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Microstructure and Hardness Properties of high velocity oxygen fuel (HVOF) Sprayed WCCo-SiC Coatings

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ABSTRACT

In this study, WCCo-SiC based coatings were produced on the surface of AISI 1050 steel using high velocity oxygen fuel (HVOF) thermal spraying technique. Ni-based powder was used to connect to together WCCo and SiC powders. X-ray diffraction (XRD) and scanning electron microscopy (SEM) were used to characterize the microstructures of WCCo-SiC based coatings. The surface hardness of substrate and coating were measured using a Vickers hardness tester. The XRD results showed that the WCCo-SiC coatings were mainly composed of WC, W_2C, SiC, Cr_5B_3, γ-Ni and Co phases. It was reported that the microstructure and microhardness of coatings generally changed depending on the amount of SiC and WCCo.

ÖZET

Anahtar Kelimeler:
WCCo,
SiC,
HVOF,
mikroyapı,
mikrosertlik

Bu çalışmada, WCCo-SiC esaslı kaplamalar, yüksek hızlı oksi yakıt (HVOF) termal sprey tekniği kullanılarak AISI 1050 çeliği yüzeyinde üretilmiştir. Ni esaslı toz, WCCo ve SiC tozlarını birbirine bağlamak için kullanılmıştır. X-ışınları difraksiyon (XRD) ve taramalı electron mikroskobu (SEM), WCCo-SiC esaslı kaplamaların mikroyapısını karakterize etmek için kullanılmıştır. Kaplamanın ve alt malzemenin yüzey sertliği Vikers sertlik cihazı ile ölçülmüştür. XRD sonuçları, WCCo-SiC kaplamalarının temel olarak WC, W_2C, SiC, Cr_5B_3, γ-Ni ve Co fazlarından oluştuğunu göstermiştir. SiC ve WCCo'un miktarına bağlı olarak kaplamaların mikroyapı ve mikrosertliği değişmiştir.

1. Introduction

Thermal spray is a group of processes that uses a concentrated heat source to melt feedstock materials while imparting kinetic energy, using process jets to propel the molten particulates toward a prepared surface. These processes are grouped into several major categories: flame spray, HVOF, detonation gun, wire arc spray, air plasma spray, vacuum plasma spray and radiofrequency plasma spray. Feedstock materials are in powder, wire, or rod form (Davis, 2004).

High-velocity oxygen fuel (HVOF) is a coating deposition process whereby a powder coating material is heated rapidly in a hot gaseous medium. Simultaneously the powder material is then projected at a high particle velocity onto a prepared substrate surface where it builds up to produce the desired coating (Herman et al., 2000, Pawlowski, 2008). High-velocity oxygen fuel (HVOF) sprayed coatings have been used widely throughout the years of the last decade mainly in industrial applications, aerospace, and power plants, because the coatings express low porosity and oxide content, high hardness and high adhesion (Mann et al., 2005, Moskowitz and Trelewicz, 1997). The main advantage of HVOF spraying process compared to other thermal spray techniques is the ability to accelerate the melted powder particles of the feedstock material at a relatively large velocity (Islak and Buytoz, 2013, Dongmo et al., 2008).

The WCCo based thermal sprayed coatings have been extensively applied to engineering components as wear resistance materials owing to their combination of high hardness and toughness (Wood, 2010, Jafari et al., 2013). Feedstock powder structures significantly affect the mechanical properties and wear resistance of WCCo coating. The hard WC particles in the coatings lead to high coating hardness and high wear resistance, while the metal binder (Co, Ni, or Co–Cr) supplies the necessary coating toughness (Venter et al., 2013, Ma et al., 2014). Despite the numerous advantages of WCCo powder, it is disadvantage that the WCCo powder is expensive.

SiC has many advantageous properties such as high melting point (2500°C), high hardness (26.46 kN) and cost-efficient (Lou et al., 2006, Islak et al., 2012). At present, a WCCo–SiC cermet coating is prepared by the HVOF thermal spraying on an AISI 1050 substrate. The microstructures, phase composition and transformation of the carbide of coating are identified by X-ray diffraction (XRD), optical microscope (OM), scanning electron microscopy (SEM). The microhardness of the coating and the substrate is tested by the Microhardness device.

2. Material and methods

In this study, high-velocity oxygen fuel (HVOF) spraying method was used in the production of WC-SiC based coatings on the surface of AISI 1050 steel. The composition of the NiCrBSi powder was 74.36 % Ni, 4.73 % Si, 3.97 % Fe, 2.76 % B, 13.68 % Cr, and 0.50 % C. The composition of the WC-12Co powder was 82 % W, 12 % Co, and 6 % C. WCCo powder had a nearly spherical structure and the average particle size was -45+15 μm, SiC powder had cornered shapes particle size of 44 μm and nickel based powders had spherical particle size of -53+15 μm. Morphology of NiCrBSi and WC-Co powders is present in Fig. 1. Mixture rates of powders were summarized in Table 1.

