Final Report

Project acronym: *NADEA*

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5129

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2. Publishable project summary

In NADEA a new family of duplex materials was developed starting from cobalt-free high entropy alloys $Al_xCrFe_2Ni_2$ with further specific alloying additions, e.g. Mo. Focus was placed on the development of dual-phase, Duplex-type micostructures along the additive manufacturing routes LMD (laser metal deposition) and L-PBF (laser powder bed fusion) including heat treatment steps. Casting processes were upgraded in parallel as conventional reference processes. The R&D tasks were aligned along the entire value chain(s), with the aim of bringing the technological maturity level from TRL2 to TRL4.
The research was targeted in particular on alloy development, powder production and process engineering as to achieve well equilibrated dual-phase microstructures and assess the material properties, here including mechanical properties as well as functional properties like corrosion and wear resistance.

The starting point at the beginning of the project was the quaternary alloy $AlCrFe_2Ni_2$, which was described by Dong et al. in a short article[1] [Dong2016] and which showed a good balance between strength and ductility in the as-cast state. Due to the high chromium content, good corrosion properties were also expected, such that the development was targeted at applications for high-performance pumps.
The joint research effort on alloy design was targeted to further develop the alloy composition following the demands and limitations from particular process conditions: For L-PBF processing with no baseplate preheating the alloy $Al_{0.8}CrFe_2Ni_2$ was developed as best-performer. For LMD processing with baseplate preheating an alloy close to $AlCrFe_2Ni_2$ was identified as best-performer. For casting processes, the alloy composition is not that critical, and $Al_{0.8}CrFe_2Ni_2$, $AlCrFe_2Ni_2$ as well as $AlCrFe_2Ni_2Mo_{0.1}$ were successfully cast into either sand molds or ceramic shell molds.

As a highlight research result, the consortium developed a deep understanding of microstructure formation in this type of alloys, especially during the solid state BCC➔FCC phase transformation. This phase transformation depends on the spinodal decomposition of the parent BCC phase, giving rise to a variety of morphological features of the resulting FCC phase. The resulting FCC displays (i) Widmanstätten plates, (ii) a novel vermicular morphology or (iii) micro-platelets. All microstructures were characterized by SEM / EBSD and TEM / HRTEM in depth. The vermicular microstructure shows a characteristic new orientation relationship between the two phases FCC and BCC, which was previously unknown.

All investigated materials show remarkably good mechanical properties with a pronounced strain hardening and good elongation at fracture. Exceptional fatigue strength was observed during cyclic tests in HCF and LCF conditions. The novel materials outpass duplex-steels and superduplex steels in this respect. The Charpy V-notched specimens however show notch toughness values ranging fro 30 to 50 Joule, being just above the requirements. The wear and corrosion resistance are competitive with super-duplex steels, however potentiodyanamic tests in 3.5NaCl solution reveal an earlier onset of pitting in anodic polarization.

The project was successfully completed with TRL4 and opens up clear exploitation options. As proof of a successful realization of TRL4, demonstrator components were successfully manufactured both additively and by casting. Several impeller designs were realized and, in the case of Otto Junker GmbH, a large pump housing.

[1] Dong, Y., Gao, X., Lu, Y., Wang, T., and Li, T. (2016). A multi-component AlCrFe2Ni2 alloy with excellent mechanical properties. Mater. Lett. 169, 62–64. https://doi:10.1016/j.matlet.2016.01.096.