Improved thermal conductivity in polymeric composites for Additive Manufacturing

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Additive Manufacturing (AM) allows realizing parts with complex geometries. In some components, as heat exchangers, highly convoluted channels for fluids are required to achieve suitable heat transfer. Generally, metal alloys are used to assembly heat exchangers, but also polymers are used for specific applications as in the case of corrosive fluids and when weight reduction is required. The critical aspects of polymers are their low mechanical properties and extremely low thermal conductivity (≈0.2 W/mK). For this reason, the wall thickness separating the fluids can reach 0.05 mm in the case of polymeric hollow fiber heat exchanger. In previous activities, we used stereolitography (SLA) to realize heat exchangers and implement inner geometries by rapid prototyping. The same heat exchangers have been realized in stainless steel by Laser Powder Bed Fusion process. Both the metal and polymeric heat exchangers have been qualified on a test bench. The results demonstrated that increasing thermal conductivity of polymeric material to few W/mK could result in achieving 80% of heat exchanged in a similar heat exchanger in stainless steel. For this reason in this work are reported the results obtained by attempting to improve the thermal conductivity of photo-curable resins for SLA and Digital Light Processing (DLP) and of thermoplastic materials for Fused Deposition Modeling (FDM). The results demonstrated that in these materials the thermal conductivity could be largely improved by the use of suitable fillers in the form of micro and nano-powders.
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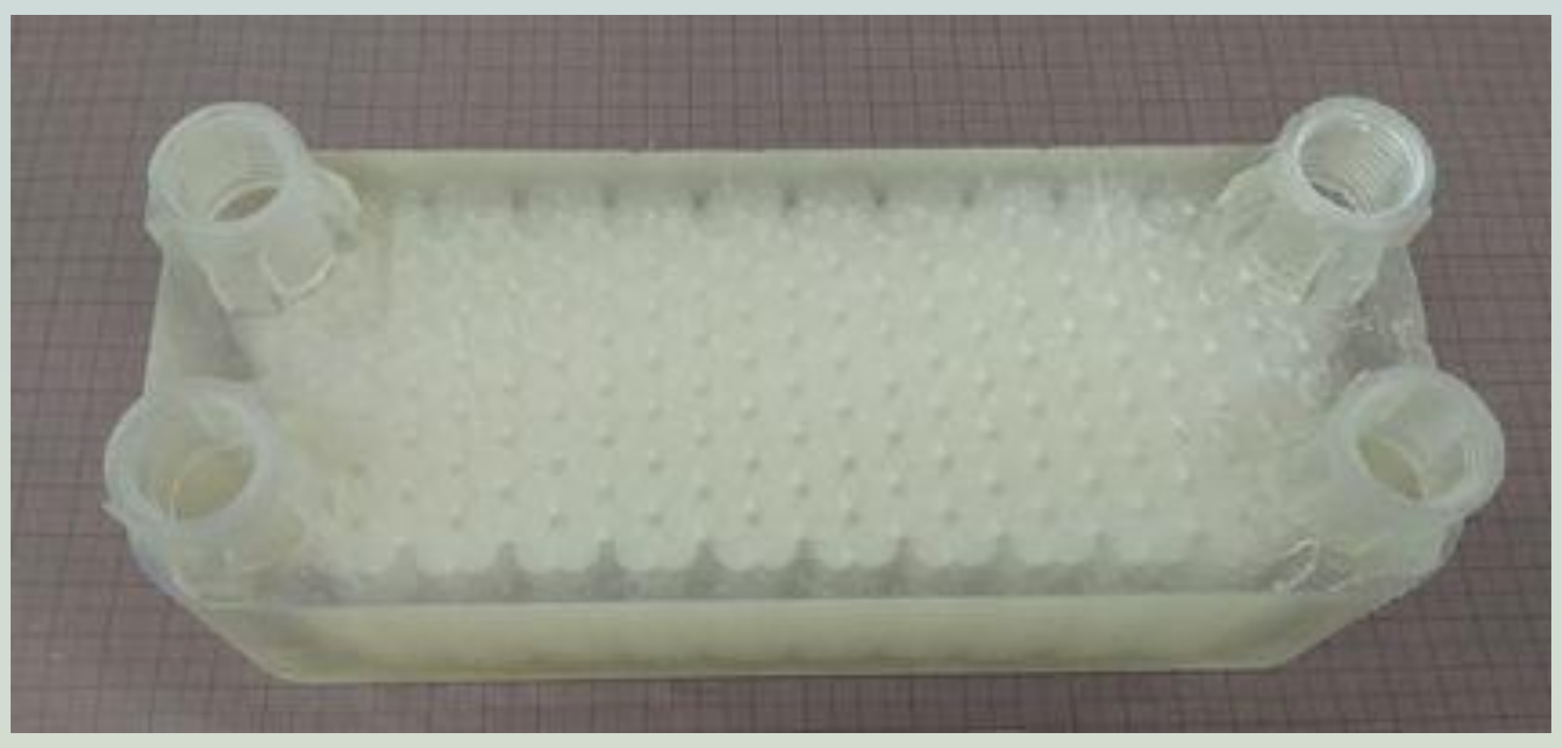
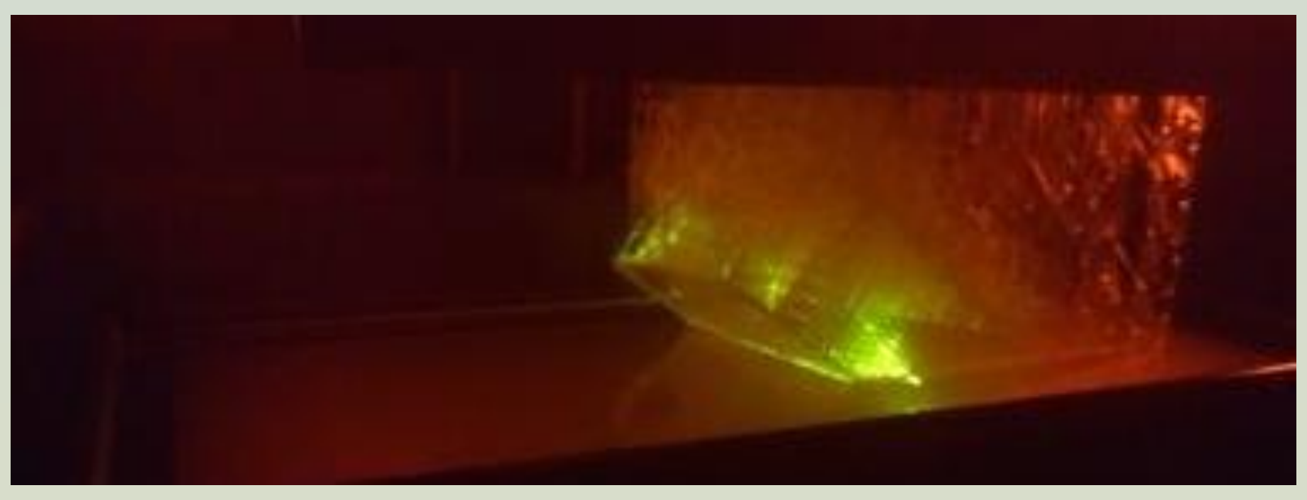
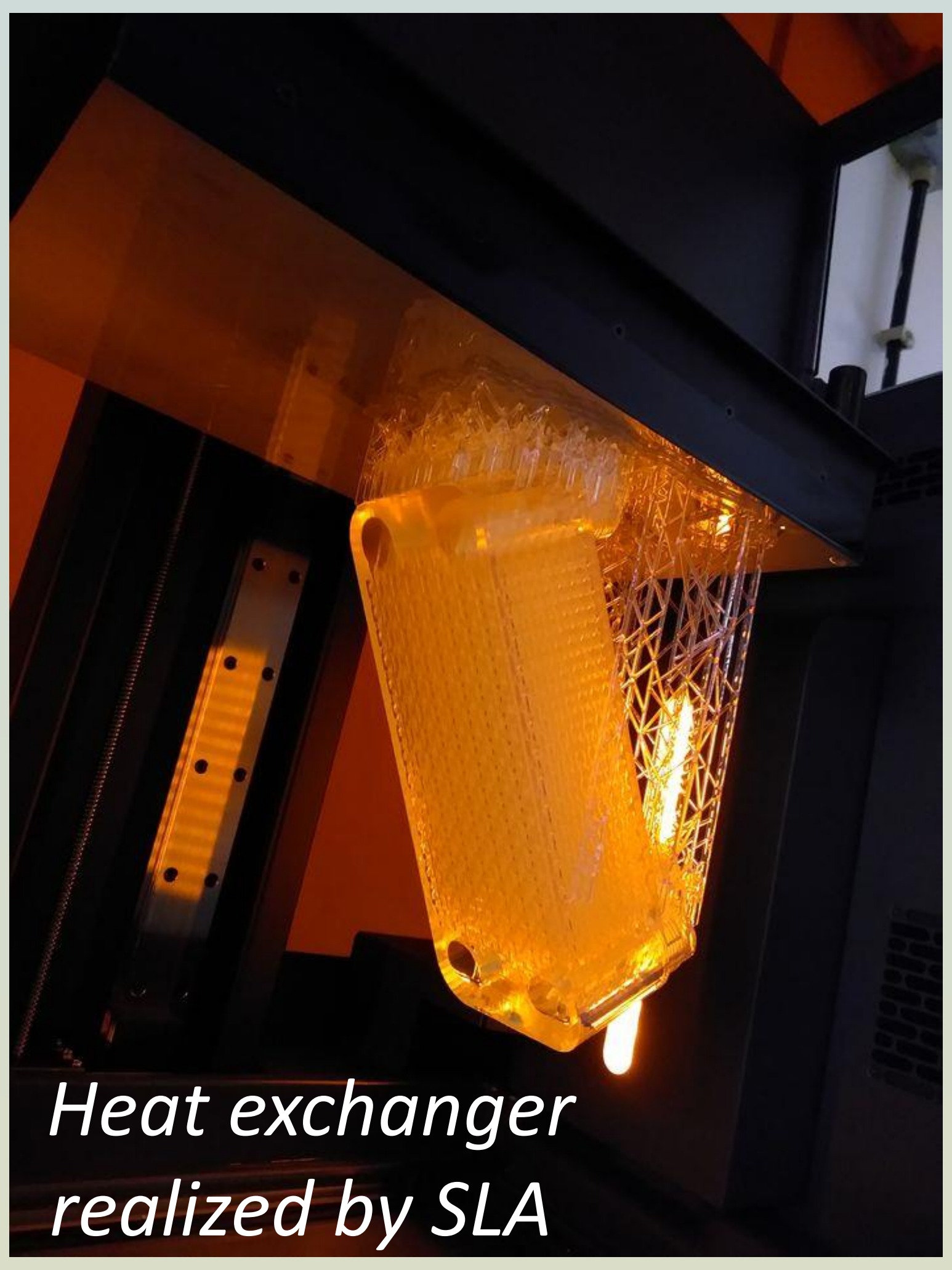
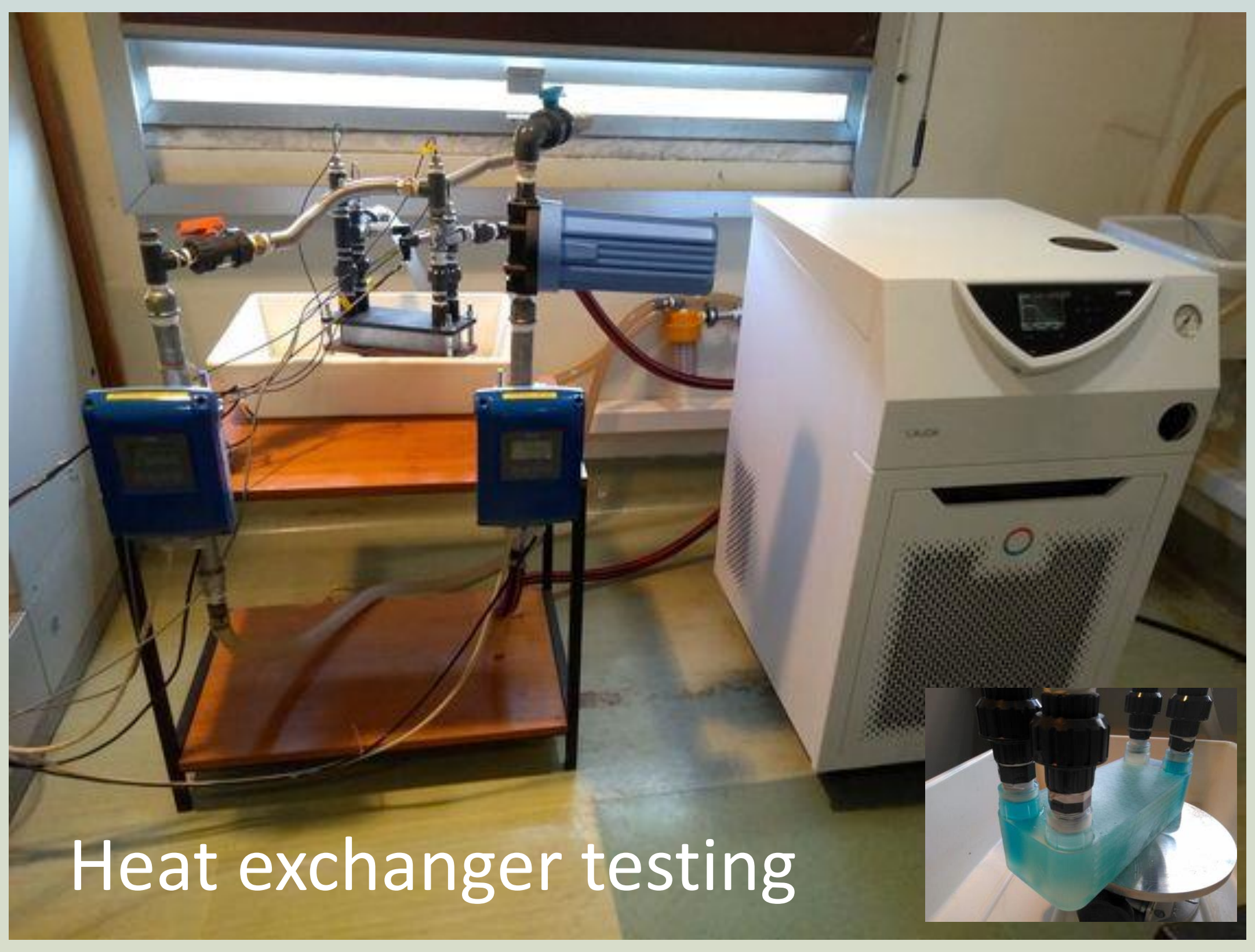




