Microstructure Analysis of Tungsten Carbide Hardfacing on Carbon Steel Blade

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Abstract. Tungsten carbide (WC) hardfacing coating is commonly used to enhance carbon steel blade performance which works in acidic and abrasive condition during production process. This paper deals with tungsten carbide (WC) hardfacing microstructure analysis on a carbon steel blade. Mixing of ilmenite ore with sulphuric acid is performed by the carbon steel blade as part of a production process. Tungsten carbide hardfacing is deposited on the carbon steel blade to enhance its wear resistance. The carbide distribution along with elemental composition analysis of the hardfaced carbon steel blade specimens is examined using Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS) and X-Ray Diffraction (XRD) respectively. Microstructure analysis revealed that different sizes of carbides with non-uniform distribution are found around the coating region. The carbide region is contains high percentage of tungsten (W) meanwhile, non-carbide region rich in tungsten (W) and iron (Fe).

Keywords:

Hardfacing, tungsten carbide, carbon steel blade

1. Introduction

Recently, researchers have shown an increased interest in surface coatings application to improve wear resistance which can prolong life of components [1, 2]. Hardfacing welding approach widely assigned in industries to provide protection for engineering components that was exposed to abrasive environment [3]. The components service life in abrasive environment can be prolonged by hardfacing deposit, especially on the parts that was exposed to production process [4-6]. There is great requirement for high performance material in hardfacing in order to provide protection to the components that operating under corrosive and wear environment [7, 8].

Tungsten carbide (WC) is a suitable hardfacing material that commonly assigned because of good wettability, high hardness and wear resistance [9, 10]. Katsich and Badisch traced the good compatibility of tungsten carbide coatings in protecting engineering components that operates in severe environment [11]. It has been suggested that wear resistance of hardfacing material is dictated by the microstructure characteristics such as carbide distribution. Desai et al. [12] and Shetty et al. [13] revealed that wear property of hardfacing material is highly influenced by amount, size and distribution of carbides in their recent studies. Van Acker et al. highlights the importance of uniform carbide distribution across all the hardfacing coating region in order to improve abrasive wear resistance [14].

Numerous studies have attempted to explain wear characteristics of blades operating in an abrasive condition. Lau et al. investigated wear mechanism of thin edge cutting blade used for grass cutting process using AISI 1090 high carbon steel blades, and concluded wear is mostly because of surface fatigue abrasion in the preliminary stage [15]. Kang et al. performed wear analysis on hardfaced rotary tiller blades and revealed a significant enhancement on protection against wear provided by the hardfacing compared to the un-hardfaced blade [16].

In this study, hardfacing coating microstructure analysis of carbon steel blades operating under severe (acidic and abrasive) environment in a digester tank was studied. In addition, the carbide distribution and elemental composition analyses of a hardfaced CD blade specimen examined under Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS) and X-Ray Diffraction (XRD) respectively.

2. Methodology

2.1 Blade and electrode

The close view of the BS3100 carbon steel Grade A3 blade shown in Figure 1. Carbon steel blade is assigned as the base metal in the hardfacing coating process. In addition, the blade grade is defined by the percentage of carbon in the blade. Carbon steel blade comprise of Carbon (C) and manganese (Mn) as the main element. Additional elements are also present in small portion as presented in Table 1. The hardfacing electrode employed is tungsten carbide (WC) electrode enclosed in tubular mild. High hardness with excellent wear and corrosion resistance promising suitability of tungsten carbide electrode in hardfacing process. The wide usage of tungsten carbide can be seen in hardfacing of cutter knives, construction machineries, pump impellers and speed mullers. The electrode is approximately 6 mm diameter and 400 mm long. Table 2 shows the chemical composition of hardfacing electrode.