After cleaning the substrate, used in Ø20x100 mm sizes, in an acetone solution, it was exposed to sandblasting process with Al_2O_3 sand having a particle size between 24-35 mesh in order for the coating layer to have a better bonding. Coatings were obtained in the TAFA JP-5000 spraying system which is designed to burn the kerosene, produced by distilling from oxygen and petroleum (Fig. 2). During the spraying process; the kerosene and oxygen pressures were fixed at 7.5 bar and 9.8 bar, respectively. The flow rate of the oxygen was adjusted to 770 l/min and the flow rate of kerosene was adjusted to 0.42 l/min. As the carrier gas; nitrogen gas with 3.4 bar pressure and 9.5 l/min. flow rate was used. In all the coatings; the spraying distance throughout the coating was selected as 320 mm and powder feed quantity was selected as 80 gr/min. Nearly 50 μm-thick Ni-20Cr bonding layer is formed between the WCCo-SiC coating layer and the substrate.

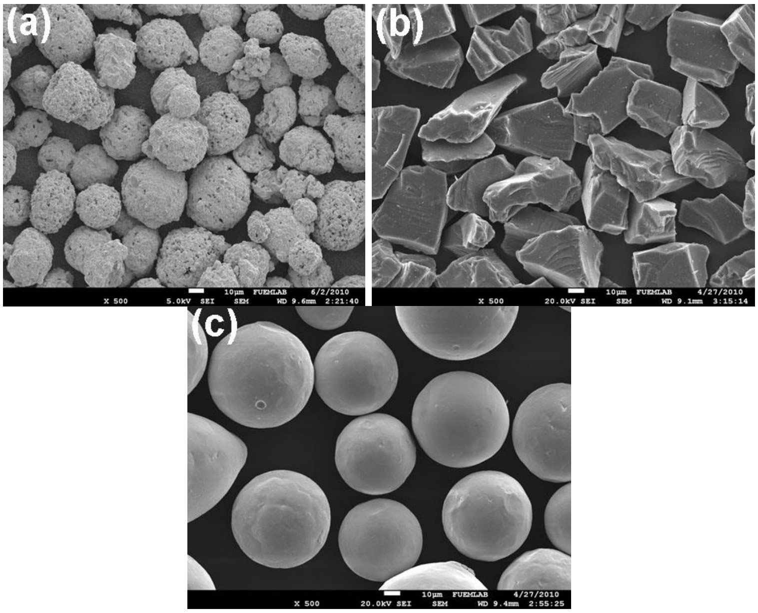


Figure 1. Coating powders: (a) WCCo, (b) SiC and (c) NiCrBSi

Table 1 Mixture rates of coating powders (wt.%)

Samples	WC-Co	SiC	NiCrBSi
S1	90	-	10
S2	65	25	10
S3	25	65	10

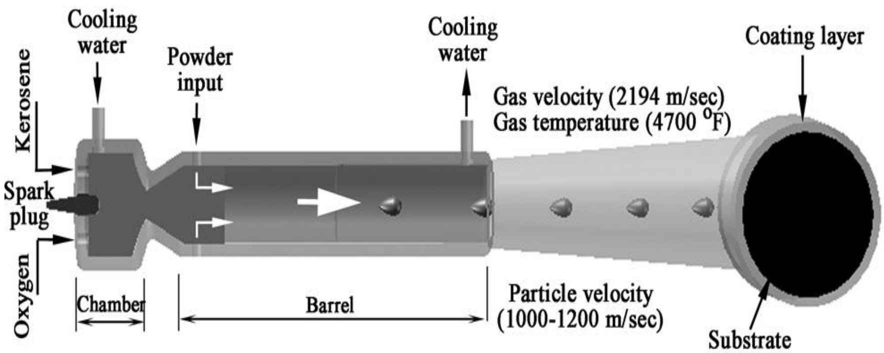


Figure 2. Schematic diagram of the HVOF coating process

Phases of samples was identified by means of X-ray diffraction using Bruker D8 Advance model diffractometer with Cu-Kα radiation (λ=1.5418 Å). The scan ranges from 20° to 90°, with a step size of 0.2° 2θ, and counting time of 0.5 s was applied at each step. The morphologies of coatings were evaluated by SEM (Carl Zeiss Ultra Plus Gemini FESEM, Australia). Chemical composition of coatings was done by means of energy dispersive spectrometry (EDS) in the SEM. Vickers microhardness measurements have been made on the sample surfaces at room temperature using a digital microhardness tester (SHIMADZU). The load was applied for 10 s and at 0.98 N.

