22D13

Development of High-Grade VPS-Tungsten Coated on Plasma-Facing Component with a High Heat Load Characteristic
高い耐熱負荷特性を有するVPS-タングステン被覆プラズマ対向機器の開発

Tomonori TOKUNAGA[1], Hideo WATANABE[2], Naoaki YOSHIDA[2], Takuya NAGASAKA[3], Ryuta KASADA[4], et al.
徳永知倫[1], 渡辺英雄[2], 吉田直亮[2], 長坂琢也[3], 笠田竜太[4],
李泳柱[4], 木村晃彦[4], 時谷政行[3], 光原昌寿[1], 檜木達也[4], 中島英治[1],
増崎貴[3], 高畠剛[5], 黒木信義[5], 江里幸一郎[6], 鈴木哲[6], 秋場真人[6]

[1]*Interdisciplinary Graduate School of Engineering Sciences, Kyushu University*
6-1, Kasuga-koen, Kasuga-city, Fukuoka 816-8580, JAPAN
[2]*Research Institute for Applied Mechanics, Kyushu University, Fukuoka, Japan*
[3]*National Institute for Fusion Science, Gifu, Japan*
[4] *Institute of Advanced Energy, Kyoto University, Kyoto, Japan*
[5]*Tocalo Co. Ltd, Hyogo, Japan*
[6]*Japan Atomic Energy Agency, Ibaraki, Japan*.
[1]九州大学総合理工学府(〒816-8580　福岡県春日市春日公園6-1)、[2]九州大学応用力学研究所、
[3]核融合科学研究所、[4]京都大学エネルギー理工学研究所、[5]トーカロ株式会社、[6]日本原子力研究開発機構

To endure very high loads of heat, neutrons, and also plasma particles, it is necessary to develop the high-grade W coating method by vacuum plasma-spraying-technique (VPS). The forming crack in the boundary of W grain stuck at the time of plasma spraying. In order to control inner layers deviation, it is effective to form the columnar grain structure which grows long over W particles epitaxially. In this paper, influence of substrate temperature and size of W powder on the various properties, such as thermal conductivity, density, microscopic structure, of the coated W were examined to develop high-grade W coating on F82H.

1. Introduction

Plasma facing surfaces of nuclear fusion reactors must endure very high loads of heat, neutrons, and also plasma particles [1]. The advantage of W is the high melting point, low tritium inventory and low erosion rate under plasma-loading. Coating with W is a promising method to protect the surfaces against these loads. Vacuum plasma-spraying (VPS) technique would be the suitable method for coating of the plasma facing surfaces because it is rather easy to coat thickly on large area. It has been confirmed that the VPS coated W layer (VPS-W) has a good physical properties compared with the atmosphereic plasma spraying (APS) W layer (APS-W) [2].

If we would want to create the VPS-W layer on the first wall materials such as a reduced activation ferritic/martensitic steel (F82H), surface temperature of the F82H should be kept below 1040 K during the coating process because its microstructure is changed above this temperature.

It was reported that columnar-like grain structure of the W should be created to avoid the intergranular fracture of the W layer. In this paper, influence of the columnar-like grain structure for the thermal conductivity was studied, and then, the requirement for getting the highly controlled columnar-like W grain was discussed.

2. Experiment Process

2.1 *VPS Coating productive method*

The F82H substrate was installed in the decompressed chamber, and then, molten W powders (18～37 μm) were sprayed up to the thickness of about 1 mm by using the scanning plasma spraying gun which can move back and forth repeatedly. During the coating phase, the surface of the F82H substrate was heated up to around 873 K due to the thermal conduction from the molten W powders.

2.2 *Coatings Assessment Procedure*

In order to know the details of the microstructure, cross-sectional specimens were observed by SEM/EBSD, and very thin cross-sectional TEM specimens were picked up by using FIB. Re-solidified grains and columnar grains were defined more than 20 μm^2 and the aspect ratio > 2.5, respectively. Then, the area ratio of columnar grains and re-solidified grains was analyzed by Orientation Imaging Microscopy (OIM), and each coating structure was compared.

2.3 *Quality of Coating Improvement*

The effects of various conditions, such as grain size of W powder, spraying distance, and substrate temperature ware examined. In order to acquire the optimal coating condition, the coating layers ware formed on various coating conditions, and the quality of coating improving effect was examined from rate of the columnar grain.

