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Neutron scattering contribution to understanding and development of high-temperature materials

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High-temperature materials are essential for energy conversion in turbines, which also includes conversion to kinetic energy for transport. Their continued development is a prerequisite for more efficient use of the available fuel resources. Understanding the basic properties of promising new materials as well as optimization of the existing ones can ensure an environmentally friendly operation of turbines.

Neutron scattering helps significantly in development of such advanced materials. Its particular advantage is the possibility to investigate structural and microstructural evolution in situ under operational conditions of materials.

Examples of structure and microstructure characterization of several types of materials important for high-temperature applications by neutron scattering are shown. First example is a contribution of in-situ Small-Angle Neutron Scattering (SANS) to understanding the behavior of Ni-base superalloy. It was found that additional γ'-precipitates are formed in Inconel-type superalloys after reheating above 570℃. These small precipitates influence mechanical properties of the alloy. Temperature dependence of their size and volume fraction as well as the kinetics of precipitate growth at 700 and 800℃ were determined.

Secondly, investigation of porosity in ceramic thermal barrier coatings by means of combined in-situ and ex-situ SANS is presented. Such coatings enable an increase of temperature in the combustion chamber of turbines employing Ni-base superalloys by more than 100 K. The pores strongly affect the thermal and mechanical properties. The in-situ measurement at high temperatures revealed that an unexpected population of nanometer-sized pores is created at about 800℃, which later sinters under simulated operational conditions at 1200℃.

Structure and microstructure evolution of newly developed Co−Re alloys at high temperatures studied by in-situ neutron diffraction and SANS is presented. Co−Re-base alloys strengthened by carbides are candidates as new high-temperature material for gas turbines (foreseen temperature during operation ≈1200℃). TaC carbides were found to be a promising option for strengthening phase as they do not dissolve up to at least 1300℃. The stability of the matrix and of the TaC phase as well as the influence of boron content on the microstructure of Co−Re alloys at high temperatures were investigated.

Although a variety of material parameters can be presently obtained, further improvement of neutron scattering techniques capability for development of high-temperature materials is desirable. Particularly, sample environment for in-situ and in-operando experiments can still be improved. For example, thermo-mechanical tests at foreseen operation temperatures of Co−Re alloys in vacuum or inert atmosphere would be of advantage. Testing environment for BEER@ESS engineering diffractometer planned also with this outlook will be presented.

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