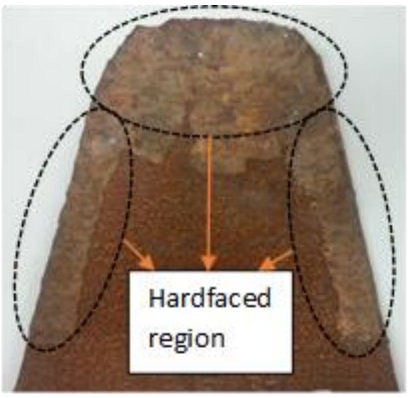

Figure 1: Hardfaced carbon steel blade

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Table 1: BS3100 carbon steel chemical composition

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

Table 2: Tungsten carbide (WC) electrode Chemical composition

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

2.2. Hardfacing method

One of the fusion/stick welding practise that is used for the purpose of metal combination is Shielded Metal Arc Welding known as SMAW. SMAW welding is considered as economical as no expensive and complex tools are required to perform this type of hardfacing. SMAW hardfacing is performed on carbon steel blade with particular welding condition as presented in Table 3. This welding condition is commonly practiced by the industry for tungsten carbide hardfacing. Figure 2 shows fully hardfaced carbon steel blade that is ready to be fixed in the digester tank for production process.

Table 3: Welding conditions using SMAW welding technique

Welding current	**Welding speed**	**Polarity**	**Electrode feed rate**	**Welding width**	**Electrode length**
150 A	0.21-0.24 cm/s	DC	0.34-0.36 cm/s	2 cm	35 cm

(a) (b)

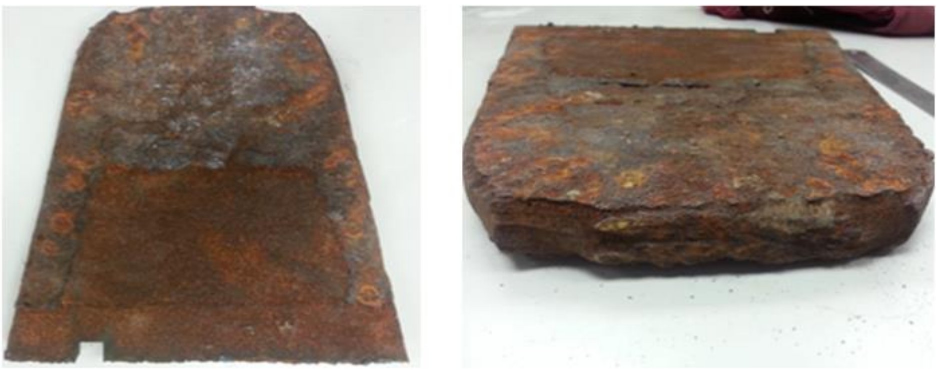


Figure 2: Hardfacing coverage of carbon steel blade using SMAW: (a) top view and (b) front view.

2.3. Specimen preparation

Figure 3 illustrates the sectioning of seven specimens at several positions from the tip of carbon steel blade. Water jet cutting is utilised for specimen sectioning with minimum cutting depth of 2 cm. The surface of the specimens are flattened using table grinder, grit papers and subsequently polishing process as shown in Figure 3. SEM, EDS and XRD analyses are performed on the prepared specimen.

