FRICTION AND WEAR BEHAVIOR OF PLASMA TRANSFERRED ARC COATING ON AISI 4140 STEEL OF BORON CARBIDE AND NICKEL POWDER MIXTURE

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Abstract: Reducing effect of wear and friction is an important research area in machine design. In order to reduce these effects; lubrication, heat treatments and coatings are used on machine parts. Hard coatings are used in wear intensive environments and Plasma Transferred Arc (PTA) Coating is an innovative hard coating method. PTA coatings are used in applications such as automotive valves, glass and ceramic molds and plastic extrusion dies. PTA coating properties are gained from coating powder, thus coating powder research is an important aspect. In this study microstructure and wear behavior of AISI 4140 steel surface coated by Boron Carbide was inspected. Two different mixtures was prepared, Ekabor II ™ powder that contains Boron Carbide and pure Boron Carbide was mixed with a Nickel base to produce two different coating powder recipes. Wear tests were conducted on a Ball-on-Disk device with circular geometry. Optical and Electron Microscopy was used to characterize microstructure of coating layer formed on the surface of AISI 4140.

Key Words: Boron Carbide, PTA, Tribology, Ball-on-Disk

Introduction

Industrial applications cause friction and wear on parts. An important research field is the reduction of wear and friction. Lubrication is the first method used to reduce friction and wear. When lubrication cannot achieve required properties surface modification techniques are used. An important surface modification technique is Plasma Transferred Arc (PTA) coating that can reach high temperatures up to 30000K and has a relatively ease of use (Liu, Liu, Xu, & Yang, 2010). Low thermal stress on material, high coating thickness and high energy density makes PTA coatings a suitable method for glass and ceramic molds, automative valves, petro-chemical vanes, lamination cylinders, plastic extrusion molds and plastic extrusion screws (Gatto, Bassoli, & Fornari, 2004). PTA coating powders are composed of a base and additional materials. Base powders are usually composed of Cobalt and Nickel powders, where as WC, NiCrWC, Cr3C2, TiC and VC additives are used on steel to achieve required properties (Deuis, Yellup, & Subramanian, 1998).

In this study effect of B4C addition on PTA coatings was examined. Two different B4C sources were used and their effect on coating properties were inspected. Coating samples than tested on Ball-on-Disk machine. Both wear test samples and metallography samples were inspected by SEM and EDS.

Materials and Methods

In this study Ekabor II (that contains 5% B_4C, 5% KBF_4 and 90% SiC (Suwattananont, n.d.)) or Boron Carbide (B_4C) was mixed with Nickel in weight ratios given at Table 1 to produce PTA powder. The coating powder produced was put on a channel prepared on 100x40x20mm AISI 4140 steel with 1 mm depth and 3 mm width. A binding agent was used for binding powder to sample surface and samples were left to dry for 24 hours in a shaded moisture controlled environment. PTA coating is conducted at 100A current with a 3mm electrode and working distance of 4mm after 24 hour period and samples were preheated at 300^{o}C. Argon was used as shielding and plasma gas at 25 l/min and 1.0 l/min flow rates respectively.

Sample	Powder	Ratio	Mixing Method
N1	Ekabor II	4%	Manual
N2	Ekabor II	8%	Manual
C1	Ekabor II	6%	Manual
C2	Ekabor II	10%	Manual
C3	Ekabor II	12%	Manual
C4	Ekabor II	4%	Mill
C5	Ekabor II	6%	Mill
D1	Ekabor II	8%	Mill
D2	Ekabor II	10%	Mill
D3	Ekabor II	12%	Mill
E1	B4C	4%	Mill
E2	B4C	6%	Mill

Table 1 PTA Powder Mixtures

Cross sections of PTA coated samples were taken for metallography analysis. Metallography specimens were prepared by standard sample preparation techniques and etched with 2% Nital etchant for 40s.

Ball-on-Disc wear tests were conducted on CSM tribometer at 3N load, 2.5 cm/s speed for 80m. Samples surfaces were prepared to 0.6µm average surface roughness prior to test. Counterpart for Ball-on-Disc tests were 3mm diameter WC balls and all tests were conducted at 25ºC ambient temperature and 35% relative humidity. In order to calculate specific wear rate wear track profiles were measured using Mutitoyo SJ-400 surface profilometer. Ball-on-Disc test results were analyzed using trib R package developed by authors (AY, 2015).

