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Preheat Treatment on the Tungsten Carbide Hardfacing: Microstructure Analysis

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Abstract
Present study reports the base material preheat treatment effect on microstructure of tungsten carbide (WC) hardfaced carbon steel digester blade which identified as CD blade. Carbon steel blade is located in a digester tank to mix sulphuric acid with ilmenite ore for the process of production. WC hardfacing is deposited on the surface of carbon steel blade to promote its wear resistance as the carbon steel blade is exposed to an abrasive and acidic condition. The influence of base material preheat treatment on microstructure, coating hardness, and elemental composition are the focal point of this work. The effect of base material preheat on hardness value and microstructure of WC hardfacing coating are investigated using hardness test (micro-Vickers) and Scanning electron microscope (SEM) respectively. The base material preheat initiates larger carbide growth in entire coating region and smaller carbide growth in non-carbide region caused by sufficient heat energy. Thus, hardness value of the coating is increased due to uniform distribution of carbides in coating region.

Keywords:
Hardfacing, carbon steel blade, tungsten carbide, preheat

1. Introduction

Coating is a layering process that deposited on the surface of a material, which known as substrate. The main purpose of surface coatings are to enhance mechanical properties of the substrate such as wear resistance, scratch resistance, corrosion resistance, wettability and adhesion, [1-3]. The coating has been broadly utilised in many mechanical and electrical applications to increase lifetime of engineering components [4].

Hardfacing is a process of coating where a layer is applied on surface of material to guard the substrate material. Hardfacing acts as layer of protection which promote components tool life. Hardfacing process main objective is to enhance the wear resistance along with corrosion resistance of engineering components operating in severe service environments [5]. The hardfacing coating deposition is widely utilised in agriculture machineries, sugar industry, mining and etc to improve abrasive wear resistance and hardness of the mechanical machineries [6]. A number of materials with excellent wear resistance properties have been investigated and developed to enhance the wear resistance of hardfacing layer [7].

Tungsten carbide is a compound form from the combination of carbon (C) and tungsten (W). Tungsten carbide is suitable hardfacing material in many industries to improve the component life [8]. This is mainly due to the properties of tungsten carbides such as high hardness, between 3000–4000

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HV which is stable at high temperature. Such attractive charateristics enables tungsten carbides to be employed as wear resistant layers [9]. The high wear resistance characteristics of tungsten carbide is the main reason to be used in hardfacing [10].

There is a compromise among many researchers that techniques and parameters of welding deposition significantly influence hardfacing performance. Deng et al. investigated hardfacing of Co-based alloy fatigue properties and concluded that hardfacing technique and temperature are major features that contribute to its performance [11]. On the other hand, few studies confirmed that hardfacing parameters and methods exhibit a significant response on mechanical and microstructural characteristics of hardfacing welding [12, 13]. The hardfacing welding techniques and procedures can govern its wear properties [14, 15].

Chaterjee demonstrated a study on the influence of base material pre heat effect on microstructure and wear rate of tungsten carbide [16]. He concluded that preheat treatment able to improve wear resistance of hardfaced components. Meanwhile, Desai et al. and Shetty et al. [17, 18] studied the mechanism of abrasive wear which influenced by hardfacing coating microstructure. They revealed that distribution, size and carbides amount have significant effect on its wear property.

This present study discusses the influence of base material preheat treatment on microstructure of tungsten carbide (WC). The base material preheat effect relative to carbide distribution, elemental composition and hardness are focused to enhance WC hardfaced carbon steel blade lifespan.

2. Materials preparation

2.1 CD Blade

The digester blade focused in present study is BS3100 Grade A3 carbon steel. Figure 1 demonstrates a hardfaced carbon steel blade which is the base material in the hardfacing coating deposition. The fraction of carbon percentage in steel determines carbon steel grade. The continuous digester (CD) blade is consisting carbon (C) and manganese (Mn) as major elements. Meanwhile, Table 1 shows other elements that present in minimal percentage.