3D printing SLA



Heat exchanger realized by SLA



Heat exchanger testing

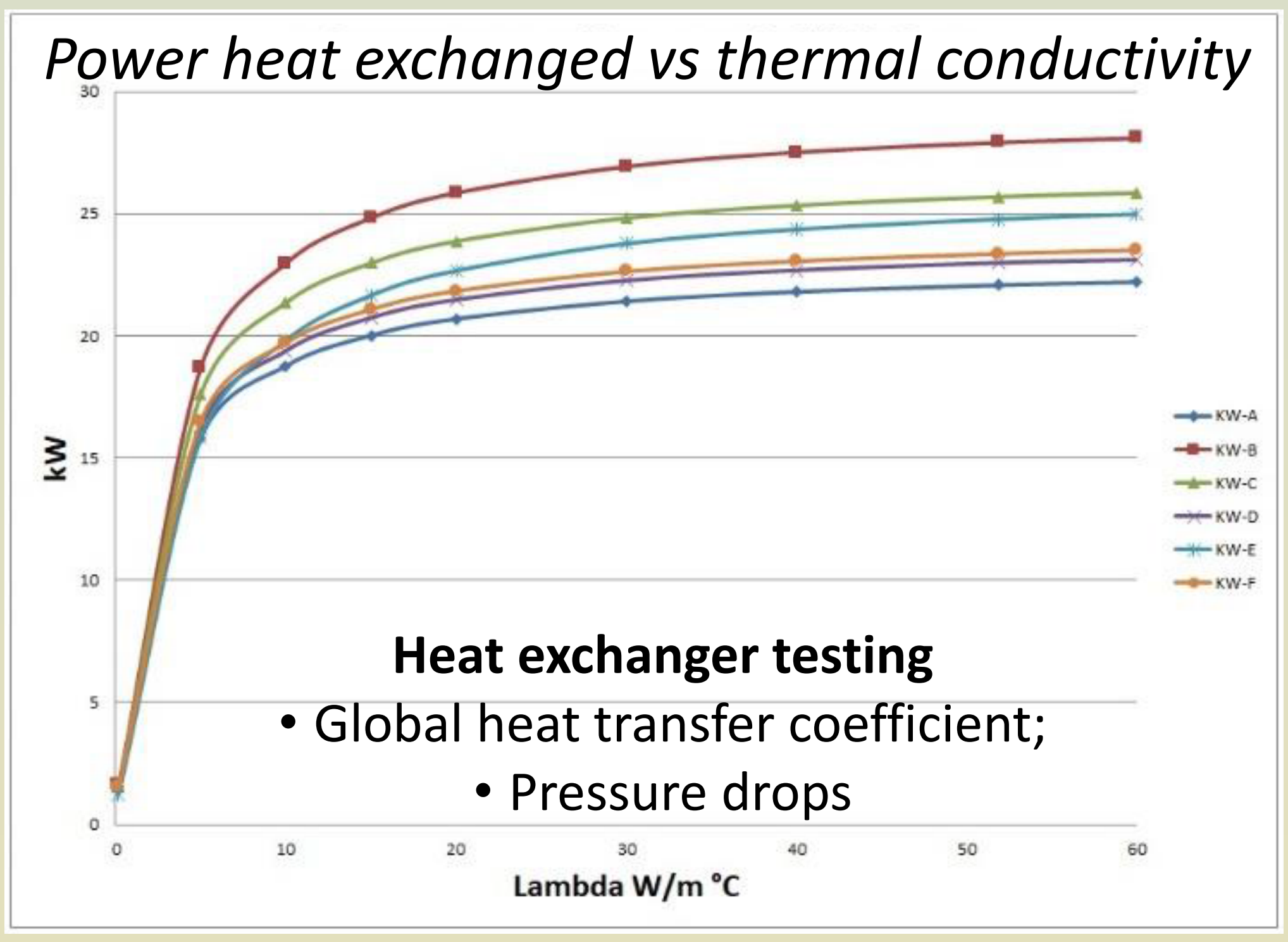
Why 3D printing of heat exchangers?

- 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;
- Highly convoluted geometries;
- Improved heat exchange efficiency;
- Useful for different applications;
- Single piece: no assembly

- Polymeric materials: **low thermal conductivity** (≈ *0.2 W/m/K*);
- Heat Exchangers testing: small increases in thermal conductivity = large increases in in heat transferred

