Effect of Deposition Regime on Tribological Behavior of VK8Coating on 1.2344 Tool Steel Obtained by Electro Spark Method

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ABSTRACT

In this study, the effect of deposition regime on the wear behavior of VK8 coating applied to 1.2344 tool steel by electro spark method (ESA) was investigated. After sample preparation, the coating with high and low regime was applied. To assess the wear behavior, the pin on disk test method according to ASTM G99-04, was used. For surveying surface morphology and cross section of the coating as well as the substrate, optical microscope and SEM were used. Also for phase evaluation of the coating, X-ray diffraction (XRD) was used. The results show that the imposed regime is very impressive on the thickness of coating and wear resistance. In low regime, less porosity, better finishing surface and lower coating thickness was achieved. In this regime, better wear resistance was obtained.

1. Introduction

Surface improvement technology, as one of the key technologies has attracted much attention in production engineering [1]. Moreover, increasing the life of workpieces such as industrial dies which are exposed to wear is an issue which has concerned the researchers, who have offered different solutions such as coating.

One of the coating methods is electro spark deposition (ESD), a micro arc welding method, in which wear or corrosion resistant materials are deposited on the surface [2]. This process is also called electro spark alloying (ESA) or spark hardening. Sparking process in gas atmosphere is a deposition method together with hardening. For deposition process via ESD, electric discharge should occur. In other words, the di-electric (gas) between the two electrodes should be decomposed into electrons and positive ions, so that it can transfer electric current. The discharge is accompanied by generating a large amount of energy which causes the plucking of the particles from anode (electrode) surface and their intense hitting to the cathode (workpiece) surface [3].

Since in ESD method, the electric circuit, atmosphere, anode and cathode are effective, variations in each of these parameters can affect the resulted layer, thus optimizing or weakening its properties.

The efficiency in ESD process is defined as the mass of deposited material in unit time and depends on energy discharge, which equals the energy saved in the capacitors during charging and is measured as follows [4]:

$$W = \frac{1}{2} CV^2 \quad (1)$$

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where W is the energy of a single pulse, V is the potential of the terminals of the capacitors at the time of discharge and C is the capacitance. Since the voltage is usually constant, the capacitance and frequency of discharge play essential roles in the amount of energy. Frequency is the reverse of required time for charging the capacitors. The required time for reaching of the capacitors to a certain voltage (V) is measured as follows:

$$t = \frac{4.6(C.V)}{I_{she}} \qquad (2)$$

where I_{she} is the current intensity of short circuit state (maximum current). Therefore, frequency (F) equals:

$$f = \frac{I_{she}}{4.6(C.V)} \qquad (3)$$

It is obvious that total energy in unit time= discharge frequency× energy of single pulse

From equation (1) it can be concluded that the energy and hence the efficiency increases with the increase of capacitance (C). In other words, with greater capacitance, the capacitors will be discharged with more energy, hence providing the electrode and the matrix with more heat for melting and evaporation. As a result, the mass of deposited material will increase. On the other hand, according to equation (3), it is obvious that with increase of capacitance during a certain time, the capacitors will be less discharged; therefore, with respect to these two parameters there is an optimum limit of capacitance for which the efficiency is maximum. Another way to give rise to total energy is increase of frequency (equation (1)). In such a state, when the current is higher than a specific limit, because of the intense gas formation, the melted metal will spread (instability); therefore, the total efficiency will decrease [4].

Electro spark method produces a dim surface. If electrical parameters such as voltage and current are low (soft or low regime), the resulted surface is more uniform; instead, the thickness of deposited layer is less. In average regimes (high regime) the thickness of deposited layer is more but there is also more tendency to developing local protrusions (decrease of uniformity) [5].

2. Materials and research methodology

In the present study, VK8 composite with WC-8%Co composition was used for coating 1.2344 hot work tool steel. At first, 5mmthick disk-shaped samples with 50mm diameter were prepared and then exposed to quench temper heat treatment, until the primary hardness of the samples reached 540HV10. Following that, in order to prepare the surface for coating, abrasion was done in different directions. The roughness of each sample surface (Ra) was calculated by a Mitutoyo (model: SJ.201) roughness tester.

Prior to the coating process, the samples were washed by alcohol for removing all contaminations. Then the coating was manually and uniformly done under argon gas for 2 min for every square centimeter. A sample was coated with high regime (H) and another sample was coated with low regime (L). Electric parameters of the instrument in different regimes are shown in Table 1. After the coating, the roughness of the coated surface of each sample was measured again. The results of surface roughness before and after coating are shown in the Table 2. Pin on disk test was performed on the coated samples at 10kg load with 0.1m/sec speed and standard pin (Tungsten carbide) according to ASTM G9904 standard. After distances of 0, 100, 200, 300, 500, 700 and 1000 m, the weight of the samples was measured and recorded.

