Improvement of wear resistance of wire drawing rolls with Cr–Ni–B–Si+WC thermal spraying powders

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Received 24 July 2007; accepted in revised form 19 November 2007

Abstract

In wire drawing process, wear of rolls must be considered because of wear that influences the economics of the forming process. In this study, a nickel based matrix reinforced with WC was deposited by low cost powder welding method on low carbon steel substrates in order to determine the wear resistance of wire drawing rolls. Powder welding method includes, contrary to plasma and high velocity oxyfuel (HVOF) spraying methods, the advantages such as the single operation of powder application-fusion, simplicity, cheapness, and the ease of application. Blends of NiCrBSi and WC powders were prepared in weight proportions of WC of 40%, 45%, 50%, 55%, and 60%, respectively. Wear performance of these coatings was investigated by the dry sliding wear experiments. The wear resistance of the metal matrix composite coatings is dependent on the amount of WC. From 40% to 60%, the increase of WC is very effective on the wear resistance. The coatings with 55% and 60% of WC were worn less than the other coatings. From 55% to 60%, further increase of WC was found not to be effective for the best wear resistance. The microscopic studies of WC particles and Ni-based matrix were characterized by the scanning electron microscopy (SEM). The SEM analysis on the worn surface of coated samples shows that the matrix is considerably worn while WC particles are not considerably worn at the beginning of the wear testing. Additionally, WC particles effectively provide protection for achievement of the wear resistance at advanced periods of the wear testing.

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Keywords: Wear; NiCrBSi; Powder welding; Tungsten carbide; Wire drawing

1. Introduction

In the application of wire drawing, the reduction of environmental burden, improvement of hygiene of labor environment and reduction of production costs, the reduction of the amount of machining lubricant used, the elimination of processes such as washing of the lubricant adhered to products, and the disposal of used lubricants are strongly desired [1]. Considerable wear occurs during the forming operation [2]. The wear occurring during wire drawing process affects the economics of the forming process, the tolerances of the formed parts, the metal flow, and the die life [3].

Nickel based coatings are used in applications when wear resistance combined with oxidation or hot corrosion resistance is required [4]. The presence of boron and silicon on composition of Ni-based alloys gives them the “self-fluxing” characteristic which is especially suited for plasma spraying or high velocity oxyfuel (HVOF) coating techniques [5]. In spite of very high energy level of plasma and HVOF spraying methods, these methods are very expensive and complex in nature. Another method for spraying the Ni-based powders is powder welding. Powder is fed from a small hopper mounted on a gas welding torch into the fuel gas supply and conveyed through the flame to the workpiece surface. The powder welding torch is very simple, cheap, and easy to use. Therefore, cost and time can be saved because of advantages such as the single operation of powder application–fusion, simplicity, cheapness and the ease of application [6].

Tungsten carbide (WC) hardmetals are often used as wear resistant materials for components exposed to high wear intensities, e.g. for cutting tools, drilling tools, dies, and mining machinery etc. [5,7]. The high hardness of the tungsten carbide (WC) grains combined with the relatively ductile binder leads to...
Table 1
Powder welding process parameter
The mark of torch | Eutectic castolin superjet eutalloy
---|---
The pressure of the oxygen | 2.5 bar
The pressure of the acetylene | 0.7 bar
The spraying angle with respect to substrate | 75°
The spraying distance | 150 mm
The powder code | Colmonoy 62 H
The size of Ni-based powder particles | 20–53 μm
The size of WC powder particles | 15–45 μm
Powder composition and its properties | 0.70% C, 14.3% Cr, 3.0% B, 4.25% Si, 4% Fe, Ni balance
Hardness: 56–61 HRC;
Density: 8.09 gr/cm³;
Melting point: 1025 °C

excellent mechanical properties [7]. A remarkable aspect of Ni-based alloy powders is the possibility of including hard ceramic particles such as tungsten carbides in order to increase the coating hardness and abrasive wear resistance [5].

There have been several studies to investigate the wear resistance of NiCrBSi coating powders containing WC particles [8–12]. In a research by K.V. Acker et al. [8] the influence of tungsten carbide particle size and the distribution on the wear resistance of laser clad WC/Ni coatings were investigated. They found that wear resistance of a Ni coating has drastically improved from the moment a small concentration of WC is added. They also determined that 5 vol.% WC is already sufficient to lower the wear by a factor of 10. In a research by H. J. Kim et al. [9], by adding 35% WC to NiCrBSiC powder, the best coating quality in terms of hardness and porosity was obtained. In addition, it was found that 25% WC addition shows the best wear resistance of Sugaru two-body abrasive wear test, while 40% WC addition shows the best wear resistance for dry sand rubber wheel (DSRW) abrasive wear test. In a research by N.Y. Sari et al. [10], it was determined that weight loss of the base metal decreased by 61% by adding 35% of WC to Ni-based coating powder, while weight loss of the base metal decreased 59% by Ni-based powders without WC in flame spraying process. Furthermore, in a study by S. Harsha et al. [11], it was found that addition of WC particles improved wear resistance of modified powder coating 2 to 8 times compared to that of unmodified powder coating. In a research by P.Wu et al. [12], it was found that the wear resistance was markedly improved by the high content of WC (50 vol.%).