Figure 1. Hardfaced continuous digester (CD) blade

Table 1. Chemical composition of continuous digester (CD) blade

Element	C	Si	Mn	P	S	Cr	Mo	Ni
Composition (%)	0.32	0.25	0.74	0.02	0.01	0.29	0.02	0.17

2.2 Hardfacing Electrode

The electrode assigned for hardfacing of CD blade is WC electrode which enclosed in a tubular mild steel. High hardness WC material has excellent wear and corrosion resistance which suitable for application in abrasive environment. The electrode is mainly used for hard surface coating of speed mullers, construction machineries and others. The electrode is about 350 mm long with 6 mm diameter. The WC electrode chemical composition is shown in Table 2.

Table 2. WC electrode chemical composition

Element	W	C	Mn	Si	Fe
Composition (%)	60.2	3.1	1.5	0.4	balance

2.3 Process of Hardfacing

Hardfacing weld is deposited on the continuous digester (CD) blade with fusion welding technique. Numerous categories of fusion/stick welding procedures are accessible in the metal combination process, i.e. plasma arc welding, electro-slag, gas–metal arc welding and others. Shielded Metal Arc Welding known as SMAW is the fusion welding method presently practiced for CD blades hardfacing. SMAW welding is employed for this specific hardfacing of CD blades as it is economical compared to other types of welding. Horizontal welding approach on a flat surface is employed to deposit WC on continuous digester (CD) blade as presented in Figure 2. Table 3 demonstrates the SMAW welding hardfacing condition. The base material preheat study is conducted by preheating the blade using torch for 3-5 minutes before weld deposition, and the required temperature is 300◦C according to industrial requirement based on present case study. Upon completion of weld deposits, the carbon steel blade is allowed to cool in air at room temperature. The effect of base material preheat on WC hardfacing coating microstructure is focused in present study. In the meantime, additional welding parameters i.e. number of layers, welding current and electrode drying are act constant variables to study base material preheat effect on hardfacing coating microstructure. Table 4 shows the welding condition assigned for various specimens.

Table 3. SMAW welding condition

Polarity	Electrode length	Electrode feed rate	Welding length	Welding size	Welding speed
DC	35 cm	0.0035 m/s	8 cm	2.0 cm	0.0025 m/s

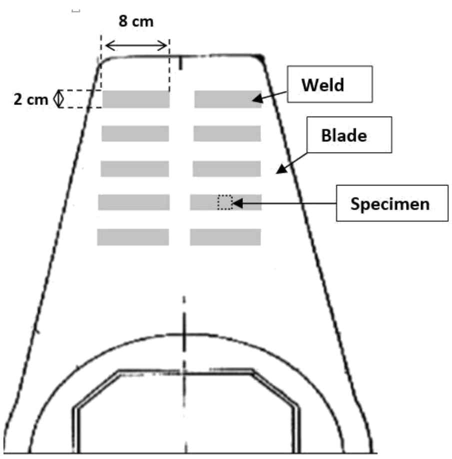


Figure 2. Schematic diagram of Hardfacing deposition on continuous digester (CD) blade

Table 4. Preheat and non-preheat blade specimens

Specimen	Current (A)	Electrode drying	Layer	Blade Preheat
1	200	Yes	1	Yes
2	200	Yes	1	No

2.4 Specimen preparation

Two different weld specimens with measurement of 10 mm x 10 mm x 25 mm are sectioned from the hardfaced CD blade using Electrical discharge machining (EDM) wire cutting as illustrated in Figure 3a. Numerous silica paper grits such as 100, 240, 500, 800, 1000, 1200 and 2000, which are 162.0 µm, 58.5 µm, 21.8 µm, 18.3 µm and 10.3 µm particle size correspondingly used to grind cross-section of the specimens. Then, polishing is executed using Polishing Suspension (Liquid Buehler) to remove fine scratches from the sectioned specimens. Microstructure analysis is performed on three different positions of specimen such as A, B and C as demonstrated in Figure 3b.