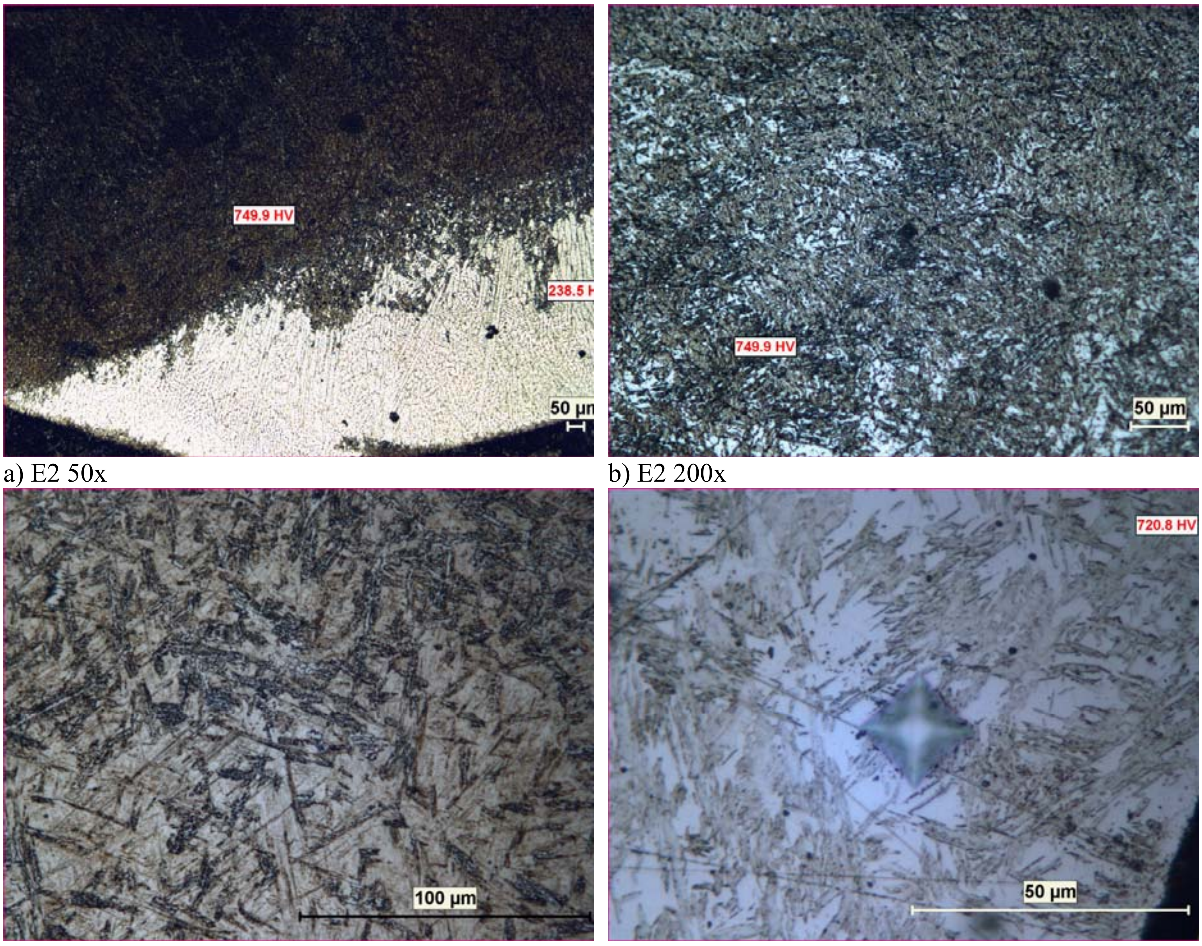
Results and Discussion

Microstructure

In order to understand coating a panoramic image of etched samples were obtained. As can be seen from **Figure *1***, coating produced different phase structures. These phases have varying hardness.