Tab1e 1. ESD Deposition Regimes

Voltage(V)	Capacity(μF)	Short Circuit Current(A)	Regime
80-50	60-30	0.8-0.25	Soft (Low)
80-120	60-150	1-2	Medial (High)
150-220	150-350	2-3	Hard

Table 2. Surface Roughness of specimens

	Substrate Roughness (Ra)	Finished Roughness(Ra)
L	0.05mμ	4.99mμ
H	0.05mμ	15.43mμ

For investigation of the wear path by SEM, a sector of the sample including the pin path was cut and mounted (Fig.1). Also, the diagram for hardness variations of cross section was constructed by Bohlermicro-hardness instrument with 10kg load. Phase analysis of the coated surface was performed by using XRD diffractometer(Phillips) with 0.05 step size and the angle 2θ in the range 10 to 100º.

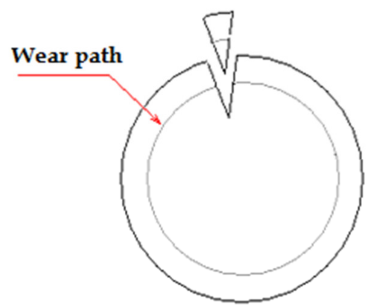

Fig.1. POD specimen and sector cut to study the wear path.

3. Results and discussion

After the heat treatment, the final hardness of the samples reached to 540 HV10. Fig. 2 shows steel hardness in different stages of heat treatment.

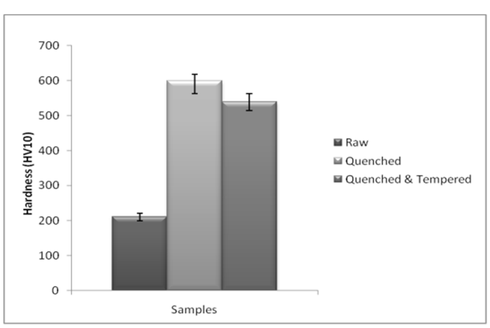

Fig.2. Hardness of specimens before and after heat treatment.

By comparing sample L and sample H the relation between the regime of coating application and the finished surface roughness can be understood. In Fig. 3 the difference of finished surface roughness due to difference in the regimes is shown. With higher regime of coating, the finished surface roughness will dramatically increase.

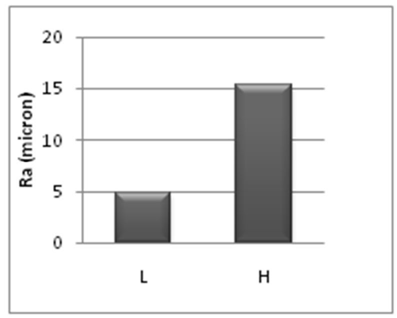

Fig.3. Finished surface roughness of coating in two regimes.

Fig. 4 illustrates diffraction pattern of sample H which was coated in high regime. The peaks are related to $W_6C_{2.54}$, W_2C and $W_2C_{0.85}$. Also, in Fig. 5 diffraction pattern of L specimen can be observed. The peaks are related to $W_6C_{2.54}$, W_2C and $W_2C_{0.85}$. As can be seen, diffraction patterns of both specimens are similar and the main resulted phases are the same. So, there is no difference between the two regimes of coating application.

The results of pin on disk test can be categorized into two sets. A set of results concerns the weight loss of specimens; another set concerns friction coefficient of the wear surface.

Fig. 6 shows the comparison between weight loss of H and L specimens. The diagram of weight loss consists of two parts. The first part is nonlinear and has a generally declining slope, while the second part is linear. In other words, during sliding distance the rate of weight loss remains constant. In the first part of the diagram, specimen H shows 190mg weight loss; in comparison, specimen L has only 9mg weight loss. To put it another way, the weight loss of sample H is 20 times greater than sample L.