(a) (b)

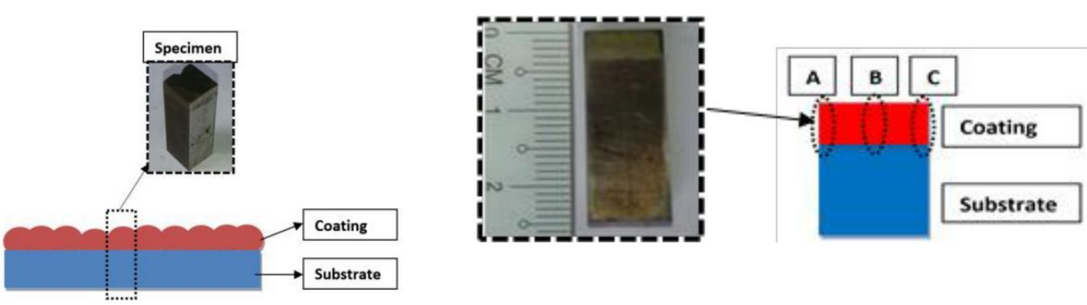


Figure 3. (a) Sectioned specimen side view (b) Schematic position of specimen cross-section for SEM analyses

3. Results

3.1 Metallography of WC hardfacing

The examination of WC hardfacing microstructure is performed using Scanning Electron Microscopy (SEM). Carbide distribution pattern is observed in SEM images. The close-up view of hardfacing specimen carbide distribution is presented in Figure 4. Hardfacing specimen contains three major region, i.e. carbide, non-carbide and substrate regions. The absence of tungsten carbide particles in substrate region motives that region being darker than coating region which are rich in tungsten carbide particles. Different size large carbide in coating region are concentrated at lower portion near the interface of coating-substrate interface with the depth around 1 mm.

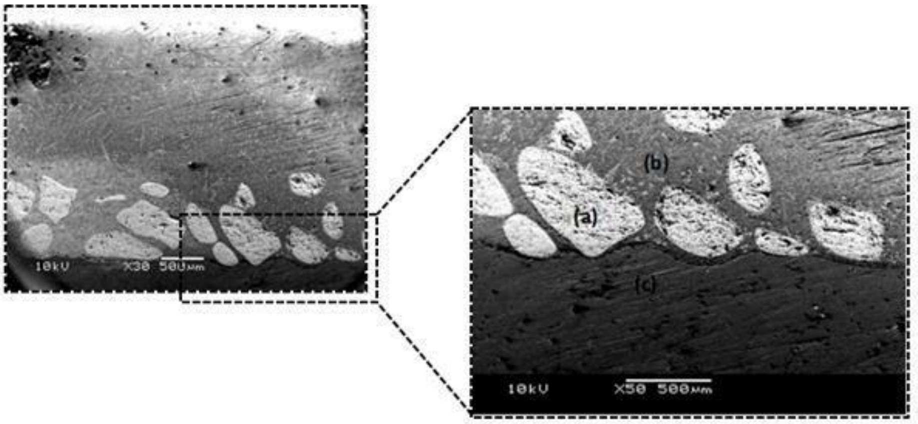
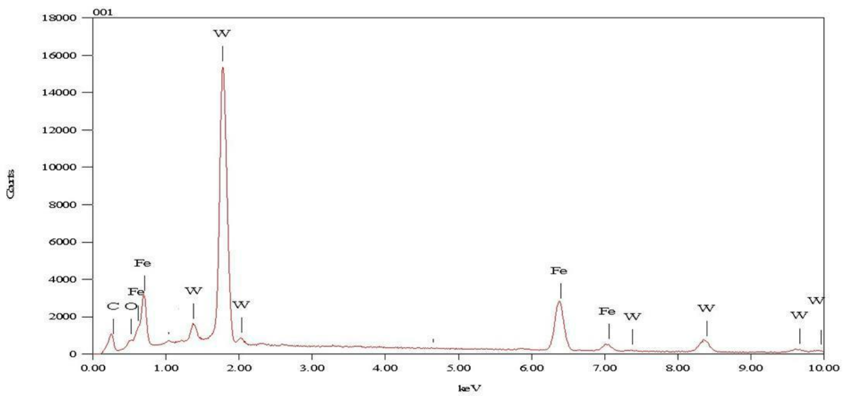


