Lin, Polymer Composites, 39 (2018) E1951-E2610 / [2] S. Choi, J. Kim, Composites Part B: Engineering, 51 (2013) 140-147

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