As a consequence, different results are claimed at the literature regarding the amount of WC particle addition to the NiCrBSi alloy for the best wear resistance. Although there are several studies on NiCrBSi coatings which are prepared by adding WC particles at low amounts (lower than 50%), there is hardly any study reported in the literature concerning the wear resistance of coating layers which are prepared by adding WC hard particles at high amounts (more than 50%) to the NiCrBSi alloy powders. In the published literature, there are no data dealing with rolls and other components while there are limited data dealing with the wear of dies [13,14] in wire drawing process.

In the present study, the aim was to improve the wear resistance of wire drawing rolls using NiCrBSi powder with WC ceramic by means of powder welding method. WC particles were added to the Ni-based powder at various ratios so as to obtain coatings with optimum WC content. In order to evaluate the effect of the WC content in the mixture, the wear experiments were performed with different mixing ratios. Following the wear tests, the worn surfaces were investigated by means of scanning electron microscope (SEM) in order to determine the effect of WC particles and the wear mechanism of coatings.

2. Experimental procedures

The rectangle shaped blocks with dimensions 12 mm (width) × 25 mm (length) × 12 mm (height) were machined out of AISI 1050 steel and used as substrate material. A mixture of a NiCrBSi alloy powder and WC powder was used as coating material. The coating layers on samples were formed by using powder welding method. In order to determine the morphology of the coating, metallographic preparations were made. The morphology of the coating was determined on polished cross section by optical microscopy. Samples were grit blasted before powder welding. The part of the samples with 25 mm length was coated lengthwise by powder welding. Procedure used to develop the coating and the chemical composition of Ni-based powders is shown in Table 1.

Commercial Ni-based powder (Colmonoy 62SA) was modified by addition of WC particles. WC particles were added to the powder alloys used for obtaining coating layers, in a range of 40 wt.% to 60 wt.%. The size of powder particles was in the range of 20 μm to 53 μm for the NiCrBSi alloy and 15 μm to 45 μm for the WC powder. The sample codes and coating powders with various WC content are listed in Table 2. In the sample codes, the first 2 numbers represent the percentage of Ni-based powder (in wt.%) while the last 2 numbers represent the percentage of WC content (in wt.%). For example, coating produced using a mixture of powder with 40% NiCrBSi–60% WC (wt.%) was stated as 40/60 coating.

In order to simulate the wear in wire drawing process, at the wear test machine, the coated experimental sample represented the roll while ring represented the wire. The dry sliding wear resistance of the coated samples was carried out by using a tribometer in block-on-ring configuration (ASTM G77), in sliding conditions, without lubricants and in air. At the wear test equipment, rectangle shaped stationary sample was pressed onto a rotating ring with 0.6 mm diameter. The test samples were subjected to wear tests in the block on ring test equipment.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Coating powder (in wt.%)</th>
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<tbody>
<tr>
<td>40/60</td>
<td>40% Ni–Cr–B–Si–60% WC</td>
</tr>
<tr>
<td>45/55</td>
<td>45% Ni–Cr–B–Si–55% WC</td>
</tr>
<tr>
<td>50/50</td>
<td>50% Ni–Cr–B–Si–50% WC</td>
</tr>
<tr>
<td>55/45</td>
<td>55% Ni–Cr–B–Si–45% WC</td>
</tr>
<tr>
<td>60/40</td>
<td>60% Ni–Cr–B–Si–40% WC</td>
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</table>
as seen in Fig. 1. AISI 1080 steel was used as ring material. It is well known that wires containing 0.8% C have structure of very fine pearlite. Therefore, before wear testing, the patenting heat treatment was applied to AISI 1080 steel and structure of very fine pearlite was obtained. In order to determine the microstructure of the ring, metallographic examination was realized. Microstructure photograph of the sample which was finally ready for metallographic examination was taken as given in Fig. 2.

Before wear testing, samples were dried by cleaning in alcohol and weighed using Scaltec electronic scale with 220 g capacity and 0.1 mg precision. Wear rate was calculated using weight loss per unit sliding distance. Before samples were weighed at the end of certain of wear test to determine the weight loss, they were cleaned in alcohol so that they were free of all abrasive particles or other foreign substances such as dust, dirt, etc. Wear testing duration was selected as 4 hours for each specimen. At least three repetitions of each test were carried out. Weight loss measurements were done at 1 h intervals. Ring was replaced after periods of 4 h. The test for each sample was finished after 180,000 revolutions or a total distance of 34,000 m. During wear tests, process parameters such as the speed of the ring, the revolution of the ring, and the load were selected constant for each sample. Operating parameters were defined as ring velocity: 2.35 m s\(^{-1}\); ring revolution: 750 rpm; normal load: 20 N; total sliding distance at the end of 4 h; 34,000 m.

