# Final Report

## Project acronym: *Reliable GF-3D*

## Project number: *PTJ: 03XP0165A/B/D*
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## M-ERA.NET Call 2017

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## 2. Publishable project summary

Additive manufacturing (AM) enables the production of complex and highly customized parts without the need of tooling or specialized labour. Amongst the AM techniques, fused filament fabrication (FFF) is the most widely utilized, due to low cost of materials and machinery. In FFF technology, the component is built up layer by layer from a meltable plastic. A thermoplastic round filament is continuously conveyed through a heated and movable extruder nozzle, melted and deposited on the already solidified part of the printed structure. The additive manufacturing method results in an inhomogeneous and hierarchically built micro- and mesostructure in the final component. As a rule, the potential of the base material cannot be fully exploited in such component, and the mechanical performance in many current applications often does not come close to the level of homogeneous injection molded parts. Significant improvements are possible through more targeted process control. While rapid developments are taking place both on the material side (filaments) and in the direction of very fast processes, large components or the use of continuous fibers, there are less knowledge available systematically addressing the causal relationships between the numerous process parameters, the resulting microstructure in the component and the macroscopically measurable mechanical properties. Such knowledge is becoming increasingly important to design and produce reliable and high quality individual FFF parts exposed to high mechanical loads and, therefore, was the main focus of this project.

An approach was developed to systematically relate printing parameters, part design and machine conditions with resulting interlayer mechanical strength. Furthermore, using this approach, a possible solution to this problem was also investigated on amorphous, semi-crystalline and fibre reinforced polymers. The interface temperature between filaments was shown to be highly correlated to the re-heating effect of newly deposited material on adjacent filaments. These re-heating effects, in turn, are inherently linked to part design and chosen deposition path. The re-heating phenomena also accounted for a large part of the calculated welding times, emphasizing the importance of design in the final properties of 3D printed parts. With the welding times, it was possible to calculate the interlayer adhesion of each print. For the amorphous polymer, full adherence to the healing theory was achieved, whereas, for the semi-crystalline polymers, a large discontinuity was found at higher welding times. This deviance from the healing theory was attributed to the crystallization phenomena, which is enhanced by higher temperature gradients and hinders the molecular movement necessary for interface healing.

Based on the above, various hardware concepts to improve the resulting microstructure were investigated and experimentally validated. As an example, an add-on pre-heating device that increased the interlayer strength of FFF parts in 184% was developed, manufactured, tested and patented. To further significantly increase mechanical stiffness and strength, continuous fibre reinforcement can be applied to the process. Within the project a new high performance filament was developed which can provide fibre volume fraction up to 50%. A new 3-d printer demonstrator was designed to showcase the potential of printing continuously reinforced components.

Moreover, an enhanced X-ray inspection concept was developed enabling full (near in-line) observation during manufacturing using specific fast scanning modes. Full non-destructive inspection combined with an adequate assessment of the mechanical relevance of micro defects is a prerequisite to establish FFF technology for reliable structural parts.