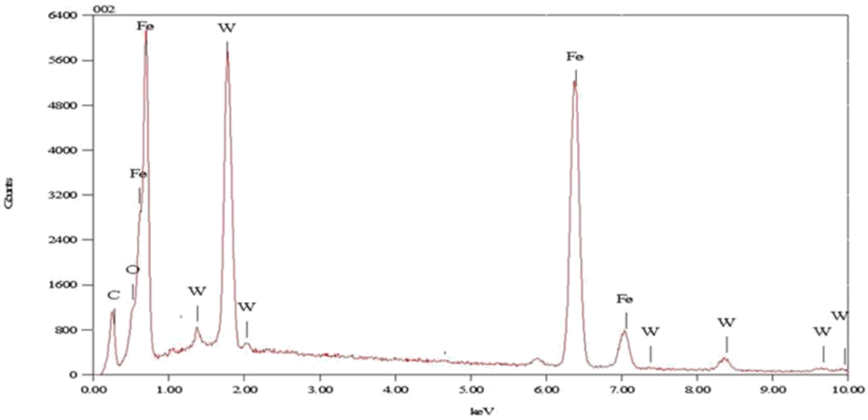
Figure 4. Carbide distribution close-up view under SEM images: a) larger carbide region, b) non-carbide region, c) substrate

Hardfaced specimen elemental composition is investigated using EDS analysis. Figure 5a, 5b and 5c illustrates elemental composition analysis of various region i.e: carbide region, non-carbide region and substrate region. Tungsten (W), oxygen (O), carbon (C), and iron (Fe) are noted in the elemental composition analysis. W is noted in high percentage at carbide region. Meanwhile, both W and Fe noted in higher percentage in non-carbide region representing carbide and binder in close proximity. It is observed that substrate region is mainly made up of Fe. Additionally, C and O elements are noted at all regions in minimal fraction. The existence of O in substrate and coating regions is attributable to oxide layer formation during carbon steel blade casting process.

(a)



(b)



(c)

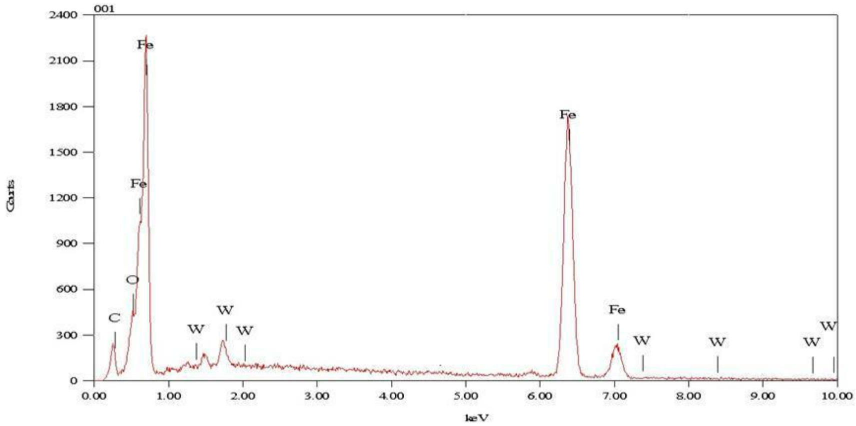


Figure 5. EDS analysis of (a) carbide region, (b) non-carbide region and (c) substrate region

3.2. Microstructural analysis

Figure 6 shows the influence of base material preheat on the overall coating region. Base material preheating is mostly optional during welding process. But, it also influences larger carbide distribution in the coating region. In fact, carbon steel preheating before welding acts as a small factor that leads to growth of larger carbide. The slow cooling rate of base material due to preheating can lead to larger carbide growth and carbide deposition at bottom of the coating. Figure 7 provides the influence of base material preheat on the microstructure of non-carbide region. The optional base material preheating during welding process greatly influences smaller carbide distribution in the non-carbide region. In fact, carbon steel preheating before welding resulting in uniform distribution of smaller carbide around the non-carbide region. The slow cooling rate of base material due to preheating can lead to smaller carbide growth.