Figure 1. Panoramic view of D1

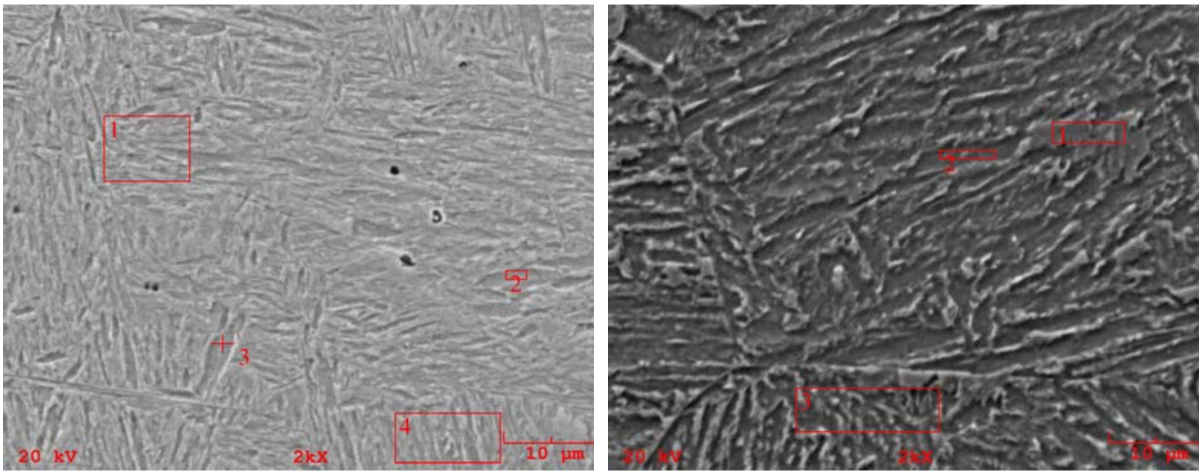
Figure *2* a, shows hardness values of different phases differ between 750HV and 240 HV. As seen in **Figure *2*** b, c and d; high hardness phases have more dendritic formations.



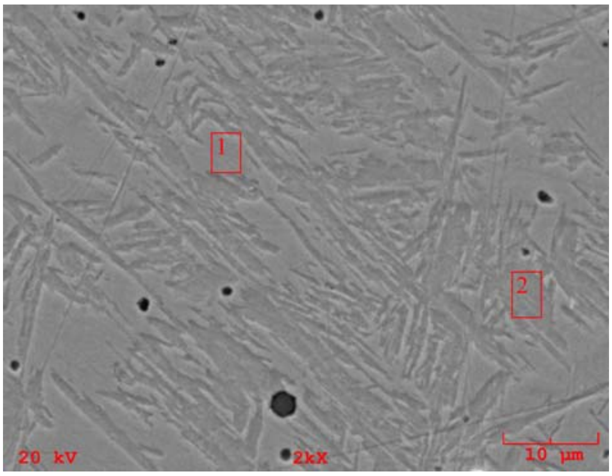
a) E2 50x
b) E2 200x
c) C1 500x
d) D3 1000x

Figure 2. Samples etched with Nital 2% 40s

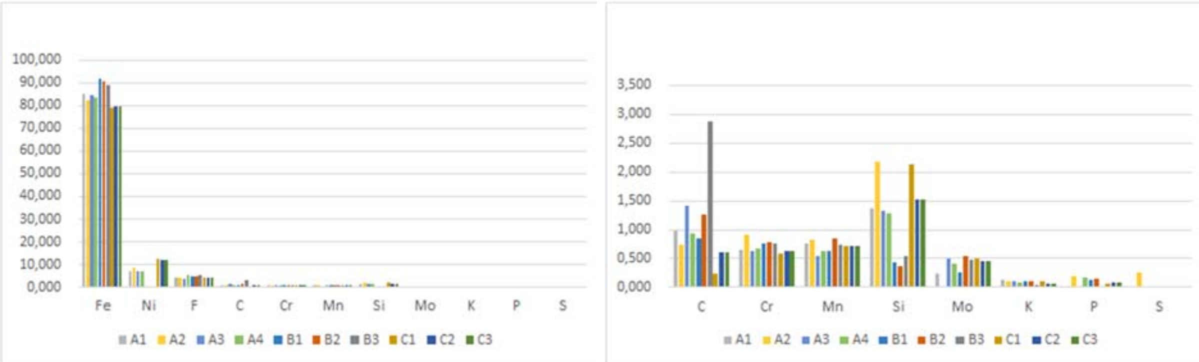
SEM and EDS analysis of samples were conducted. As a representation SEM images and EDS results of sample D3 is given at **Figure *3*** and **Figure *4*** respectively. SEM results show there are dendritic formations and carbide phases. EDS analysis determines Cr and Mn from substrate mixed into the coating.