3. Results and Discussion

3.1. Microstructure

SEM images of WCCo-SiC coatings produced using HVOF are given in Fig. 3. According to images, total coating thickness varies between 150 and 250 μm (including bond layer). From the microstructure images of the coatings; it was understood that the coating layer had a laminar structure. This was caused by re-solidification of molten or semi-molten coating powders (Ramesh et al., 2010). SEMs show that the coating is very dense and has a good contact with the substrate. This indicates that the coating does have a tight adherence to the substrate due to the higher velocity of HVOF thermal spraying. Generally, porosity amount is very low in the coating produced by HVOF. This is because the high impact velocity of the coating particles causes high density and high cohesive strength of individual splats (Scrivani et al.,, 2001). The maximum value of porosity, measured along the cross-sectional area using image analyser software, was found to vary between 1.5% and 2.5%. It is clearly seen from SEM images that the amount of pore increases with increasing of wt. % SiC rate. The reason for this situation may be the decreasing of binder metal amount (Co). Also from the SEM images, it is seen the SiC particles were not homogeneously distributed throughout the microstructure of coatings. This may be because SiC having less density than WCCo scattered to environment during HVOF process.

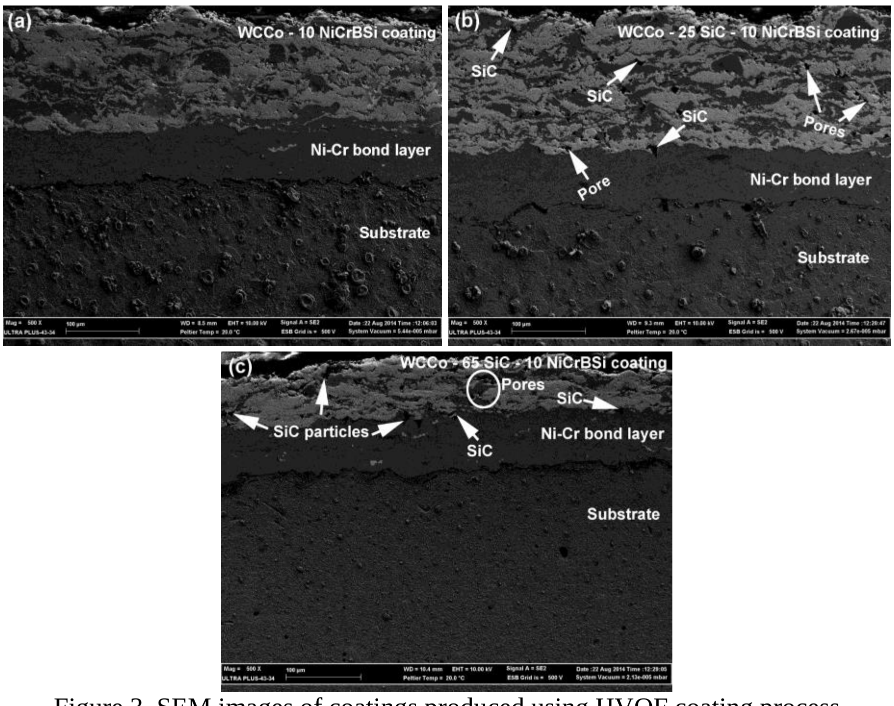
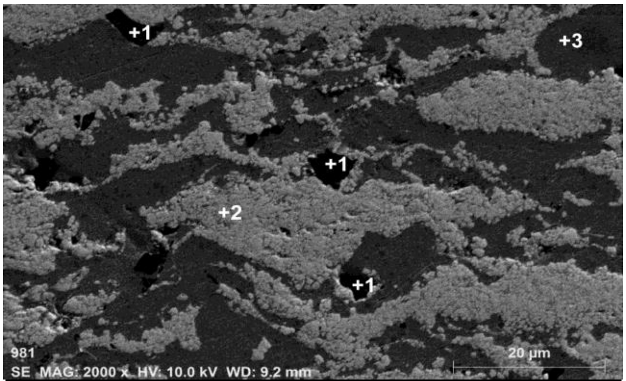


Figure 3. SEM images of coatings produced using HVOF coating process

Fig. 4 shows the SEM micrographs showing surface and the EDS analysis at the selected points on the S3 coating. Point 1 (black coloured area) represents SiC particle. Point 2 (light grey coloured area) indicates WC-Co splats. The WC grains were mainly equiaxed in shape and embedded in the Co matrix. Point 3 (dark grey coloured area) represents NiCrBSi powder which contains higher amount of Ni with minor content of Cr, C, B, Fe, and Si. The EDS data and XRD graph (Fig. 5) don't show detectable presence of oxygen or oxide phases.