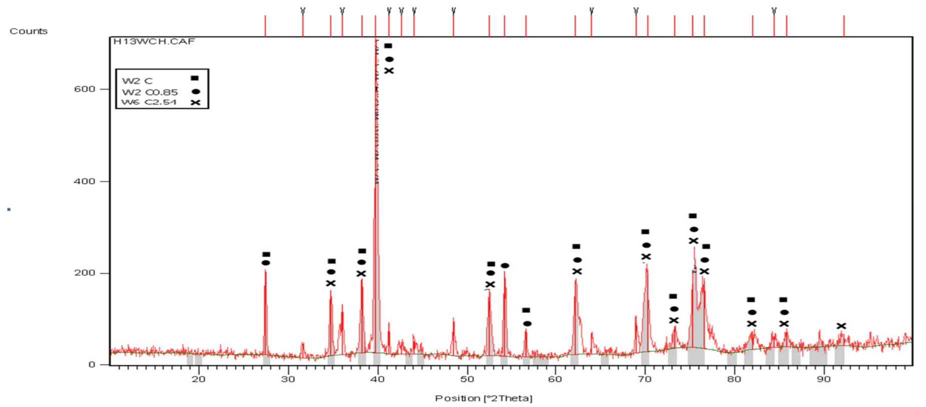

Fig.4. XRD pattern of coating of H specimen.

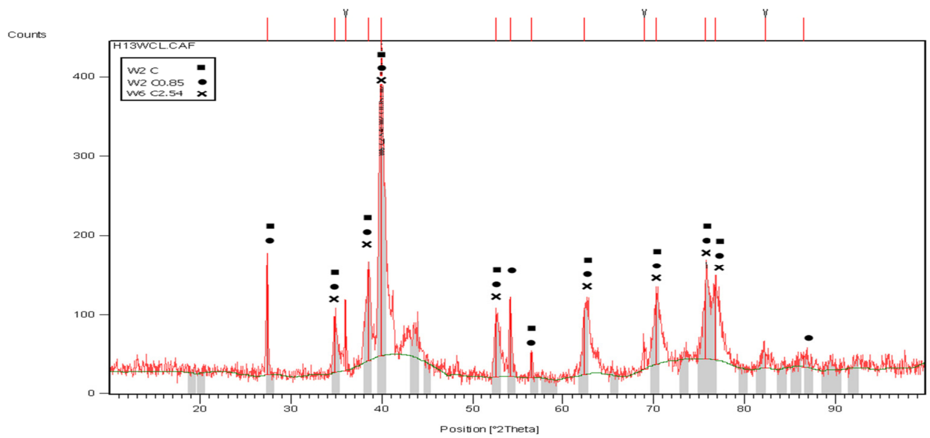

Fig.5. XRD pattern of coating of L specimen.

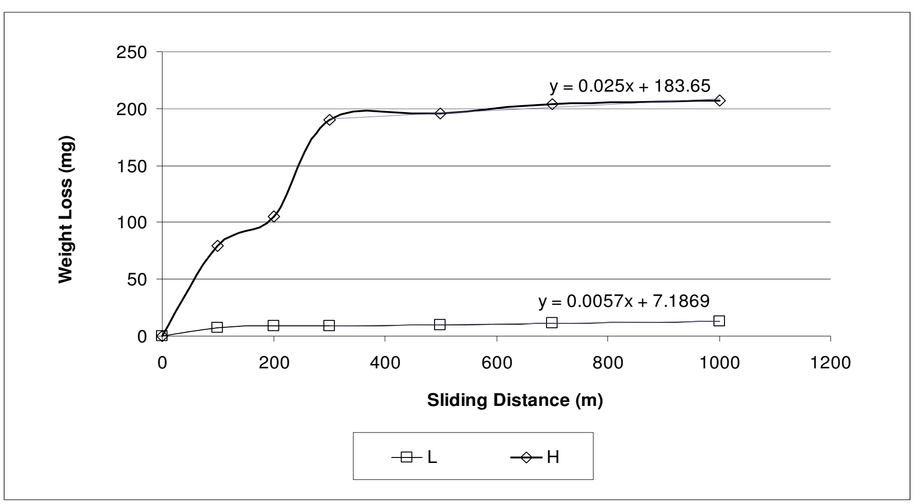

Fig.6. Weight loss during sliding distance.