a) SEM image of D3
b) SEM image of D3



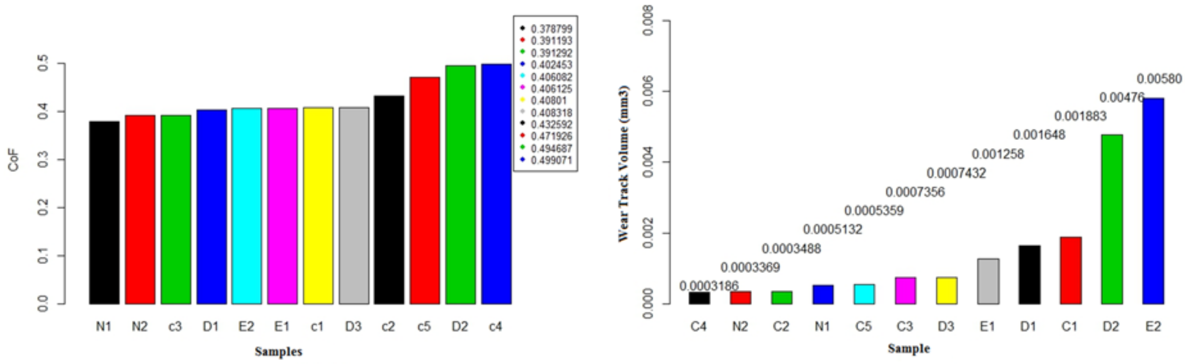
c) SEM image of D3
Figure 3. SEM images of sample D3



a) Element Weight Ratios of sample D3 b) Element Weight Ratios of sample D3 lower values
Figure 4. EDS Analysis of sample D3

3.2 Ball-on-Disk Test

The results of ball-on-disk tests were analyzed using trib on R. Coefficient of friction and wear track volumes of samples are given at **Figure 5**. The sample with the least amount of wear track volume, C4 has the highest CoF.



a) Coefficient of Friction of Samples b) Wear Track Volume of Samples
Figure 5. Coefficient of Friction and Wear Track Volume

In order to understand wear characteristics, change in friction force with respect to distance graph given at **Figure *6*** should be inspected. As seen from figure C4 sample that contains 4% Ekabor II and was prepared at mill reached steady state around 30m like the other samples but then friction force started to increase. As seen from **Figure *7*** C4 has the smallest wear track of all samples.