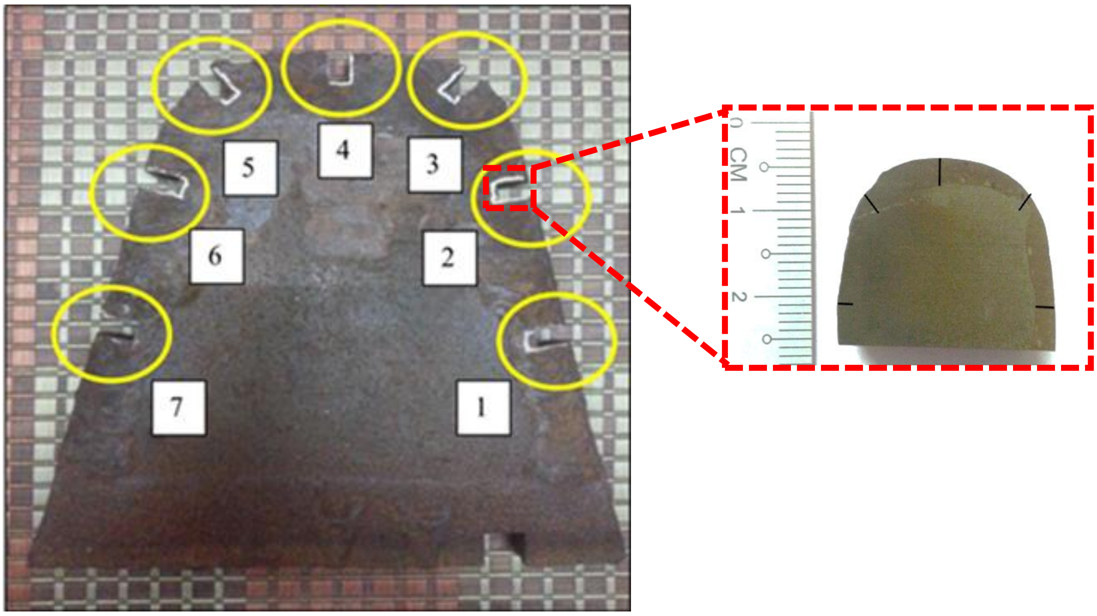


Figure 3: Cross section view of the specimen from carbon steel blade

3. Results and discussion

3.1. Microstructure and elemental composition analyses

SEM is used to analyse the microstructure of the specimens. The backscattered SEM images distinguish the coating and substrate regions by brightness contrast. The distribution pattern of carbide is observed in SEM images. Figure 4 illustrates a close-up view of carbide distribution in the coating. The hardfacing coating region is composed of different sizes of carbide. It is found that large carbides tended to concentrate in the lower part of coating region (near the coating-substrate interface), at about 1 mm in size. The top part of the coating tended toward smaller carbides. Since large carbides are harder and denser, it was deposited at bottom (sunk) of non-carbide metal matrix region and formed at the interface between the substrate and coating. Figure 5 presents close-up view of non-carbide region under SEM. It is noted that the smaller carbide in non-carbide region are not fully grown carbides which are in small grain size and needle like shape. It is believed that the microstructure characteristic such as the type, amount, size, and the distribution of carbides has a great influence on the wear properties. The substrate region is distinguished as being darker compared to the coating region due to the absence of tungsten carbide particles.

