Tungsten fibre-reinforced copper composites for high temperature and high heat flux applications

The present offer describes a tungsten fibre-reinforced copper (Wf-Cu) composite material concept that exploits the properties of commercially available drawn high-strength tungsten fibres embedded in a high conductivity copper matrix. With this approach, materials that can be realised exhibit outstanding property combinations regarding conductivity and strength. Such a composite material can hence be of interest in general regarding demanding high temperature and high heat flux applications. The development of Wf-Cu was being performed by fusion R&D institutions as potentially advanced heat sink materials for highly loaded, actively cooled plasma facing components.

Description of the technology

In many areas of technology, composite materials are being increasingly applied due to the fact that with such materials, not only superior properties compared with monolithic materials can be achieved but also tailored anisotropic properties can be realised in order that a material can specifically meet service conditions. In this context, materials that allow operation at high temperature are essential for various industries including e.g. material processing and production or power generation. Often, demanding high temperature applications require materials that combine good mechanical and thermophysical properties, i.e. a high thermal or electrical conductivity with high strength properties.

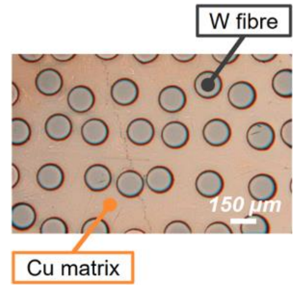

Fig.1 Metallographic microsection of a unidirectionally reinforced Wf-Cu composite material

The Wf-Cu composite described within the present offer can be regarded as a material concept that extends the operational range of existing engineering materials in terms of realisable material property combinations, mainly with respect to conductivity and strength. In this sense, Wf-Cu materials might also be relevant with respect to other high temperature and high heat flux applications outside the field of nuclear fusion technology. Associated with the development work regarding Wf-Cu, know-how has been elaborated with respect to the manufacturing of such composites in terms of fibrous tungsten preform preparation by means of textile technological methods (Figure 2) as well as composite material fabrication by means of industrially viable liquid copper infiltration methods.

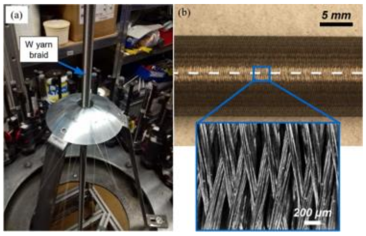

Fig.2 (a) Image illustrating the circular braiding with tungsten fibres and (b) microscopic images of a corresponding braid.

An essential step regarding the development of Wf-Cu in the area of nuclear fusion technology was demonstrated through the fabrication of actively cooled plasma-facing component mock-ups that comprised Wf-Cu pipes as central heat sink (cf. Figure 3). Several of such mock-ups were successfully high heat flux tested under relevant loadings which ultimately demonstrates the viability of Wf-Cu metal matrix composites as materials for high heat flux applications.

Fig.3 Plasma-facing component mock-up with Wf-Cu heat sink pipe

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Innovation and advantages of the offer

The mechanical strength of a Wf-Cu material was determined in hoop direction on a pipe specimen. These experiments yielded a hoop tensile strength of 1200 MPa at room temperature and 1060 MPa at a test temperature of 200 °C, respectively. If these numbers are classified into the landscape of existing high temperature materials it can be stated that the tested Wf-Cu material exhibits strength properties in the range of Nickel-based superalloys which are materials that are e.g. usually used in the most highly loaded parts of gas turbine engines. However, such Nickel-based alloys typically exhibit thermal conductivities of around 20 W/mK. In comparison, the conductivity of Wf-Cu is significantly higher as a result of the comparable high conductivities of W (173 W/mK at 20 °C, 110 W/mK at 1000 °C) and Cu (401 W/mK at 20 °C, 334 W/mK at 1000°C). In this sense, the innovation of the Wf-Cu composite is due to the fact that this material offers a unique combination of material properties in terms of conductivity and strength.

Non-fusion Applications

The unique combination of material properties in terms of conductivity and strength can qualify the material with respect to demanding high temperature and high heat flux applications, as e.g. in high-temperature heat exchangers or combustion chambers of aerospace propulsion engines. Possibly, Wf-Cu might also be of interest with respect to nuclear applications.

EUROfusion Heritage

The exhaust of power and particles is currently considered as one of the ultimate challenges in view of the design of a future magnetic confinement thermonuclear demonstration fusion reactor (DEMO). One predominantly challenging aspect in this regard is the design and manufacture of divertor target plasma-facing components (PFCs) that have to sustain intense particle, heat and neutron fluxes during fusion operation. Current state-of-the-art water-cooled divertor target PFC designs make use of tungsten as a plasma-facing material while copper alloys are regarded as most appropriate candidate materials for the heat sink of such highly loaded PFCs. However, issues arise when such a design is applied to a DEMO environment. In this context, it has in the literature been underlined that the use of copper alloys as structural heat sink materials in divertor PFCs implies a high design engineering risk mainly due to the behaviour of these materials under neutron irradiation characterised by a pronounced loss of ductility at lower temperatures and a loss of strength at elevated temperatures. In order to address this issue, development work was started and pursued during recent years regarding Wf-Cu composites as potentially advanced heat sink materials for highly loaded, actively cooled PFCs. With such metal matrix composites enhanced material properties can be realised in order that the operating temperature range of PFC heat sinks can be extended.

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