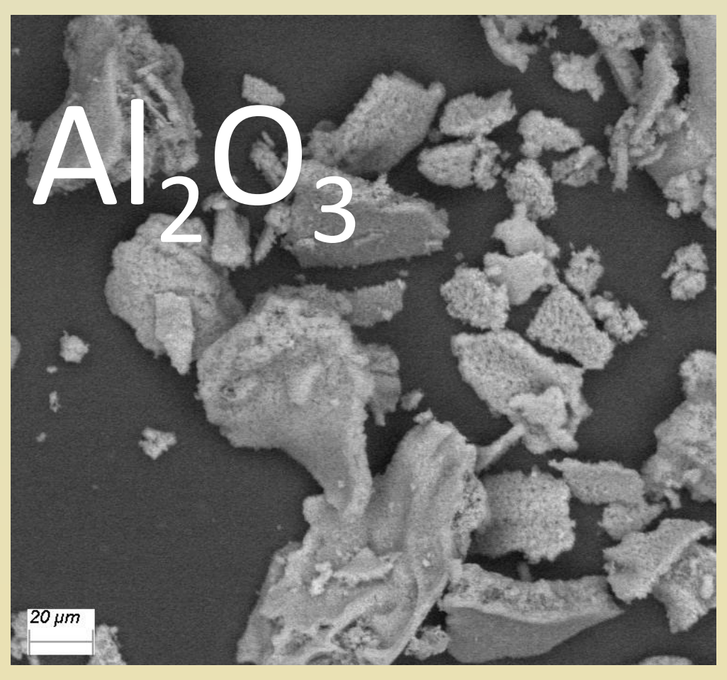
$$\frac{1}{Ud} = \frac{1}{h_1} + \frac{s}{k} + \frac{1}{h_2} \qquad \frac{1}{Ud} \cong \frac{s}{k}$$

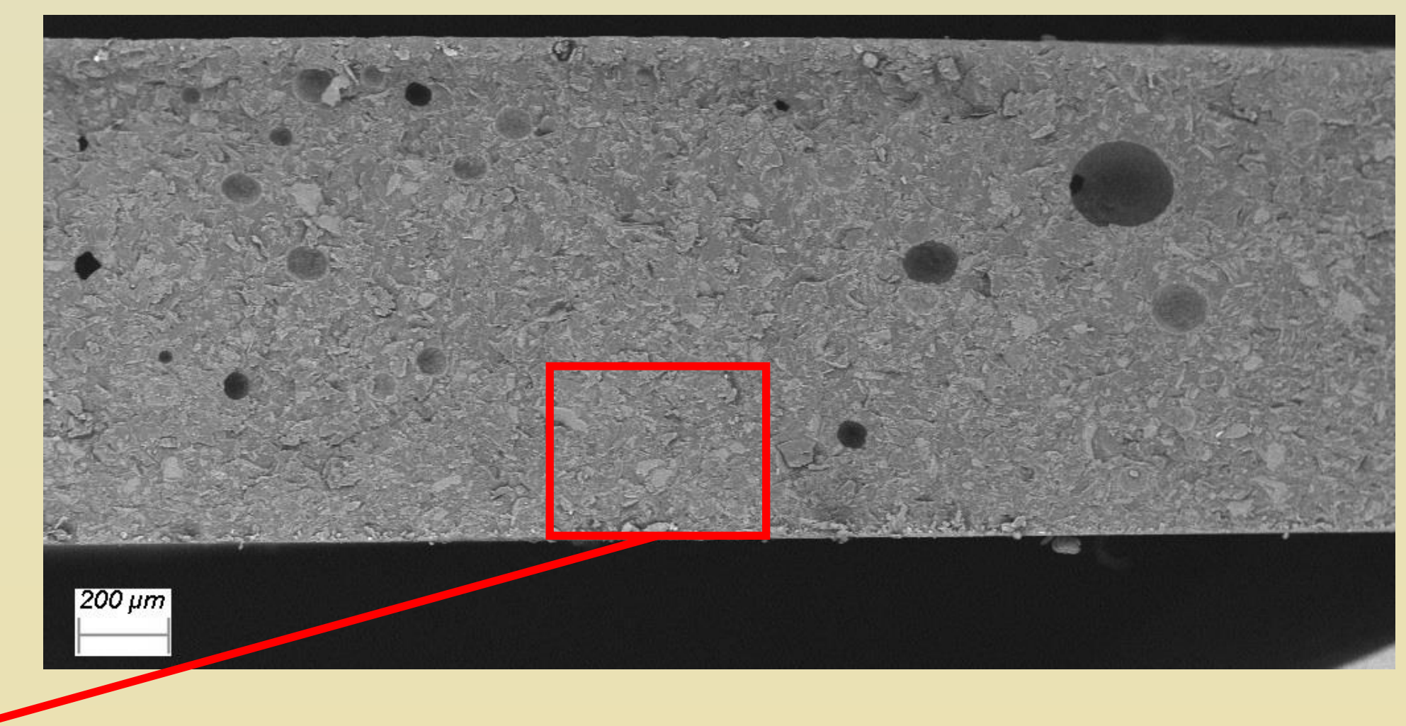
Power heat exchanged vs thermal conductivity