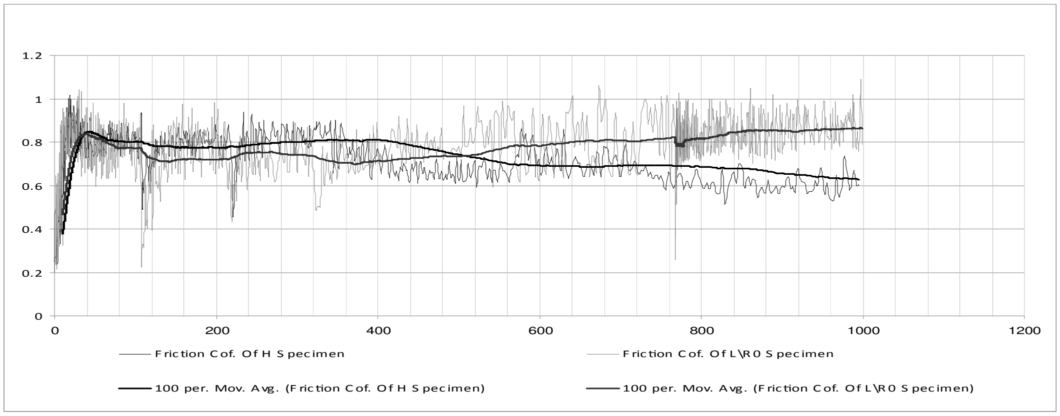

Fig.7. Friction force variation during sliding distance.

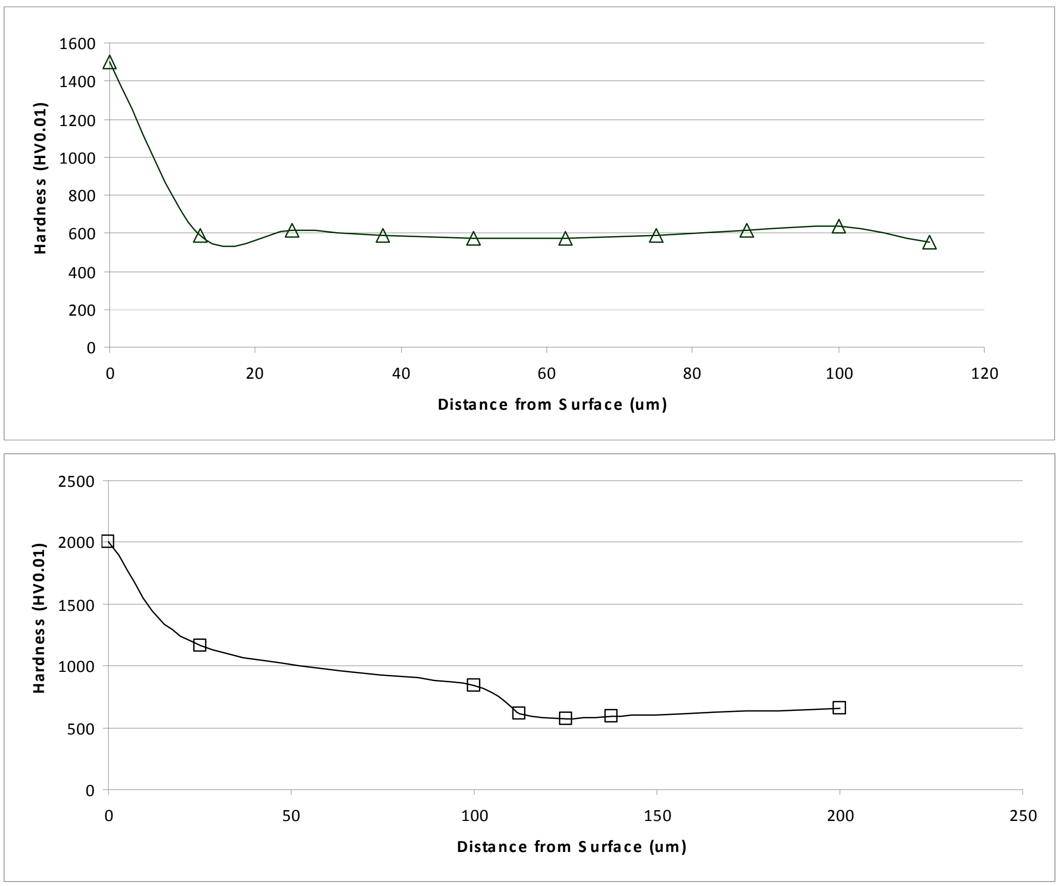

Fig.8. Micro-hardness diagram of H and L specimen.

This can be explained by the roughness of the surface and the presence of micro protrusions. In the first 300 m of the test, because of the exposure of the tops of protrusions and porosity of the surface, the amount of weight loss was high. The reasons for this claim will be more investigated in microscopic images of the wear surface and cross section of the coating.

