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Vacuum plasma spraying of functionally graded tungsten/EUROFER97 coatings for fusion applications

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ABSTRACT

As structural materials for future fusion power plants, reduced activation ferritic martensitic steels as EUROFER97 can be used. Unfortunately, the interaction of the plasma with the steel would result in a limited lifetime, so protective layers are investigated. An excellent protective material is tungsten, as it shows unique properties with respect to low sputtering, high melting points and low activation. However, the mismatch of thermo-physical properties between tungsten and EUROFER97 can lead to large stress levels and even failure.

A possible way to overcome this problem is the use of functionally graded material (FGM). The paper will describe the manufacture of these FGMs by vacuum plasma spraying and their characterization. First of all, two different feeding lines have been used to produce the coatings. A major problem lies in different melting points of tungsten and steel. So the particle size distribution has to be adjusted to achieve sufficient melting of both materials during the spray process. In a second step, the feeding rates were optimized to obtain the wanted amount of tungsten and steel phases in the graded structures. In a thermal spray process, the gradient cannot be made continuously, however it has to be applied in a step-wise manner. In this investigation, samples with 3 and 5 different concentrations (excluding the pure steel and tungsten part) have been produced. The microstructures of these layers have been investigated. In addition, hardness was measured and the residual stress state was determined by the hole drilling method.

1. Introduction

In a future fusion power plant of tokamak type the nuclear fusion reactions will occur inside torus shaped vacuum vessel in a very hot plasma in which the charged particles are confined by magnetic fields. The fast neutrons as the reaction product carrying the major part of the fusion energy are desired to leave the plasma and transfer their energy to the blanket which mainly consists of the plasma facing first wall (FW) and the tritium breeding units (BUs) behind. Despite the magnetic confinement heavy ions might escape the plasma at the edge and hit the FW causing its erosion due to physical and chemical sputtering, surface bubble formation and blistering [1]. Therefore the FW made out of EUROFER, a reduced activation ferritic martensitic (RAFM) steel, shall be protected by a sacrificial coating. As suitable material for the coating, tungsten is considered due to its crucial properties, i.e. particularly high melting point (3422 °C [2],), low sputtering yield, high thermal conductivity, low activation and plasma compatibility.

Coating of a EUROFER component with a tungsten layer however would result in large residual stresses due to the large mismatch in the coefficient of thermal expansion (CTE) between these two materials (tungsten 4.4 10^{-6}/K, EUROFER 1.2 10^{-5}/K [3],). These stresses may cause failure of the coating systems either directly after processing or accelerate its failure during operation. To solve this problem the concept of functionally graded material (FGM) is adopted by introducing an interlayer between the tungsten coat and the EUROFER substrate made of graded tungsten/EUROFER material in which the composition of tungsten is gradually increased from 0% on the substrate side to 100% on the coat side [2,4,5]. Assuming that the mechanical properties are similarly graded according to the linear mixing rule, great potential of a sufficiently thick FG interlayer in reducing residual stresses could be determined by means of comprehensive finite element simulations [6,7].

Different coating techniques have been discussed in the past to deposit thick tungsten coatings. One option is the use of magnetron sputtering [8], however, typically it leads to rather long processing times for obtaining coatings in the several hundred micrometer range. A suitable alternative is thermal spraying. In the past, it has been frequently demonstrated that thermal spraying is a suitable process for the

