The fatigue response of the IN939 superalloy prepared by additive manufacturing

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Background incl. aims
Ni-based superalloys have become a time-honored high-temperature material. The first steps in their development were directed towards optimizing the manufacturing processes, chemical composition, and microstructure. The additive manufacturing (AM) technologies, also commonly called 3D printing, emerged and changed some classical approach. AM offers several advantages such as design freedom, very good efficiency of material usage, possibility to create hierarchical structures, crystallographic texture etc. Recently, the parameters of Laser Powder Bed Fusion (L-PBF) were optimized for the nickel based superalloy IN939. The main aim of the contribution is to address fatigue and thermomechanical fatigue (TMF) properties to the specific microstructure of the IN939 prepared by the L-PBF.

Methods
Microstructural analysis was performed by the mean of scanning and transmission electron microscopy. The Tescan Lyra 3 FEG/FIB scanning electron microscope equipped by the energy dispersive spectroscopy and backscattered electron diffraction detector (EBSD) was used the microstructural analysis, texture measurement and grain size evaluation. The Talos 200i transmission electron microscope equipped by the energy dispersive spectroscopy was adopted for the analysis of typical cell structure and strengthening particles.
The material was prepared by AM method. To achieve ideal microstructure, the IN939 was exposed to three-step heat treatment: solution annealing at 1175°C for 45 minutes followed by two step precipitation hardening 1000°C/6h + 800°C/4h.

The isothermal fatigue at 800 °C with symmetrical push-pull cycle was measure. The two modes of TMF, in-phase and out-of-phase loading were used for testing. During in-phase loading, the maximum mechanical loading corresponds to the maximum temperature, while in the out-of-phase mode, the maximum temperature corresponds to the minimum loading.

Results
Microstructural analysis revealed elongated grains with a preferential orientation <001> parallel to building. IN939 incorporates a considerable amount of a reinforced gamma prime phase that is embedded coherently within the matrix.
The fatigue properties at 800 °C and response to the TMF loading were measured. Obviously, the TMF is more detrimental than pure fatigue in very low cycle region, especially the in-phase TMF loading. The differences between particular loading modes decreases with decreasing strain amplitude. The EBSD measurement revealed no grain coarsening or changes in crystallographic texture. The fatigue cracks propagated predominantly along grain boundaries.

Conclusion
Following conclusion based on obtained results can be drawn :
- The typical AM microstructure consist of dislocation cells with crystalographic texture was revealed.
- The In-phase TMF mode seems to be most damaging in very high strain amplitude region, while the diffences in fatigue life in low strain amplitude region are almost negligible.
- The crack propagation path along grain boundaries was documented.

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Keywords:

IN939 superalloy, fatigue, additive manufacturing