Functionally Graded Materials (FGMs)

A functionally graded transition between two materials with different material properties like thermal expansion increases the reliability of the connection between the two materials and provides the ability to control deformation, dynamic response, wear, corrosion, etc. FGMs can be used to connect many different materials such as metal/ceramic, alumina/zirconia, alumina/steel, tungsten-carbide/steel, tungsten/copper, polymer/concrete, bones/metal, and aluminium/polyethylene.

Description of the technology

In the fusion domain tungsten layers are required as toppings for ferritic/martensitic steel material on the blanket or the divertor in a fusion reactor and they have to be reliably connected to the carrier material. This is a challenge as the two materials differ in their thermal expansion. A continuous transition between the two materials (Functionally Graded Materials; FGM's) is able to drastically reduce thermal induced stresses. The joining of dissimilar materials, with the opportunity to benefit from the properties of two material systems, provides both the ability to control deformation, dynamic response, corrosion, and wear, and the ability to apply FGMs to different complex environments. FGM's have been successfully produced by a variety of techniques, such as electro–deposition, infiltration, sintering, explosive welding, physical and chemical vapor deposition, laser sintering and vacuum plasma spraying. The vacuum plasma spraying technique has been developed at Research Center Juelich.

	Layer thickness	Gradation range	Vacuum	Feasibility
Vacuum plasma spraying	+	+	+	+
Magnetron sputtering	-	+	+	+
Resistance sintering under ultra high pressure	+	+	-	+
Conventional sintering	+	+	+	-
Electro-deposition	-	-	+	?
Laser sintering	+	+	+	?
Infiltration method	+	-	+	?

Fig. 1: Screening of fabrication methods. The feasibility of some methods to produce W/Fe FGMs is unknown yet, but they are appropriate for other materials.

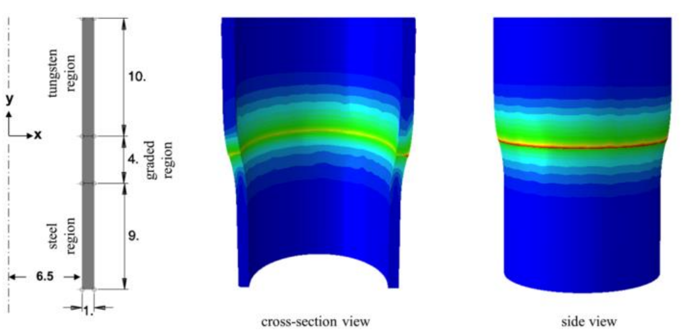

Fig. 2: Deformation through the cooling down after joining of tungsten/steel tubes at high temperature (deformations are amplified in this representation)

An evaluation of these fabrication methods against the four categories layer thickness, gradation range, vacuum and feasibility is given in Fig. 1. The ability to produce thick layers and to realize layers with the full gradation range are regarded as positive process features, because these aspects are important for the successful reduction of thermal induced stresses by a smooth gradation. The vacuum conditions are important for the avoidance of oxides, which otherwise would reduce the joining strength. VPS seems to be a very promising process fulfilling all four criteria. It provides the full gradation range from 0% to 100 %, the deposition takes place at a rather low pressure and sufficient thick layers of up to 1-2 mm are technically feasible.

EUROfusion
TECHNOLOGY TRANSFER PROGRAMME

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Innovation and advantages of the offer

Tests at the FZJ have shown that the functionally graded transition between two materials with different thermal expansion increases the reliability of the connection between the two materials and provides the ability to control deformation, dynamic response, wear, and corrosion. FGMs can be used to connect many different materials such as metal/ceramic, alumina/zirconia, alumina/steel, tungsten-carbide/steel, polymer/concrete, bones/metal, and aluminium/polyethylene.

Non-fusion Applications

Besides the possibility of combining materials with different thermal expansion in the fusion domain where tungsten layers are required as toppings for Eurofer material on the blanket or the divertor in a fusion reactor, there is a huge range of potential domains of application for processes of connecting materials with different properties such as metal/ceramic, alumina/zirconia, alumina/steel, tungsten-carbide/steel, polymer/concrete, bones/metal, and aluminium/polyethylene.

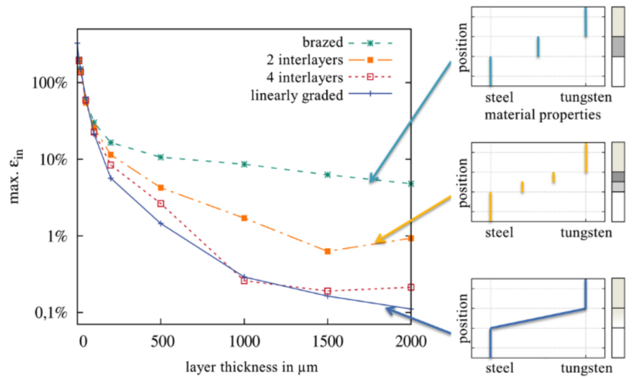

Fig. 3: Inelastic strain reduction within the steel region achieved by the use of functionally graded joints

Fusion Heritage

Tungsten layers are required on top of the ferritic/martensitic steel of the blanket or divertor in a fusion reactor, and these must be reliably connected to the carrier material. This is a challenge as the two materials differ in their thermal expansion. A continuous transition between the two materials (Functionally Graded Materials) has the potential to solve this problem.

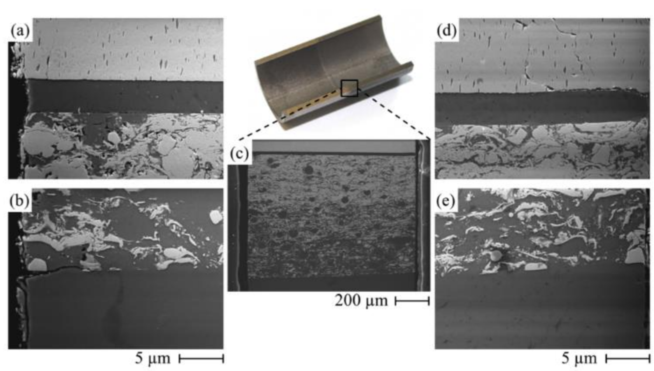

Fig 4: Thermal cycling of vacuum plasma sprayed W/Steel-FGMs between 20 °C and 650 °C

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