Modification of thermally sprayed cemented carbide layer by friction stir processing†

MORISADA Yoshiaki *, FUJII Hidetoshi **, MIZUNO Tadashi ***, ABE Genryu ***, NAGAOKA Toru * and FUKUSUMI Masao *

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1. Introduction

Applicable fields of cemented carbide are wide and they are used as the base metals for cutting tools, dies, molds, etc. However, W, Co, and Ni, which are the main compositional elements of the cemented carbide, are rare and expensive. The amount of these elements should be reduced for resource savings and cost reduction. Additionally, the shape and the size of the sintered cemented carbide are limited because of the equipment used for sintering. Therefore, a coating technique to form the sound cemented carbide layer with its original mechanical properties is desired.

Although thermally sprayed coatings can produce the cemented carbide layer on a substrate, the as-sprayed cemented carbide layer contains many defects and its hardness is much lower than that of the sintered cemented carbide [1, 2]. The weak adherence between the cemented carbide layer and the substrate is also a serious problem for many applications. In the past decade, laser heating treatment of the thermally sprayed layer has been studied to increase its mechanical properties [3]. However, the hardness shows a non-uniform distribution in the depth direction of the cemented carbide layer and it is still lower than that of the sintered cemented carbide. In this study, the modification of a thermally sprayed cemented carbide layer by the FSP is investigated in order to improve the mechanical properties and enhance their applicable fields.

2. Experimental Procedure

Commercially available WC-20mass%CrC-7mass%Ni powder (mean diameter: 40 μm, Sumitomo Metal Mining Co., Ltd.) and WC-12mass%Co powder (mean diameter: 40 μm, Sumitomo Metal Mining Co., Ltd.) were sprayed on an SKD61 substrate (17 mm×175 mm×230 mm) by JP5000 HVOF thermal spraying equipment (Eutectic of Japan, Ltd.). The carrier gas, gun speed, and fuel were Ar, 3 mm/min, and coal oil, respectively. The thickness of the thermally sprayed cemented carbide layer was about 300μm. The thermally sprayed cemented carbide layer was modified by the FSP. The FSP tool made of sintered WC-Co cemented carbide had a columnar shape (φ12 mm) without a probe. A constant tool rotating rate of 600 rpm was used and the constant travel speed was 50 mm/min. A tool tilt angle of 3°was used.

Transverse sections of the as-sprayed and the FSPed samples were mounted and then mechanically polished. The microstructure of the cemented carbide layer was observed by SEM (JEOL JSM-6460LA). The distribution of the nanometer-sized defects and the microstructure of the metallic binder were evaluated by TEM (JEOL JEM-4000EX) at the accelerating voltage of 400 kV. The specimens for the TEM observations were prepared by FIB (Hitachi High-Technologies Corporation, FB-2000A). The microhardness was measured using a micro-vickers hardness tester (Akashi HM-124) with a load of 300 g.

3. Results and Discussion

Figure 1 shows the microstructural change of the WC-CrC-Ni layer following FSP. The porosities in the WC-CrC-Ni layer disappeared due to the FSP. Additionally, the WC particles were densely packed. It is considered that the plastic flow of the Ni binder induced by the FSP led to the rearrangement of the WC particles. The Cr_3C_2 particles were fragmented and deformed by the tool and were dispersed in the matrix. TEM images of the FSPed cemented carbide layers showed that the microstructure of the metallic binder was refined on a nanometer scale by the FSP. The grain size of Ni and Co was refined to ～200 nm by the FSP as shown in **Fig. 2**. It is considered that they were recrystallized by the severe plastic deformation during the FSP.

The microhardness horizontal profiles for the as-sprayed and the FSPed cemented carbide layer are shown in **Fig. 3**. The microhardness at 100 μm from the surface was measured for the horizontal profile. The average microhardness of the as-sprayed WC-CrC-Ni layer was about 1200 HV which was similar to that of the thermally sprayed WC-CrC-Ni layer reported by other researchers [4]. The microhardness of the FSPed zone reached ～2000 HV. The microhardness of the WC-Co layer was also increased by the FSP from about 1200 to 2000 HV.

Generally, the hardness of the cemented carbide was increased by the reduction of the metallic binder content

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* Osaka Municipal Technical Research Institute, Osaka, Japan
** JWRI, Osaka University, Osaka, Japan
*** AMC Corporation, Osaka, Japan

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and close to that of the monolithic WC. The obtained microhardness of 2000 HV was nearly the same value as that of the sintered WC. It should be mentioned that the microhardness of the FSPed zone was higher than that of the sintered cemented carbide with the same chemical composition. It is difficult to explain such a large increase in the microhardness by only the elimination of the defects in the as-sprayed layer. It is considered that the grain refinement of the Ni and Co binder and the rearrangement of the WC particles assisted in the change of the microhardness. The improvement of the mechanical properties of the cemented carbide has been studied by the decrease in the grain size of the WC particles [5]. For example, the spark plasma sintered WC-Co with the WC particles of ～100 nm and the hot pressed WC-Co with the WC particles of 169 nm had values of 1887 and 2084 HV, respectively [6, 7]. On the other hand, there was no effective process to refine the microstructure of the metallic binder in the cemented carbide. Although the grain of the metallic materials could be refined by the recrystallization process, it was difficult for the cemented carbides because of their high deformation resistance. In this study, the plastic flow was successfully induced to the thermally sprayed cemented carbide layer using the rotating tool made of WC-Co.