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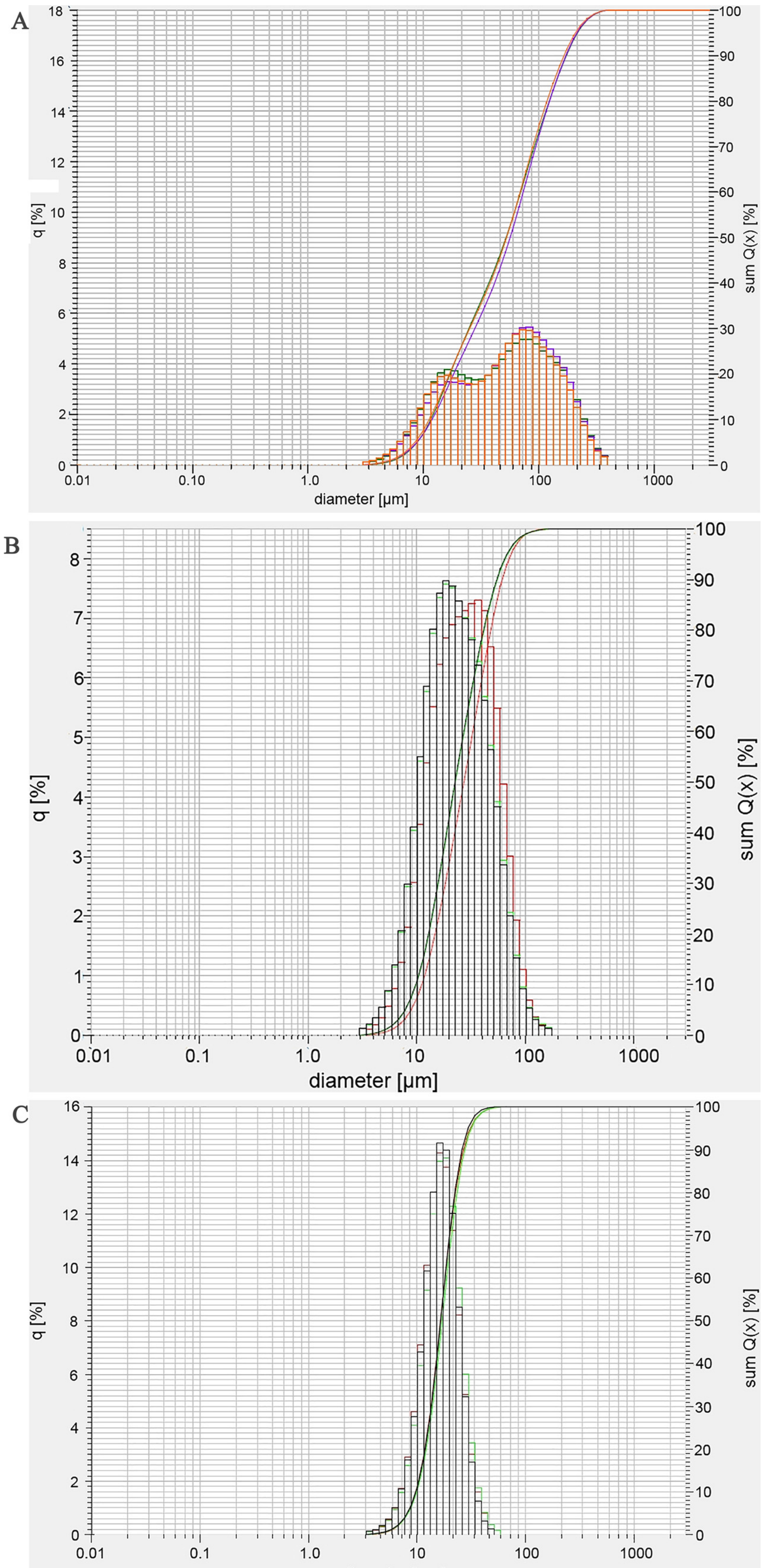

Fig. 1. Particle size distributions of the used EuroFer97 (a unsieved (green without ultrasonic agitation, magenta 3 min ultrasonic agitation, orange 2 times 3 min ultrasonic agitation), b sieved (red without ultrasonic agitation, green 3 min ultrasonic agitation, black 2 times 3 min ultrasonic agitation)) and the tungsten powder (AW3105A1, c (red without ultrasonic agitation, green 3 min ultrasonic agitation, black 2 times 3 min ultrasonic agitation)) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).