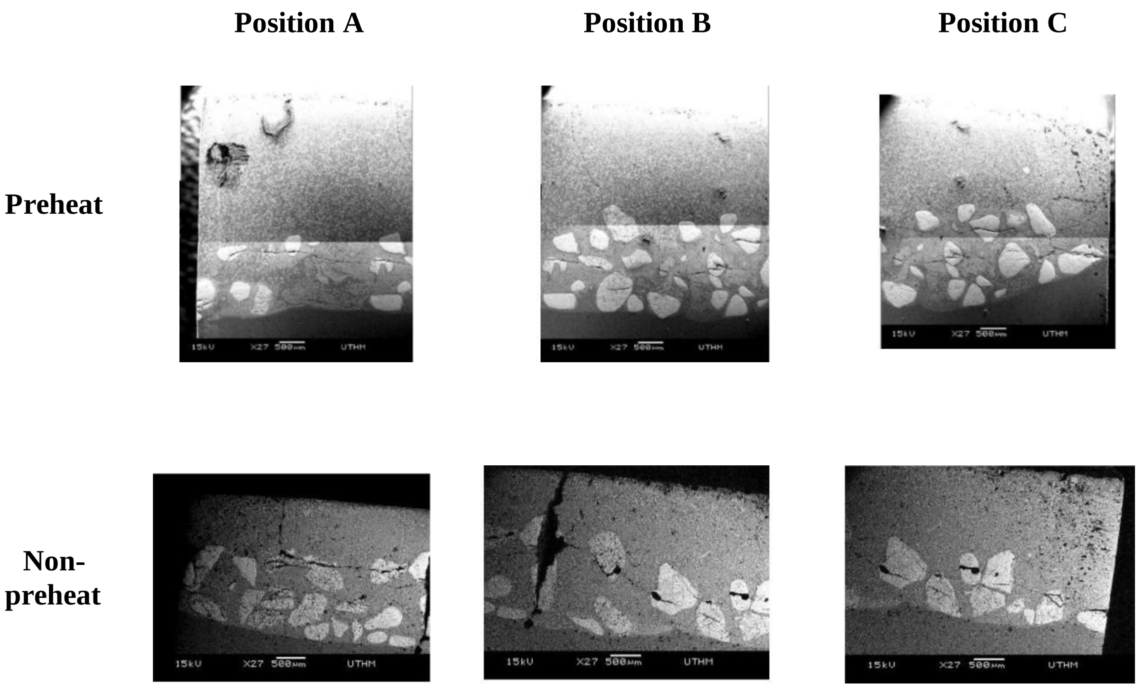


Figure 6. Overall coating region microstructure for preheated and non-preheated carbon steel blade specimens (magnification scale: 27)

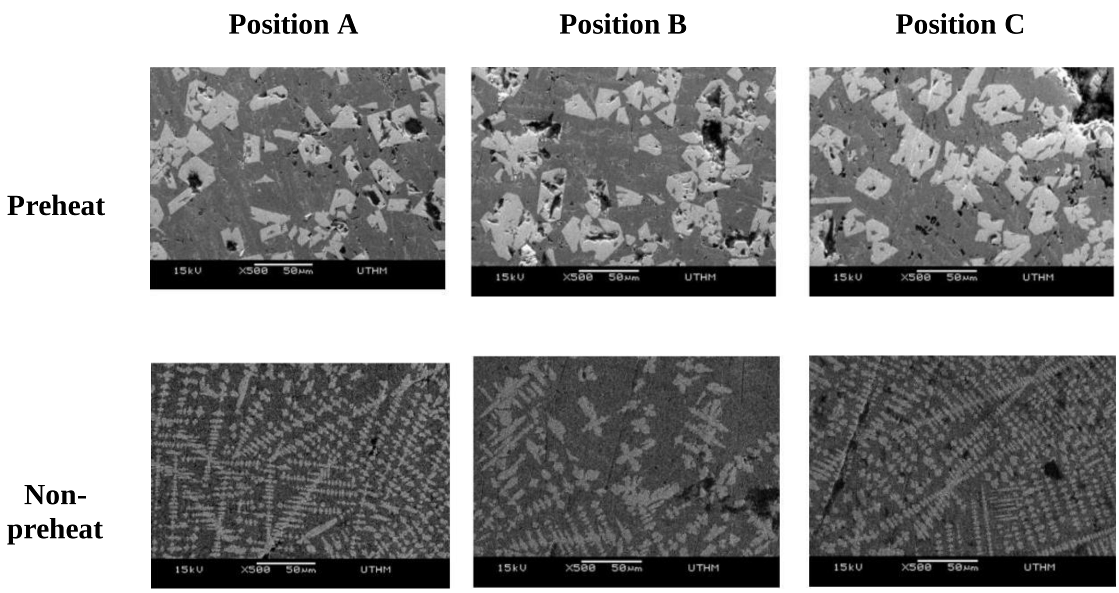


Figure 7. Non-carbide region microstructure for preheated and non-preheated carbon steel blade specimens (magnification scale: 500)

3.3. Hardness analysis

0.5 HV load Micro-Vickers hardness tester is assigned to perform hardness test at different position such as carbide, non-carbide and substrate regions. Figure 8 exhibits the hardness values of various hardfaced region such as carbide, non-carbide and substrate regions respectively. Non-carbide region demonstrates lower hardness value than carbide region. Higher hardness value of 1795 HV is registered at carbide regions. Meanwhile hardness value of 814 HV is registered at non-carbide region. Higher hardness value is achieved as the indentation during hardness test is biased towards concentrated carbide region.