3. Results and Discussions

3.4 *Substrate Temperature and W Powder Grain Size*

Influence of substrate temperature and size of W powder were examined with several substrate temperature and two type of W powder (18 μm, 37 μm), respectively. As substrate temperature became high, microcrack decreased and the rate of the columnar grain became higher. Moreover, compared with the coating which made of 18 μm, the ratio of columnar grain of W layer which made of 37 μm increased to two times, because liquid state of large particle could be kept long due to large heat capacity. Fig.1 shows that correlation between columnar grain rate, the density and the thermal diffusivity. It is observed that the density and the thermal diffusivity are highly sensitive to changes in ratio of columnar grain. When the ratio of a columnar grain was 40% or less, density and thermal diffusivity increased in proportion to the rate of a columnar grain increasing. It is considered that the fraction of a columnar grain have a major effect on inhibition of microcrack formation. On the other hand, when the ratio of columnar grain was upward of 40%, density and thermal diffusivity are not sensitive to changes in ratio of columnar grain. It is considered that the microcrack decreased enough according to the increase effect in a columnar grain, but a constant amount of pores remained. These results indicate that if the fraction of the columnar grains is more than 40%, micro-cracking can be suppressed well.

3.6 *Spray Coating Improvement with 37 μm particle*

W layers were formed on some conditions which kept substrate temperature about 873K to compare influence of columnar grain. The cross-sectional micrograph of Sample1 and Sample2 is shown in Fig.2. Condition of Sample1 was basal condition. And, condition of Sample2 which was coated with W powder that cut off under 25 μm from an average size of 37 μm, can get the highest ratio of columnar grain. Ratio of columnar grain of Sample2 was increase from 33.6% to 45.5%. On the other hand, the ratio of re-solidified grain was decrease from 18.25 % to 13.5 %. Coating conditions are about 873 K during VPS coating, and contribute to increasing of ratio of columnar grain. Especially, when particle-size-distribution of W powder is narrowed, W powder poured into the plasma jet can be kept molten state more uniformly.

4. Summary

Micro-cracks in the direction parallel to the W layer causes heat conductivity decrease. When the ratio of columnar grain up to 40%, increase of columnar grain have a major effect on inhibition of microcrack formation. This indicates that one should reduce un-melted/re-solidified particles to improve adhesion. Rather large grain size (37 μm in average) is also effective for increasing of large columnar grains due to their high heat capacity. Moreover, on the coating conditions of Sample2, the ratio of the columnar grain was able to obtain more than 40% also with the substrate temperature 873K.

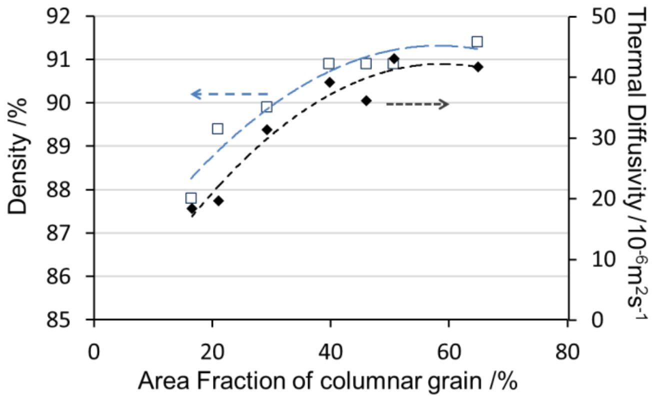

Fig.1: Correlation between ratio of columnar grain, the density and the thermal diffusivity

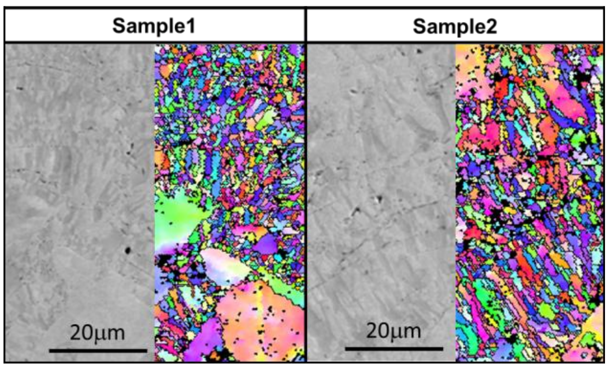

Fig2: Cross-sectional SEM/EBSD micrograph of VPS-W (Sample1) basal coating condition with 37 μm (Sample2) W powder which cut off under 25 μm

References

[1] N.Yoshida, J. Nucl. Mater. 266–269 (1999) 197–206.

[2] Y.Yahiro, M.Mitsuhara, K.Tokunaga, N.Yoshida, et al., J. Nucl. Mater. 386–388 (2009) 784–788.

[3] K. Tokunaga, T. Matsubara, Y. Miyamoto, Y. Takao, N. Yoshida, et al., J. Nucl. Mater. 283–287 (2000) 1121–1127