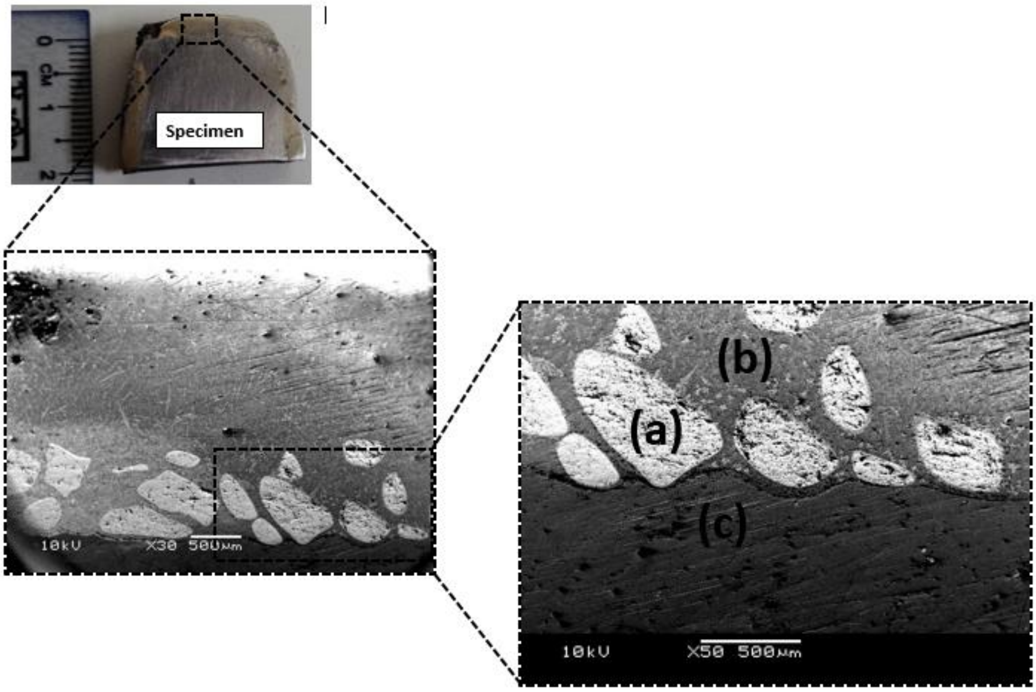


Figure 4: Close-up view of carbide distribution under SEM: a) carbide region, b) non-carbide region, c) substrate

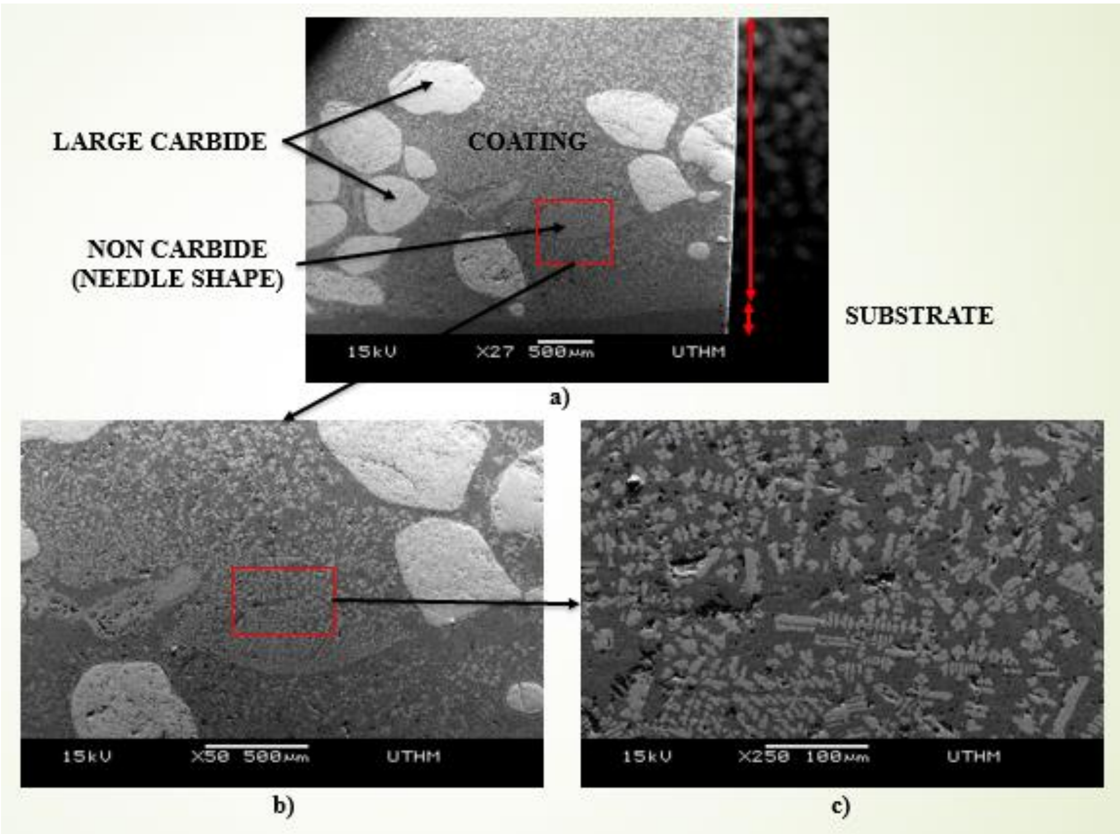
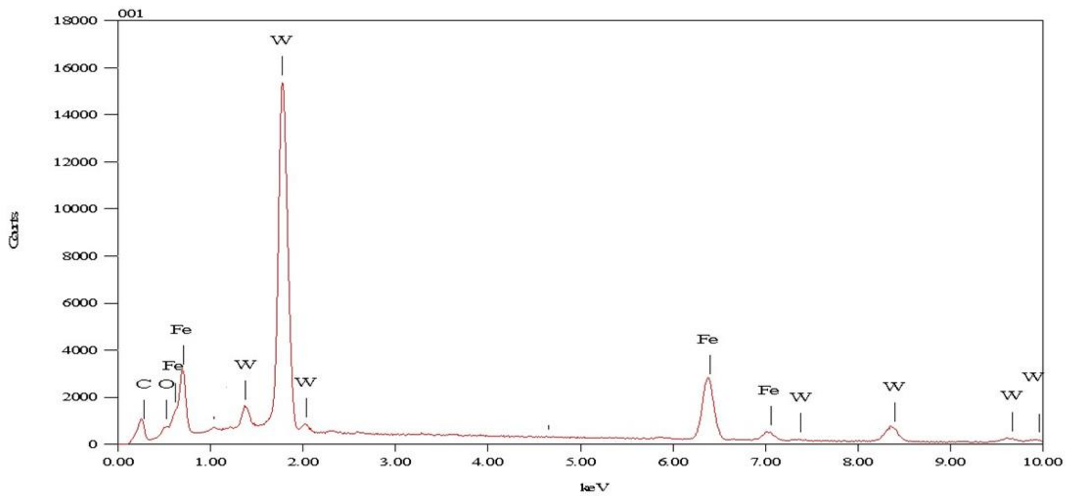