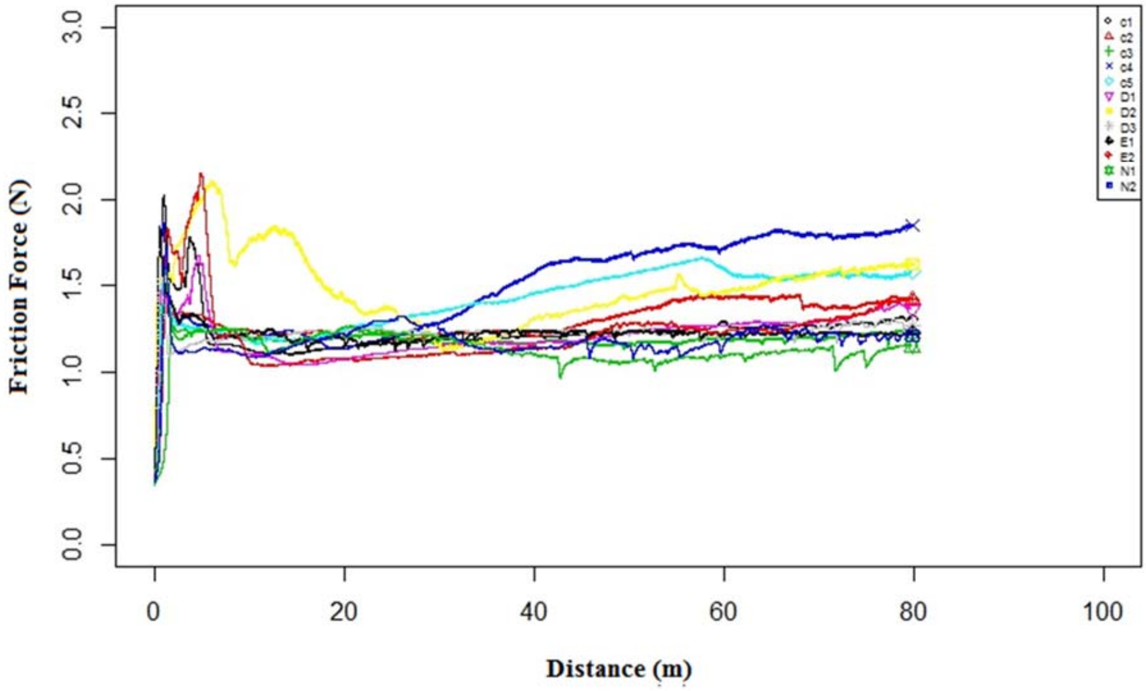


Figure 6. Friction Force vs Distance graph

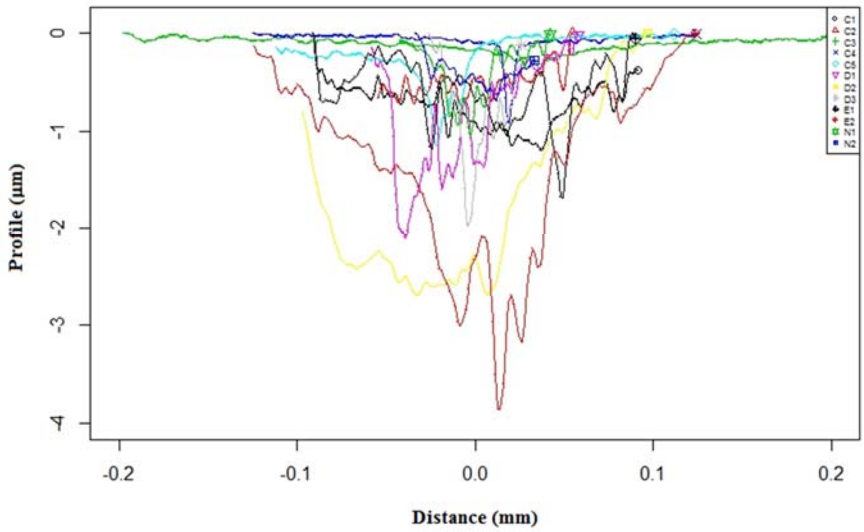
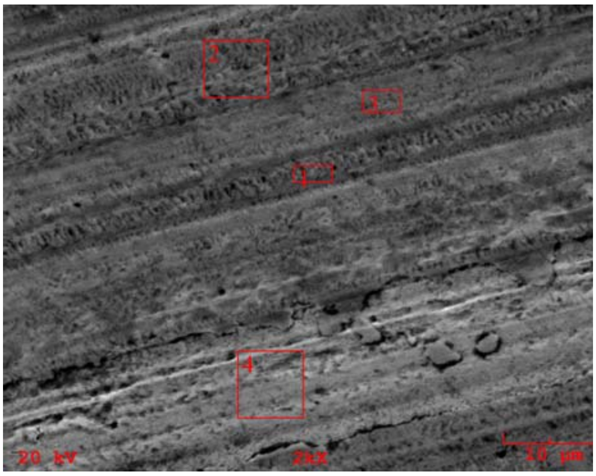
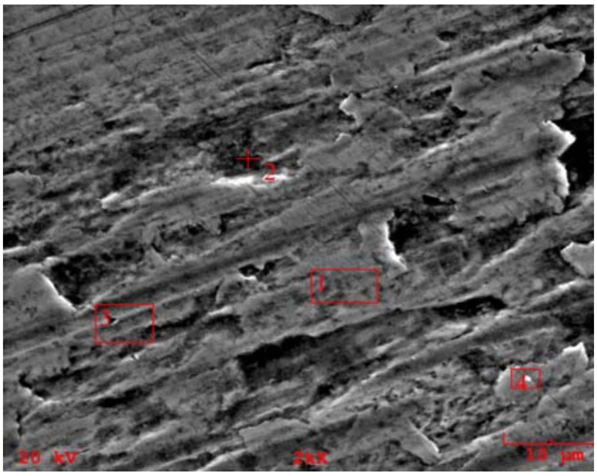