At the end of the 34,000 m sliding distance, surface topography of each worn test sample was examined under JEOL/JSM-6060LV scanning electron microscope and photographs were taken of the worn surfaces of samples.

3. Results and discussion

WC particles in coating layer were bonded very well to the matrix as seen in Fig. 3. All coatings were completely crack-free. The distribution of the WC particles was homogeneous throughout the coating. Fig. 4 shows the wear performance of the coatings tested using block-on-ring wear test for coatings with different WC content at 34,000 m sliding distance. As seen in Fig. 4, the wear rate of the coated samples containing 55 and 60 wt.% of WC is lower than those of the other samples. From 55 to 60%, the increase of WC content scarcely alters the wear
rate. Although further increase of the WC content does not contribute much to the improvement of the wear resistance, the increase of WC content up to 55% improves the wear resistance.

Cumulative wear rates of the samples as a function of the sliding distance are illustrated in Fig. 5. As seen in Fig. 5, the amount of wear as a function of sliding distance increased linearly for coated samples containing low WC contents as 40 and 45 wt.% while it increased at an amount that gradually decreases for samples containing high WC contents as 50, 55 and 60 wt.%.

Also, it can be derived from Figs. 4 and 5 that wear ratio falls off in gradually decreasing amounts along with the increase in the carbide amount to exhibit a parabolic change.

Ni-based matrix is preferentially worn while WC particles which have high hardness are not worn significantly during the friction. At the beginning of friction, the increase of WC content decreased the amount of wear, because WC particles provided effective protection for the matrix against to wear. At the further periods, tungsten carbide particles embedded in the matrix as a result of the wear of matrix form protrudes that contribute to the decrease of the wear amount. This situation can also be seen on SEM micrographs in Fig. 6. At 8500 m and 34,000 m sliding distances, SEM micrographs of wear surface of the sample containing 55 wt.% of WC are shown in Fig. 6a and b, respectively. As seen in Fig. 6a, at the first periods of wear, Ni-based matrix was worn while WC particles were not worn remarkably. At 34,000 m sliding distance, some wear scratches and cracks were observed on the surface of WC particles (Fig. 6b). Even at 34,000 m sliding distance, the bonding of WC ceramics to the matrix is very strong. In addition, at 25,500 m sliding distance, SEM micrographs of wear surface of the samples containing 55 and 60 wt.% of WC are shown in Fig. 7a and b, respectively. Again, in addition to the wear scratches on the surface of Ni-based matrix, some wear scratches and cracks were observed on the surface of WC particles (Fig. 7). Wear surface of the samples containing 55 and 60 wt.% of WC showed similarity at 25,500 m sliding distance. In addition, at 34,000 m sliding distance, the SEM image of wear surface of the sample containing 55 wt.% of WC (Fig. 6b) showed similarity with the samples which were worn at 25,500 m sliding distance (Fig. 7a and b). In other words, wear traces on the matrix, and scratches and cracks are seen on WC particles. Probably, WC particles together with matrix which was worn came to an effective position from 25,500 m sliding distance. Matrix was protected against wearing through the scratching.

Fig. 4. Wear rate of samples according to WC content at 34,000 m sliding distance.

Fig. 5. Cumulative wear rates of the samples as a function of sliding distance.

Fig. 6. SEM micrographs of the worn surface of coated samples at 2.35 ms\(^{-1}\) sliding velocity. (a) Sample with 45\%NiCrBSi–55\%WC (wt.\%) at 8500 m sliding distance. (b) Sample with 45\%NiCrBSi–55\%WC (wt.\%) at 34,000 m sliding distance. [(A) Scratch, (B) Crack].

Fig. 7. Wear surface of the samples containing 55 and 60 wt.% of WC showed similarity at 25,500 m sliding distance. In addition, at 34,000 m sliding distance, the SEM image of wear surface of the sample containing 55 wt.% of WC (Fig. 6b) showed similarity with the samples which were worn at 25,500 m sliding distance (Fig. 7a and b). In other words, wear traces on the matrix, and scratches and cracks are seen on WC particles. Probably, WC particles together with matrix which was worn came to an effective position from 25,500 m sliding distance. Matrix was protected against wearing through the scratching.
cracking, and fracturing of WC particles. As seen in Figs. 6 and 7, it could be explained that the wear of coating layer was decreased depending on the wear time by means of WC particles rising above the matrix.