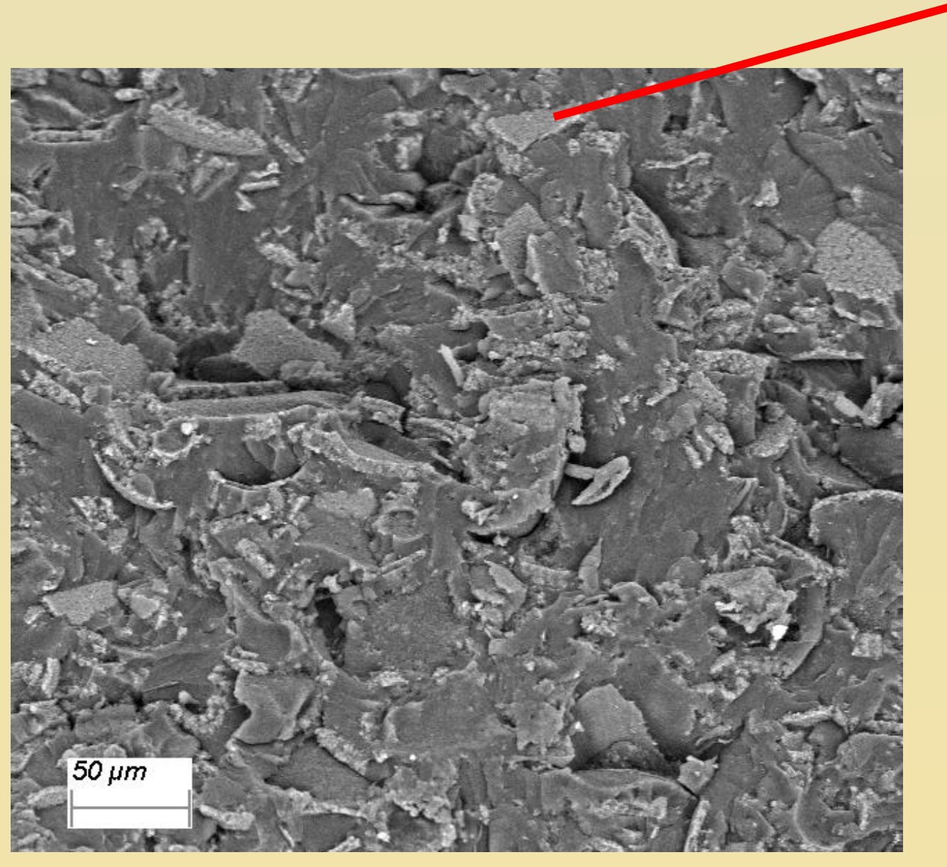


Heat exchanger testing
- Global heat transfer coefficient;
- Pressure drops

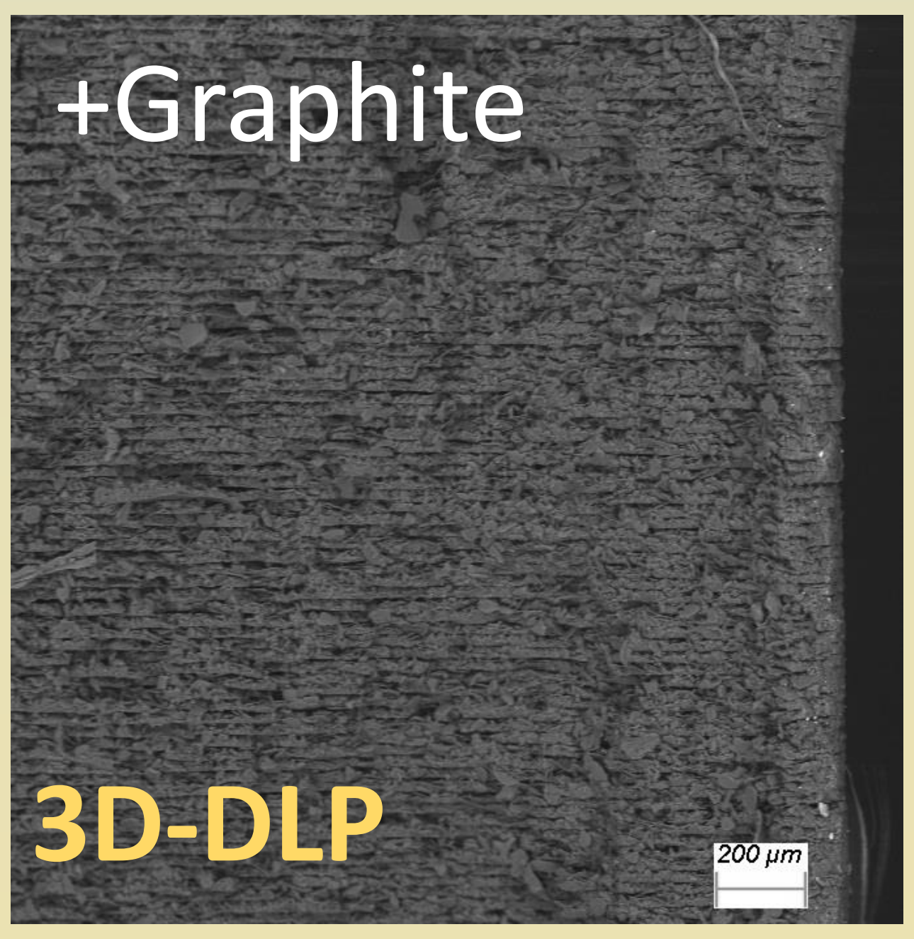
Main objective of the research: improving thermal conductivity of polymeric materials for AM