Marks	B	C	Si	Cr	Co	Ni	W	Fe
1	-	35	65	-	-	-	-	-
2	-	6.5	-	-	11,8	-	81,7	-
3	2.8	0.7	4.5	14.5	-	73.6	-	3.9

Figure 4. EDS analysis data of S3 coating

Fig. 5 shows the X-ray diffraction spectra of coated surfaces. It indicates that they are only composed of WC, W_2C, SiC, Cr_5B_3, Co and γ-Ni phases. WC peak is more dominant in the free-SiC coating (S1). As increasing amount of SiC powder, the intensity of the WC peak decreased, and SiC peak begun to form. The formation of W_2C phase was regarded as a product of decarburisation in the thermal spraying (Islak and Buytoz, 2013). Stewart et al. (2000) reported that W_2C formed on splat quenching and was caused by dissolution of WC in the Co matrix. Co phase is present on all three coatings.

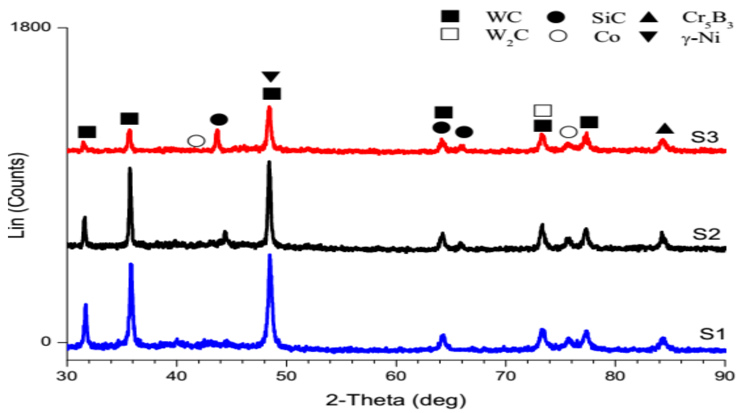


Figure 5. XRD graph of coatings

3.2. Microhardness

Hardness is an important mechanical property of the coating integrities. Fig. 6 shows the microhardness profiles in relation to the distance from the surface for WCCo-SiC coatings produced using HVOF. About 4.5 times increase was determined in the hardness values of the coatings compared to the substrate. This significant increase in the microhardness of the coatings might be associated with to the distribution of the hard phases such as WC, W_2C, SiC and Cr_5B_3 in Ni based matrix. A slight increase in hardness was observed based on the increase in the addition of SiC powder. With increasing from 0 wt.% to 65 wt.% of SiC amount, average hardness value increases from 1150 $HV_{0.1}$ to 1375 $HV_{0.1}$. In other words, hardness difference is about 225 $HV_{0.1}$. Although SiC powder is cheaper than WCCo powder, the hardness of coating with SiC is higher than that of WCCo. Despite this advantage of SiC powder, properties of coatings such as microstructure characterization, phase formation and hardness should be considered together in terms of positiveness of coating.

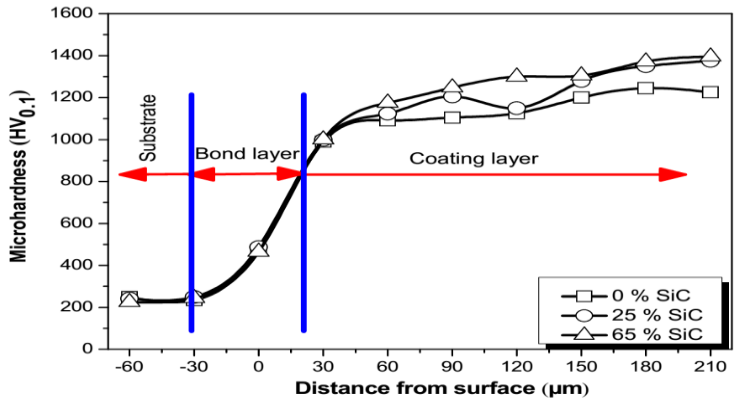


Figure 6. Microhardness graph of coatings

4. Conclusions

In this study, the microstructure and microhardness properties of the WCCo-SiC coatings produced using HVOF were investigated. Base on the results of this investigation, the following conclusions can be drawn:

1. According to SEM images of coatings, total coating thickness varies between 150 and 250 μm (including bond layer), and the coating layer has a laminar structure. Also, SiC particles were not homogeneously distributed throughout the microstructure of coatings.

2. The coatings consist of WC, W_2C, SiC, Cr_5B_3, Co and γ-Ni phases.

3. A slight increase in hardness was observed based on the increase in the addition of SiC powder. With increasing from 0 wt.% to 65 wt.% of SiC amount, average hardness value increases from 1150 $HV_{0.1}$ to 1375 $HV_{0.1}$.

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