Executive Summary:
Phase and strain monitoring during direct metal deposition of Ni-superalloy by in-situ neutron and synchrotron diffraction (PhaNi-Neutron)

The PhaNi-Neutron project, conducted by the Fraunhofer Institute for Material and Beam Technology IWS, focused on the phase and strain monitoring during the laser based direct energy deposition (DED-LB/M) of Ni-superalloys using in-situ neutron and synchrotron diffraction techniques. The project aimed to enhance the understanding of the solidification processes and phase evolution in additive manufacturing, specifically for the nickel superalloys IN718 and IN625.

Key Objectives:

1. **Phase Precipitation Analysis:** Investigating phase kinetics during DED to better understand the relationships with process parameters, temperature distribution and microstructure.
2. **Strain Build-up Monitoring:** Utilizing neutron diffraction to characterize dynamic stress and strain evolution during the DED process.
3. **Traditional Laboratory Characterization:** Correlating microstructural details with in-situ and ex-situ measurements to enhance understanding of material properties.

Main Tasks:

1. **System Interface Planning:** Development of improved system setups and interfaces for synchronized data acquisition, enhanced temperature monitoring and process repeatability.
2. **Material Characterization:** Comprehensive characterization of feedstock materials and DED samples through various techniques, including EDX, SEM, and EBSD.
3. **In-situ Measurements:** Execution of in-situ synchrotron and neutron measurements to capture real-time data on phase kinetics, stress and strain evolution and thermal dynamics during the deposition process.
4. **Data Analysis:** Comparison of collected data to identify correlations between process parameters, microstructural characteristics, and mechanical properties.

Results Achieved:

- An improved system and measuring set-up were developed that enabled stable process regimes with synchronized data acquisition, comprehensive sample temperature monitoring and good process repeatability
- The set-up was successfully employed for in-situ synchrotron and neutron measurements
- Traditional laboratory characterization was conducted to verify synchrotron data and process repeatability
- In-situ synchrotron measurements were processed and analyzed, providing insights into the solidification kinetics and phase formation of IN625 and IN718.
- Findings show that the solidification front and phase evolution kinetics are significantly influenced by the process parameters, with notable differences observed between slow and fast deposition rates.
- Analyzed ex-situ neutron measurement data indicates a minor impact of the process parameters on the stress and strain in the substrate-deposit interface region.
- A comprehensive and statistically validated dataset for a clearly defined geometry with known boundary conditions for DED-LB/M of IN625 and IN718 were achieved that could be a valuable input for the tuning and validation of process simulation models.

Unachieved Objectives:
Despite the best efforts of IWS staff, certain objectives could not be fully realized within the project timeframe:

- The in-situ neutron data analysis was not completed due to unforeseen challenges, including delays in measurement campaigns and technical issues with data processing.
- The comprehensive understanding of the dynamic strain evolution during DED, as initially proposed, remains incomplete.

Future Work:

- Further analysis of neutron data is planned if funding can be obtained, to enhance the understanding of internal stresses and their impact on part integrity.
- Data from the project could be utilized in follow-up activities to improve predictive models for DED process simulations.

This project represents a significant step forward in the field of additive manufacturing, providing a framework for future research and development activities looking to employ in-situ synchrotron or neutron measurements. The insights gained will contribute to the optimization of DED processes, ultimately benefiting the aerospace and engineering industries.