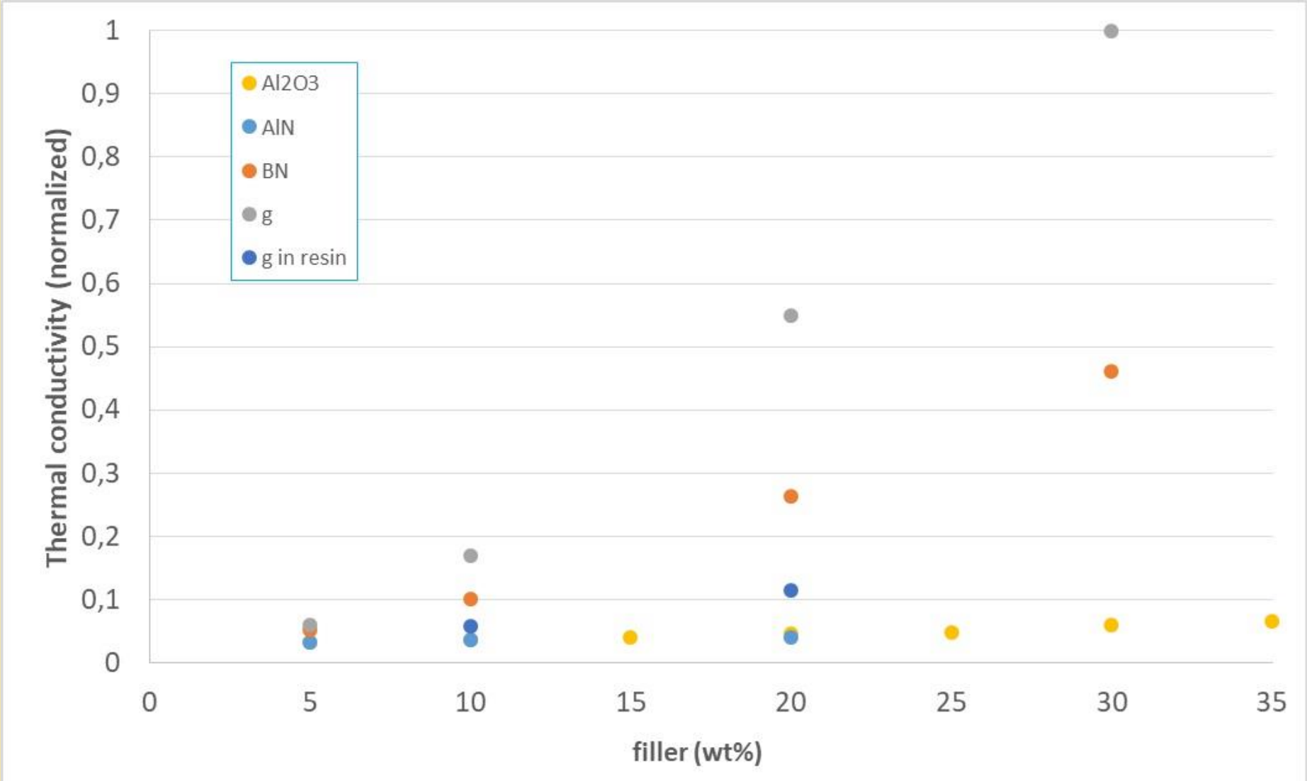




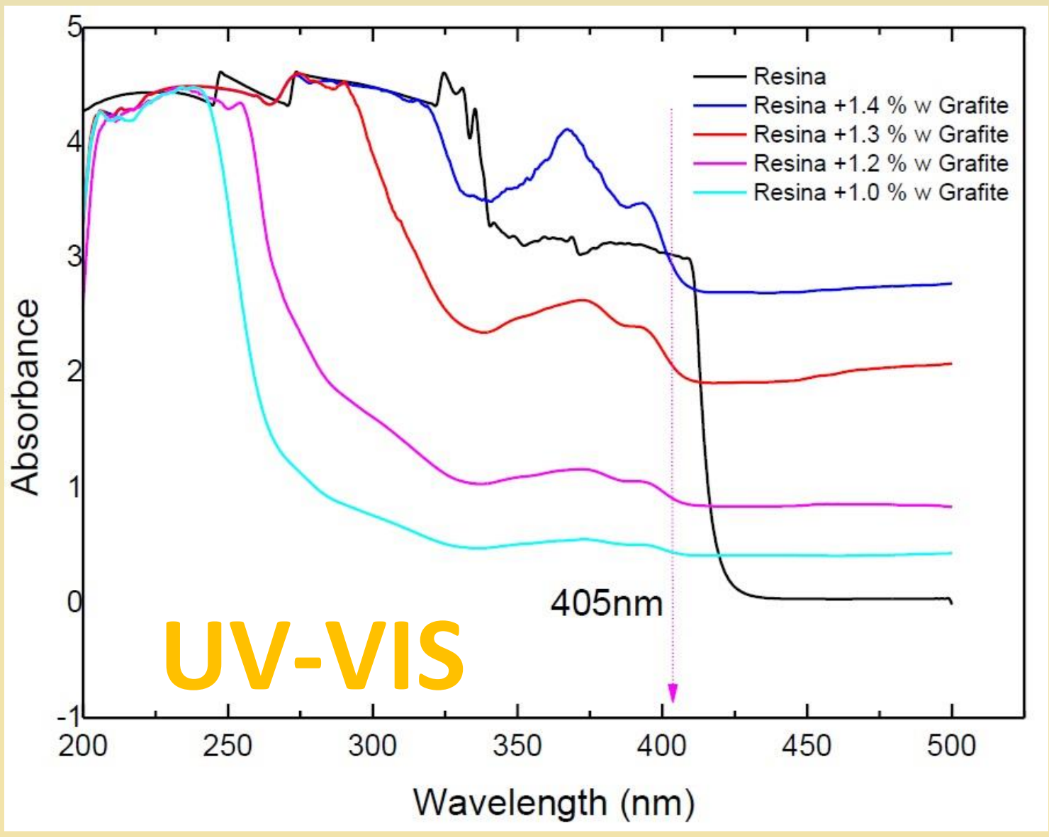


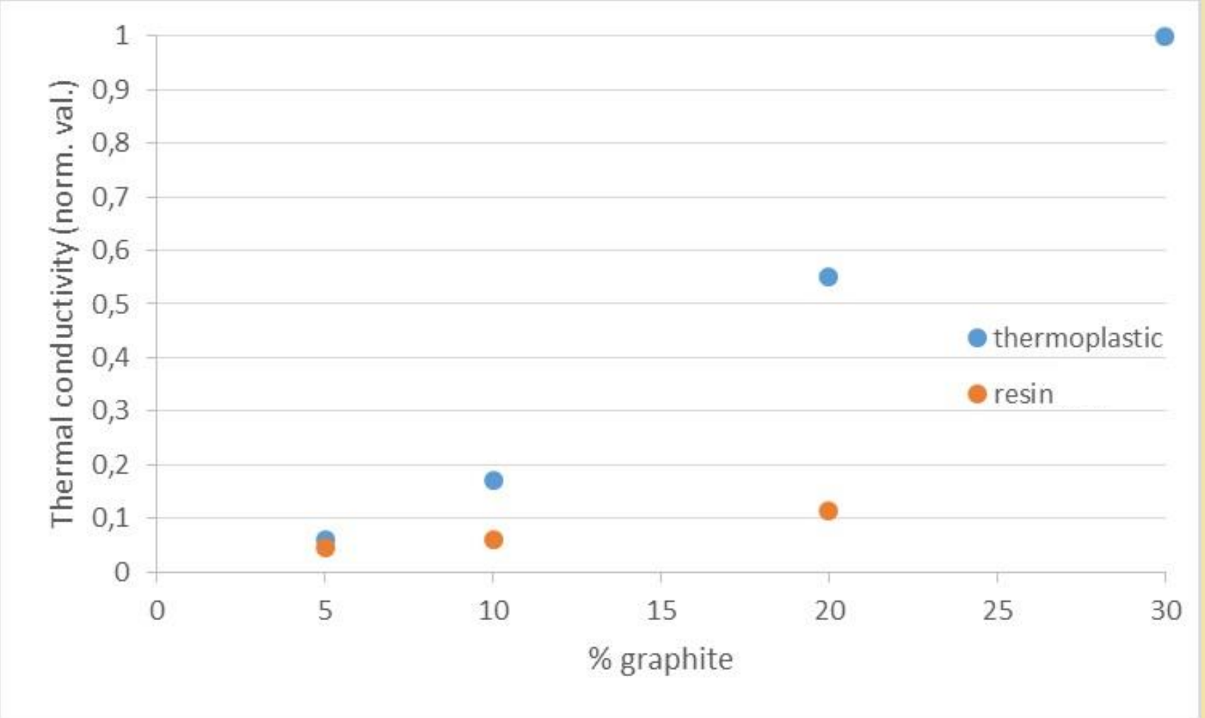
Material	k (W/mK)
Al_2O_3	20-30
AlN	130-260
BN	3-740
graphite	25-470





Thermal conductivity vs filler content





Generally particles of materials with low density and high thermal conductivity are used to improve thermal properties of polymers: carbon nanostructures, ceramics: oxides, nitrides, borides [1,2]

The activity focused on Al_2O_3, AlN, BN and graphite.

Main limitations are related to **material dispersion** and alteration of properties of **photocurable resins**.

Microscopic investigation revealed:
- Particle agglomeration;
- Presence of porosities;
- Suitable dispersion of aggregates
- Photo-cured resin and no cracks;
- Suitable wettability of the filler

Conclusions: Highly convoluted internal geometries can be realized by Additive manufacturing (AM). Polymeric heat exchangers have been realized by SLA and tested on a dedicated test bench. Large improvements in heat transfer of heat exchangers realized by AM (SLA, DLP, FDM etc.) could be obtained by increasing thermal conductivity of polymeric materials of few W/mK. In this work, materials for AM have been modified by the use of dispersion of suitable particles: carbon based and ceramic materials. Measures, performed with hotdisk method, revealed improved thermal conductivity in thermoplastic and photo-curable resins useful for FDM, DLP and SLA processes.

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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