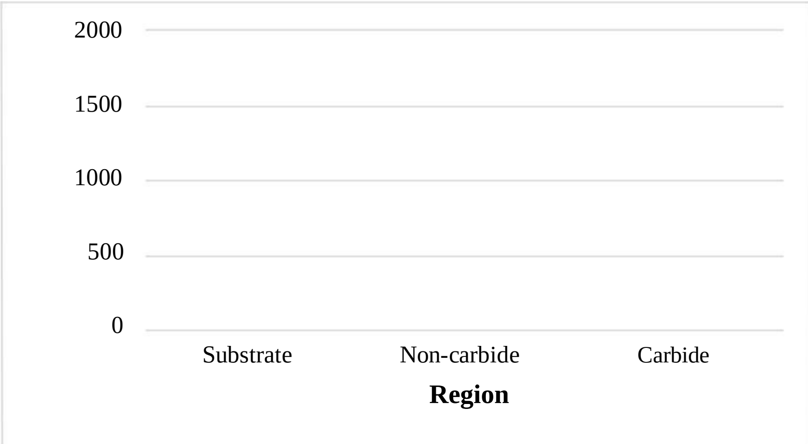


Figure 8. WC hardfaced continuous digester (CD) blade specimen hardness according to different region

Non-carbide region hardness for preheated and non-preheated blade specimens are demonstrated in Figure 9. Higher hardness values are recorded for base material preheated specimen compared to non-preheated specimen. Base material preheat treatment results in uniform distribution of smaller carbide in the coating region. It is noteworthy to mention that better wear resistance can be achieved with increased hardness as hardness is commonly indicates material wear resistance [19]. Hence, base material preheat treatment can assure uniformity in smaller carbide distribution over the entire coating region to obtain increased hardness and improving the wear resistance.

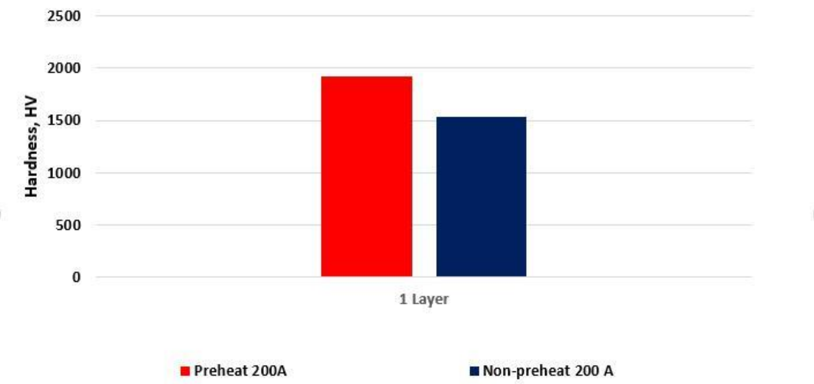


Figure 9. Non-carbide region hardness value for preheated and non-preheated carbon steel blade specimens

4. Conclusion

An investigation on the influence of base material preheat treatment on tungsten carbide (WC) hardfacing microstructure is performed. The effect of base material preheat on microstructure of coating, elemental composition and hardness is studied comprehensively. Following conclusions can be drawn based on present study:

Base material preheat treatment provides sufficient heat energy enabling larger carbide growth in entire coating region with uniform distribution of smaller carbide at non-carbide region.

Carbide region demonstrates higher hardness value than non-carbide region. W is noticed in higher fraction at carbide region. Non-carbide region consist of W and Fe indicating close proximity of carbide and binder.

Base material preheat treatment promising carbide distribution in uniform manner over the coating region which can improve coating hardness. Thus, hardfaced CD blade wear resistance and lifetime can be enhanced.

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