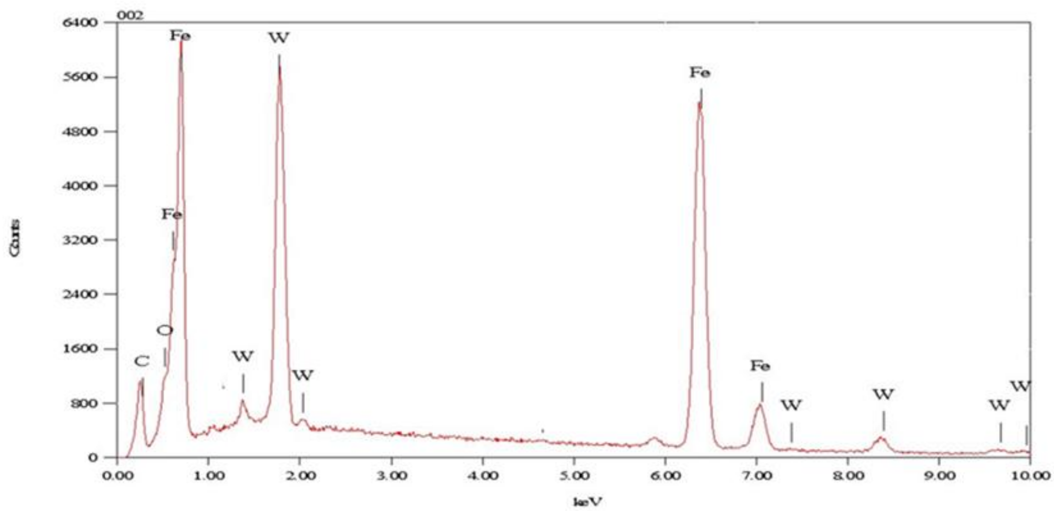
Figure 5: Close-up view of non-carbide region under SEM

EDS analysis is conducted to determine the elemental composition of the substrate and the coating. EDS analysis results are presented in Figure 6a, 6b and 6c define the carbide region, non-carbide region and substrate region, respectively, based on Figure 4. It is apparent from the figures that tungsten (W), carbon (C), oxygen (O) and iron (Fe) are identified in the EDS analysis. As expected, a high percentage of W is found in the carbide region. The non-carbide region is rich in both W and Fe indicative of carbide and binder in close proximity. The substrate region mainly consisted of Fe. In addition, other elements such as C and O are noted in minimum composition in all regions. Furthermore, the presence of O in both coating and substrate regions is believed to be due to the presence of an oxide layer that formed during the casting process of the blade.