In the second part of the diagram, the trend of weight loss is extrapolated with a line. The slope of the line for sample H is 0.025 and for sample L is 0.0057. It means that in the stability part, too, the rate of weight loss of sample L is 4.4 times better.
In studying the diagram of friction coefficient of these two specimens, as can be seen in Fig. 7, specimen H has friction coefficient of about 0.8 up to 400m sliding distance, but it decreases to about 0.55 after that. For specimen L in the first 500m the friction coefficient is in the range of 0.7 to 0.75 and has increased up to about 0.85 after the mentioned distance.
Micro hardness results of coating and substrate are presented below. The substrate hardness in the depth of the samples varies in the range of 500 to 600 Vickers. The hardness of specimen H is higher than specimen L. It can be concluded that this is due to the alloying phenomenon in electro spark method. In specimen L in which the coating thickness is less (between 15-20µm) the amount of diluting of the coating by substrate materials is greater and thus a decrease in hardness can be observed. But in specimen H in which the coating is thicker (about 90-110µm), the dilution of the coating by substrate materials is lower; therefore, it gives rise to hardness. This trend of hardness decrease can be better observed in specimen H which has several data in the width of the coating.
Another significant point is that the partial decrease of hardness occurs exactly under the interface and is, to some extent, lower than the hardness in the depth of the substrate. This decrease of hardness is due to heat affected zone (HAZ), though to a little extent [6]. This zone was illustrated in optical microscope images taken from the etched areas of the specimens (Fig.9). Because of the increase of input heat in higher regimes, in the hardness diagram of specimen H (Fig.8) a wider heat affected zone under the coating can be observed.
Therefore it can be concluded that with increase of regime, the heat affected zone under the coating becomes wider.

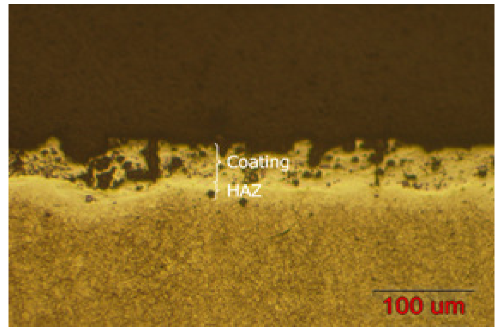

Fig.9. Etched cross-section of H specimen,coating & HAZ.

Fig. 10 shows the cross section of specimen H and L. As can be seen, the thickness of the coating in high regime is about 100µm and in low regime is about 20µm, which is due to variations of electric parameters such as voltage and current (high or low regimes) [5]. In low regime specimen the resulted surface is more uniform but the thickness of the deposited layer is less. On the other hand, in high regime thicker deposited layer can be obtained, but the tendency to developing local protrusion is more (decrease of uniformity) [5]. The completely continuous interface in both samples shows optimum metallurgical adhesion between the coating and the matrix.

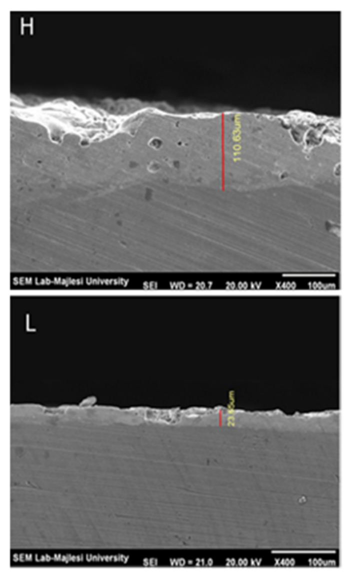

Fig.10. Cross-section of H & L specimen thickness coating in two regimes.

4. Conclusion

1. The thickness of the coating obtained by high regime is 4 times greater than that of the coating developed in low regime and it has dramaticallygreaterroughness(3times greater than low regime coating) and is very porous. In contrast, the low regime coating is thinner and has less surface roughness and porosity.
2. In the wear test, the weight decrease of high regime sample in nonlinear part of the weight decrease diagram is 20 times greater and in the linear part it is 4.4 times greater than weight loss of low regime coating.
3. Coating hardness in low regime was 1500HV0.01 and in high regime was measured as 2000HV0.01. According to hardness curves it can be inferred that:

Surface hardness is related to the regime of coating application. In high regime, due to distance from alloying region, Tungsten carbide is more pure and has higher hardness.

• Hardness gradually decreases across the coating, which is due to alloying in lower layers of the coating.

• The region of hardness decrease under the coating is related to heat affected zone (HAZ) of the coating. In metallographic images, the width of this zone is approximately half of the thickness of the coating.

4. There is an optimum metallurgical adhesion between the coating and the substrate. SEM images show diffusion of the coating and the substrate.

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