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Technology qualification of W based water-cooled target modules for Wendelstein 7-X

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Wendelstein 7-X, located at IPP in Greifswald, Germany, is the largest stellarator in the world with modular superconducting coils. It started plasma experiments with a water-cooled first wall including a carbon fiber reinforced carbon (CFC) based divertor in 2022, allowing for long pulse operation.
As a next step, plasma performance of a stellarator has to be demonstrated with carbon-free plasma-facing materials to ensure low tritium retention. Therefore, a project was launched in 2021 to develop a next generation divertor with a plasma facing surface made of W based material. One task is to optimize the geometry of the plasma-facing surface to prevent overloads, improve particle exhaust and maximize impurity retention away from the core plasma. In parallel, a second task is the structural design of a W based target module and the qualification of suitable manufacturing technologies, which is conducted in the framework of the EUROfusion funded WPDIV program. Similar design constraints are imposed as for the current CFC divertor in terms of design heat load (10 MW/m^2), plasma-facing surface shape, cooling water supply and target module size and weight.
This paper presents the progress on the qualification of the manufacturing technologies of the design presented in [Fellinger: 2023]. The main technology under qualification is an additively manufactured CuCrZr heat sink made using laser powder bed fusion (LPBF) with a functionally graded plasma-facing coating of W/Cu or WNiFe/Cu, applied by cold gas spraying or low-pressure plasma spraying. Alternative to a coating, a mosaic of so-called sandwich tiles is diffusion bonded or brazed onto the heat sink. These flat tiles exist of W or WNiFe onto which a thin soft copper layer is galvanized or diffusion welded. As the normal direction of the tiles varies over the plasma-facing surface, an external uniaxial jacket cannot apply contact pressure during bonding. Therefore, the Cu side of the tiles are diffusion bonded using a paste with nano-sized Cu particles at moderate temperatures (< 550℃) and an external pressure that can be realized by springs or other technologies. Alternatively, the tiles are brazed at high temperature (~980℃) without pressure using a Cu/Au braze foil. Notably, Ni89P11 and Ag based brazes have been successfully been tested in high heat flux (HHF) tests in the past [Tokitani: 2021, Böswirth: 2024], but P is not compatible with CuCrZr and Ag is not allowed in W7X.
The paper shows results of thermal and mechanical properties of WNiFe and LPBF made CuCrZr, and the He leak tightness of LPBF samples. Furthermore, microstructural analyses are presented on bonding trials with nano-paste, coated samples and on sandwich tiles before and after HHF tests. Finally, thermal and hydraulic design simulations were performed and confirmed by results of hydraulic tests and HHF tests on LPBF made CuCrZr heat sinks. These tests demonstrated that the heat sink can handle the design heat load with robust margin towards the allowed pressure drop and CuCrZr limit temperature.

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