(a)



(b)



c)

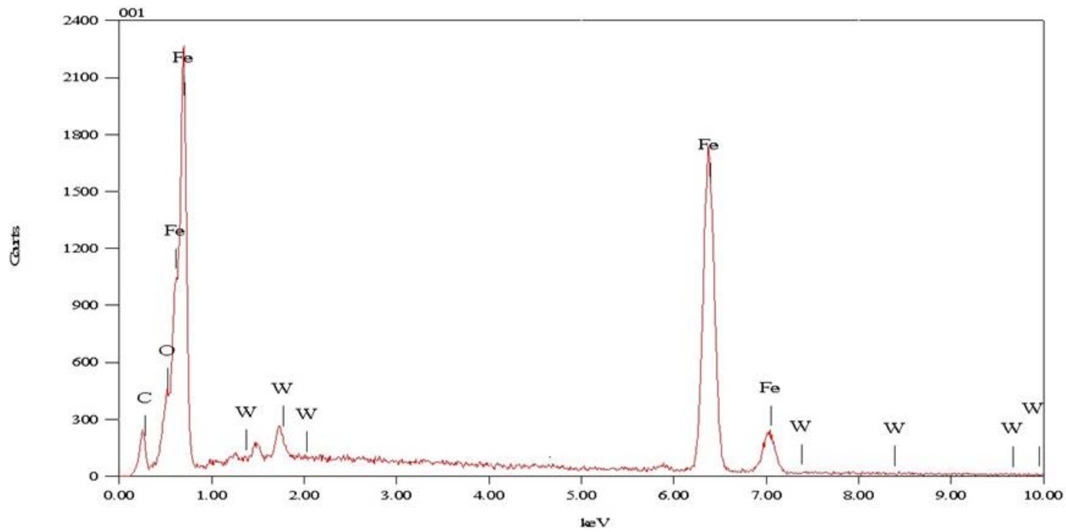


Figure 6: EDS elemental composition analysis of (a) carbide region, (b) non-carbide region and (c) substrate region

Table 4 shows the percentage of the component detect in the XRD analysis for coating. The results of XRD analysis confirmed the presence of Iron (Fe), Tungsten Carbide (W_2C) and Iron Tungsten Carbide (Fe_3W_3C). During hardfacing, the melted Tungsten Carbide (WC) electrode is distributed among iron and as the result of solidification, the iron tungsten carbide was formed. The presence of Fe_3W_3C in these coatings are expected to be of high wear resistance. It is noted that tungsten carbide (W_2C) act as reinforcement particle meanwhile iron (Fe) and iron tungsten carbide (FeW_3C) are the metal matrix in the coating region.

Table 4: XRD analysis on coating

Element/Compound	Percentage (%)
Iron (Fe)	37.8
Tungsten Carbide (W_2C)	20.7
Iron Tungsten Carbide (FeW_3C)	41.4

4. Conclusion

A microstructure analysis of tungsten carbide (WC) hardfacing on a carbon steel blade is studied comprehensively. Microstructure and elemental composition analyses are performed. The following conclusions can be drawn from the obtained results:

- SEM images of the hardfacing showed in detail how the coating was made up of carbide and non-carbide regions. Different sizes of carbides with non-uniform distribution are found around the coating region.
- EDS analysis confirmed high percentage of W is found in the carbide region, meanwhile non-carbide region contains both W and Fe indicative of carbide and binder in close proximity.
- XRD analysis proved the formation of iron tungsten carbide is due to distribution of melted WC electrode among iron the result of solidification.

