Final Report

Project acronym: *ELAM*

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M-ERA.NET Call 20*16*

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2. Publishable project summary

The M-era.Net project "Ultrafine eutectics by laser additive manufacturing" ELAM aimed at developing new high strength titanium-iron based eutectic alloys by laser-based additive layer manufacturing (ALM). Although ultrafine eutectics had been subject of research for decades and show remarkable mechanical properties, none of these alloys could be applied for industrial applications since no economically and technically viable processing route existed. Conventional rapid cooling techniques required for the ultrafine microstructure are limited to small components and simple geometries. The pivotal idea of the ELAM project was to apply ALM techniques that inherently possess very high cooling rates and are, thus, ideal for processing ultrafine eutectics and hierarchically structured near-eutectic alloys.

The project encompassed on the one hand alloy design by thermodynamic calculations, process- and phase-field simulations and on the other hand the development of a process chain consisting of powder production and additive manufacturing processes to the point of demonstrator production and demonstrator testing. The development of the additive manufacturing processes laser powder bed fusion (LPBF) and laser metal deposition (LMD) was supported by microstructural analyses and mechanical testing.

Within the project Ti-rich alloys based on the eutectic Ti-TiFe were processed by LPBF whereas Fe-rich alloys based on the eutectic Fe-Fe_2Ti were built by LMD. The LPBF process as well as the LMD process required enhanced pre-heat temperatures for the production of crack-free samples. In addition, advanced inert gas concepts were necessary because the elevated temperatures were critical due to increased oxidation rates.

Besides the expected ultrafine eutectic structures, interlayer boundaries (ILB) were found in the Fe-rich eutectic, which are in fact melt pool boundaries, being a typical meso-scale features of several ALM materials. The ILBs show primary Fe_2Ti particles with a globular morphology being enveloped by the (Fe)-phase. The microstructure of the Ti-rich eutectic systems is inherently more complex due to the eutectoid reaction that was higher than the pre-heat temperature of the LPBF process and, as a consequence, the formation of α-Ti and TiFe from β-Ti occurred. Complementary to the 2D analyses microstructures of both systems have been quantitatively characterized by holographic and ptychographic synchrotron X-ray computed tomography at ESRF.

Compression tests revealed very high strength but also the brittle nature of the material at room temperature. However, both systems show high ductility, while maintaining high strength, at temperatures between 450 and 600 °C.

Exploiting the specific advantages of the ALM processes and the two eutectic systems, two demonstrator types were designed and manufactured, namely compressor wheels by LPBF of Ti-rich alloys and rotatory anvils by LMD of Fe-rich alloys. The centrifugal tests of the compressor wheels where carried out up to speeds at which unbalancing became too high, while the testing of the rotatory anvils was limited by the presence of stress concentrators.

In summary, this proposal represented the first attempt to produce ultrafine Ti- and Fe-based eutectics by ALM, spanning activities along the entire manufacturing chain from fundamental materials development, powder production, ALM process and post-treatment developments to demonstrator testing.