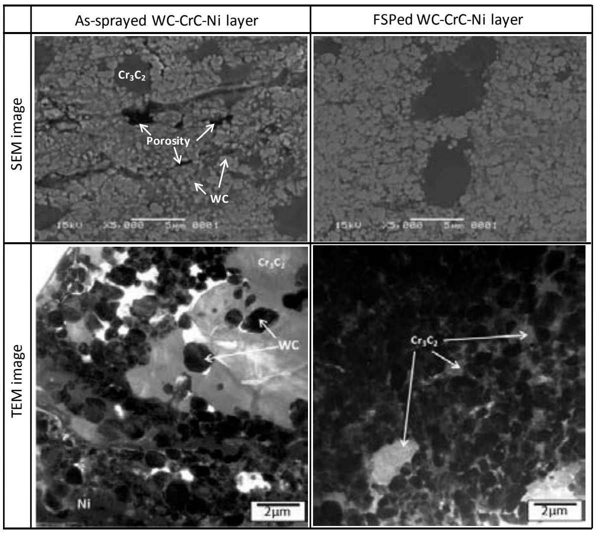

Fig. 1 Microstructural change of the WC-CrC-Ni layer by the FSP.

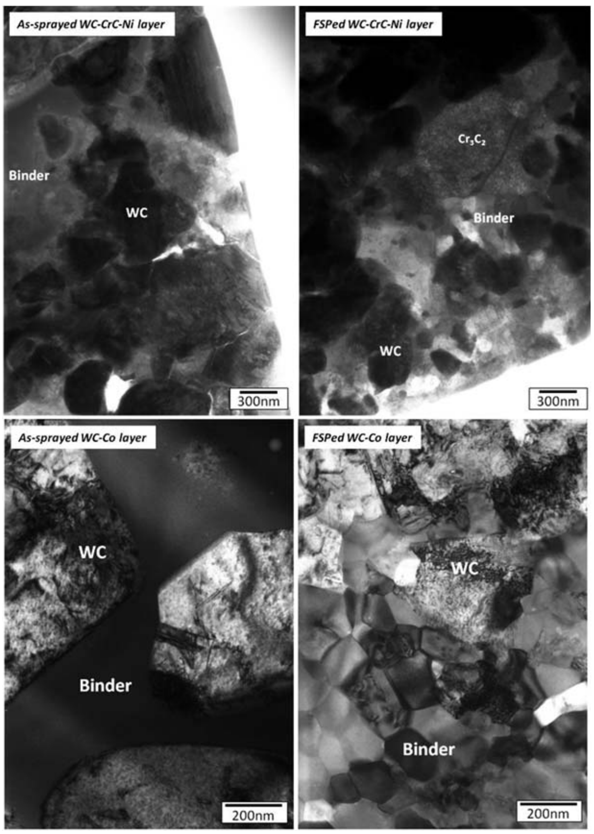

Fig. 2 TEM images of the as-sprayed and the FSPed cemented carbide layers.

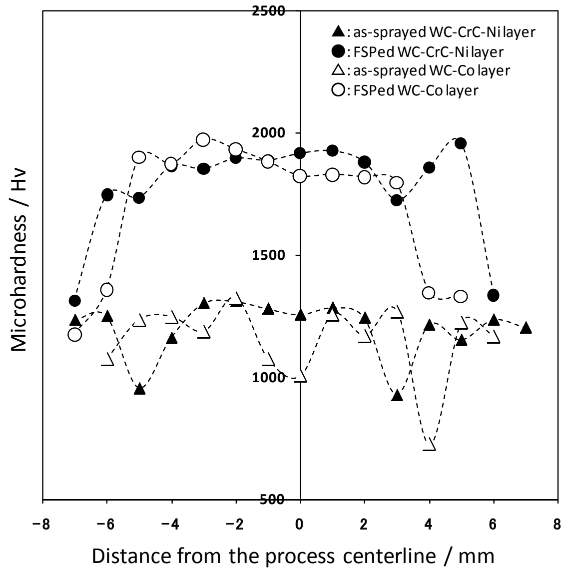

Fig. 3 Microhardness horizontal profiles of the cross-section of the as-sprayed and the FSPed cemented carbide layer.

4. Conclusions

The thermally sprayed cemented carbide layer was successfully modified by the FSP. The obtained results are summarized as follows.

(1) The cemented carbide layer can be stirred by the rotating tool made of WC-Co. The defects in the cemented carbide layer disappear and the WC particles are closely packed after the FSP.
(2) The Ni binder, the Cr_3C_2 particles in the WC-CrC-Ni layer, and the Co binder are refined by the FSP.
(3) The FSPed cemented carbide layer has an extremely high microhardness of ～2000 HV which is higher than that of the sintered cemented carbide with the same composition.

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