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References

[1] Tobi, A. M., Ding, J., Pearson, S., Leen, S. B., & Shipway, P. H. (2010). The effect of gross sliding fretting wear on stress distributions in thin W-DLC coating systems. Tribology International, 43(10), 1917-1932.
[2] Tobi, A. M., Shipway, P. H., & Leen, S. B. (2011). Gross slip fretting wear performance of a layered thin W-DLC coating: Damage mechanisms and life modelling. Wear, 271(9), 1572-1584.
[3] Hornung, J., Zikin, A., Pichelbauer, K., Kalin, M., & Kirchgaßner, M. (2013). Influence of cooling speed on the microstructure and wear behaviour of hypereutectic Fe–Cr–C hardfacings. Materials Science and Engineering: A, 576, 243-251.
[4] Kim, C. K., Lee, S., Jung, J. Y., & Ahn, S. (2003). Effects of complex carbide fraction on high-temperature wear properties of hardfacing alloys reinforced with complex carbides. Materials Science and Engineering: A, 349(1), 1-11.
[5] Gregory, E. N. (1980). Selection of materials for hardfacing. The Welding Institute, Weld Surfacing and Hardfacing, 22-27.
[6] Gülenç, B., & Kahraman, N. (2003). Wear behaviour of bulldozer rollers welded using a submerged arc welding process. Materials & design, 24(7), 537-542.
[7] Marimuthu, K., & Murugan, N. (2013). Prediction and optimisation of weld bead geometry of plasma transferred arc hardfaced valve seat rings. Surface Engineering, 19(2), 143-149.
[8] Deng, H., Shi, H., & Tsuruoka, S. (2010). Influence of coating thickness and temperature on mechanical properties of steel deposited with Co-based alloy hardfacing coating. Surface and Coatings Technology, 204(23), 3927-3934.
[9] Ahmad, N. A., Kamdi, Z., Mohamad, Z., Omar, A. S., Latif, N. A., & Tobi, A. M. (2017). Characterization of WC-10Ni HVOF Coating for Carbon Steel Blade. In IOP Conference Series: Materials Science and Engineering (Vol. 165, No. 1, p. 012022). IOP Publishing.
[10] Tobi, A. M., Kamdi, Z., Ismail, M. I., Nagentrau, M., Roslan, L. N. H., Mohamad, Z. & Latif, N. A. (2017). Abrasive Wear Failure Analysis of Tungsten Carbide Hard facing on Carbon Steel Blade. In IOP Conference Series: Materials Science and Engineering (Vol. 165, No. 1, p. 012020). IOP Publishing
[11] Katsich, C., & Badisch, E. (2011). Effect of carbide degradation in a Ni-based hardfacing under abrasive and combined impact/abrasive conditions. Surface and Coatings Technology, 206(6), 1062-1068.
[12] Desai, V. M., Rao, C. M., Kosel, T. H., & Fiore, N. F. (1984). Effect of carbide size on the abrasion of cobalt-base powder metallurgy alloys. Wear, 94(1), 89-101.
[13] Shetty, H. R., Kosel, T. H., & Fiore, N. F. (1982). A study of abrasive wear mechanisms using diamond and alumina scratch tests. Wear, 80(3), 347-376.
[14] Van Acker, K., Vanhoyweghen, D., Persoons, R., & Vangrunderbeek, J. (2005). Influence of tungsten carbide particle size and distribution on the wear resistance of laser clad WC/Ni coatings. Wear, 258(1), 194-202.
[15] Lau, K. H., Mei, D., Yeung, C. F., & Man, H. C. (2000). Wear characteristics and mechanisms of a thin edge cutting blade. Journal of Materials Processing Technology, 102(1), 203-207.
[16] Kang, A. S., Cheema, G. S., & Singla, S. (2014). Wear Behaviour of Hardfacings on Rotary Tiller Blades. Procedia Engineering, 97, 1442-1451.