At 34,000 m sliding distance, the SEM micrograph of wear surface of the sample containing 60 wt.% of WC are shown in Fig. 8. The sample containing 60 wt.% of WC shows similarity with the sample containing 55 wt.% of WC. In other words, at 34,000 m sliding distance, WC particles embedded in a Ni-based matrix, rising above the matrix, were worn less. Therefore, the coating layer was protected against wearing. The amounts of wear of the samples containing 55 and 60 wt.% of WC were nearly equal. Therefore, the effective protection of WC particles began from 50 wt.% and more. At the sample containing 60 wt.% of WC, the wear rates of matrix were not changed during wear.

The quantity of wear scratches, occurred on the matrix, shows some variation at the advanced wear periods. At the advanced sliding distances, WC particles effectively protect the matrix at the samples containing a certain proportion of WC (50 wt.% and/or more) and thus the amount of wear begins to reduce. Although this phenomenon is valid for all samples, there are some differences in the depth and the amount of wear scratches on the surfaces of Ni-based matrix and WC particles. At 8500 m and 34,000 m sliding distances, concerning the sample containing 40 wt.% of WC, which was worn more than the other samples, the SEM micrographs

![Fig. 7. SEM micrographs of the worn surface of coated samples containing 55 (a) and 60 (b) wt.% of WC at 25,500 m sliding distance and 2.35 ms⁻¹ sliding velocity. [A) Scratch, (B) Crack.](image)

![Fig. 8. SEM micrograph of the worn surface of sample with 40% NiCrBSi–60% WC (wt.%) at 34,000 m sliding distance and 2.35 ms⁻¹ sliding velocity.](image)

![Fig. 9. SEM micrographs of the worn surface of coating layer obtained with 40% WC content(wt.%) in NiCrBSi–WC powder mixture at 8500 m (a) and 34,000 m (b) sliding distances and 2.35 ms⁻¹ sliding velocity.](image)
of the worn surface are given in Fig. 9. The cases which were stated for the samples containing 55 and 60 wt.% of WC are also valid for the sample containing 40 wt.% of WC. But, the worn surface of this sample containing lowest WC (40 wt.%) showed deeper microgrooves compared to the other samples. As seen in Fig. 9a, at the beginning of friction, the depth and intensity of the wear scratches occurred at the sample containing lowest WC (40 wt.%) are seen to be more than that of the sample(Fig. 6a) containing 55 wt% of WC. At advanced periods, in addition to wear of Ni-based matrix, wear scratches were seen on the surface of WC particles (Fig. 9b). Again, the depth and intensity of the wear scratches occurred at the sample containing lowest WC (40 wt.%) are seen to be more than that of the sample (Fig. 6b) containing 55 wt% of WC. Therefore, the sample containing 40 wt.% of WC showed high amount of wear due to both the drastically worn of bonding phase with Ni-based and the scratched of WC particles.

Without considering the WC content, the wear mechanism of all the samples is microploughing of soft binding Ni-based matrix, and microcracking and microcutting in hard and wear resistant carbides. These stated wear traces can easily be seen from the SEM micrographs of the samples. However, since microploughing mechanism is more effective than these wear mechanisms during the friction, the effectiveness of microploughing mechanism decreases as the distance between the carbides decreases, and this results in an increase in wear resistance.

4. Conclusions

Coatings of five types of NiCrBSi+WC with various WC particle contents were deposited on AISI 1050 steel. The WC content in the coating powders was found to affect the wear resistance considerably up to a certain degree. Although the wear mechanism of all the samples showed similarity, the depth and the amount of wear scratches on the surface of samples showed difference.

As carbide density decreases, the surface area more resistant to wear decreases. On the other hand, matrix surface with much lower resistance than carbides increases and cause the formation of deep scratches that increase wear. Thus, carbide surfaces with high wear resistance and the distance between carbides gain importance. Naturally, as this distance increases, the matrix surface will be less protected by carbides and deep scratches will be formed on the matrix that will also increase wear.

Distance between WC particles is corresponding to 55 wt.% of WC in the present study. The further increase of this proportion (55 wt.%) was not significantly contributed to protect the matrix against wear. At the lower proportions of WC (e.g. 40 wt.%), the matrix is not effectively protected due to increase of the distance between WC particles. Therefore, the sample containing 40 wt.% of WC showed deeper and wider scratches which were formed on wear surface. In this study, optimum weight proportion of WC was found to be 55 wt.% in order to obtain the best wear resistance.

Acknowledgements

This investigation was sponsored by the Senkron Metal and Ceramic Coating Ltd. Co. We thank to T. Halamoglu and G. Bozoglu for supporting fabrication of coatings. We also thank to T. Sinmazcelik for wear test equipment.

References