Figure 7. Wear Track Profile

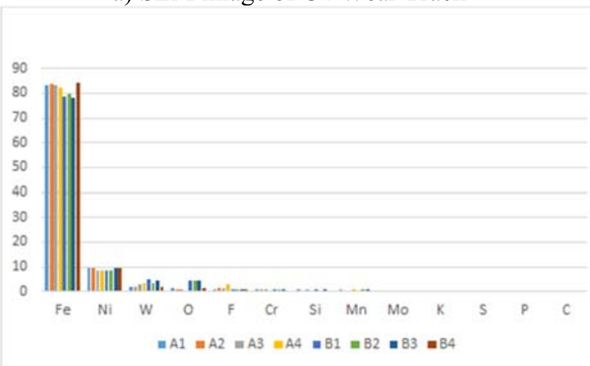
So as to understand wear mechanism SEM and EDS analysis of wear tracks of samples were conducted. C4 shown adhesive and abrasive wear behavior and as seen from **Figure *8***. D3 however show mostly abrasive wear as seen at **Figure *9***.



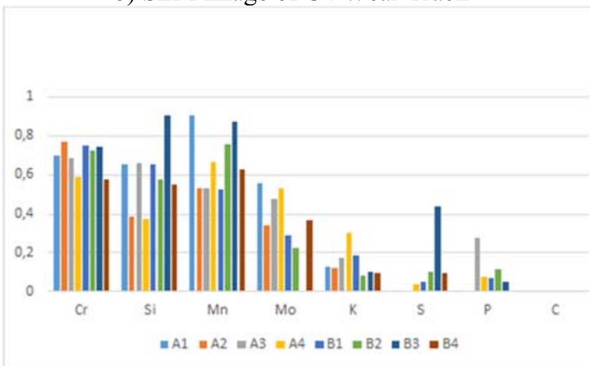
a) SEM image of C4 Wear Track



b) SEM image of C4 Wear Track

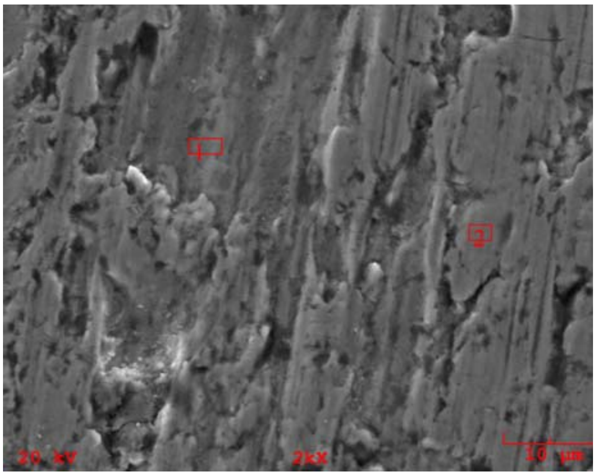


c) EDS analysis of C4 Wear Track

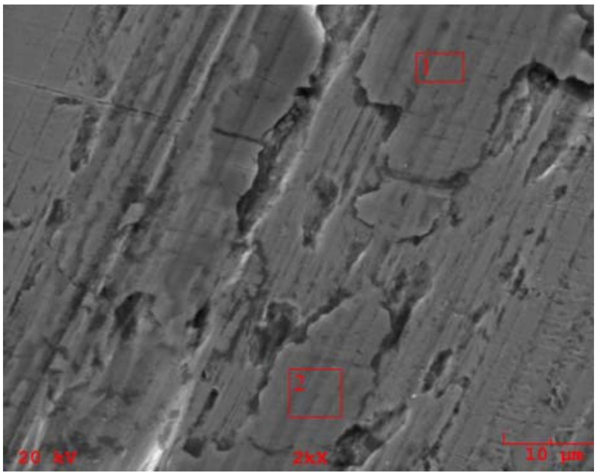


d) EDS analysis of C4 Wear Track Lower Values

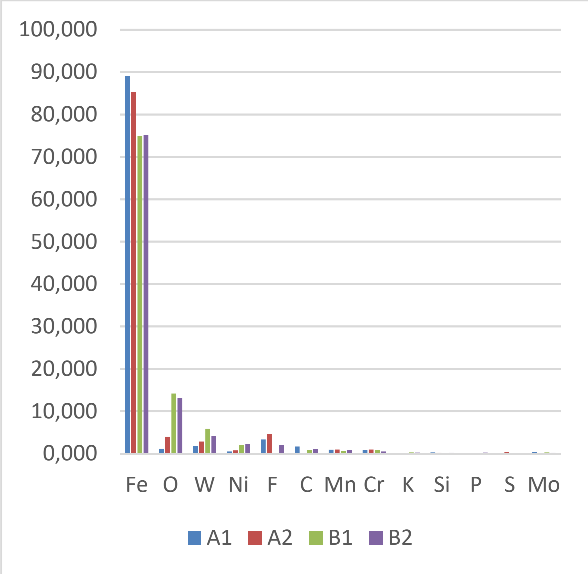
Figure 8. SEM and EDS of C4 wear track

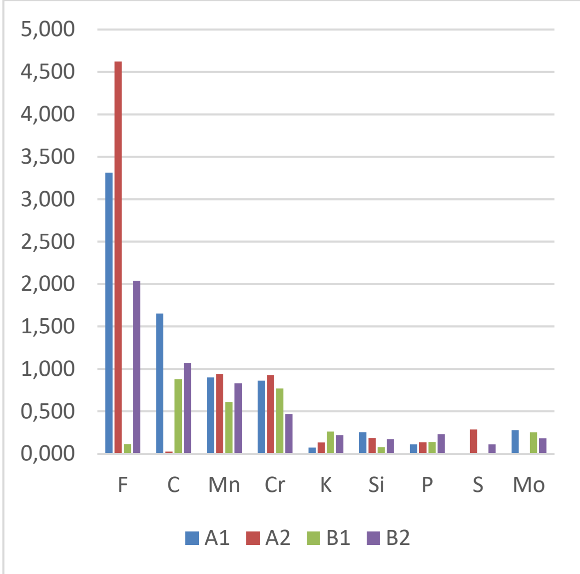


a) SEM image of D3 Wear Track



b) SEM image of D3 Wear Track





c) EDS analysis of D3 Wear Track d) EDS analysis of D3 Wear Track Lower Values

Figure 9. SEM and EDS analysis of D3 Wear Track

High percentage of Tungsten (W) content in EDS results show that there exists higher adhesive wear on samples. This is the result of two mechanisms working on samples. First the wetting angle of Nickel to Tungsten is 0 (de Macedo, da Silva, & de Melo, 2003). Zero wetting angle means Nickel will coat WC if melts while wear tests. In studies conducted on WC cutting tools on Nickel alloys it was found that WC diffuses to Nickel and tool wear is observed (Xue & Chen, 2011), (Liao & Shiue, 1996). A study on NiCrSiB coating found that Nickel adheres to WC and hard carbides or borides remove that layer of Nickel and cause adhesion (da Silva & D'Oliveira, 2016). These studies confirm that adhesive wear is main wear mechanism on these samples.

In order to understand the relations between wear track volume, coefficient of friction and mixture ratio a 3d graphic was plotted. As seen from ***Figure 10***, 2 samples are out of pattern. Those were E2 (6% B_4C) and D2 (10% Ekabor II ™). These are result of increased abrasive wear on samples. Adhesive wear generated particles and those particles act as third body and caused an increase in abrasive wear.

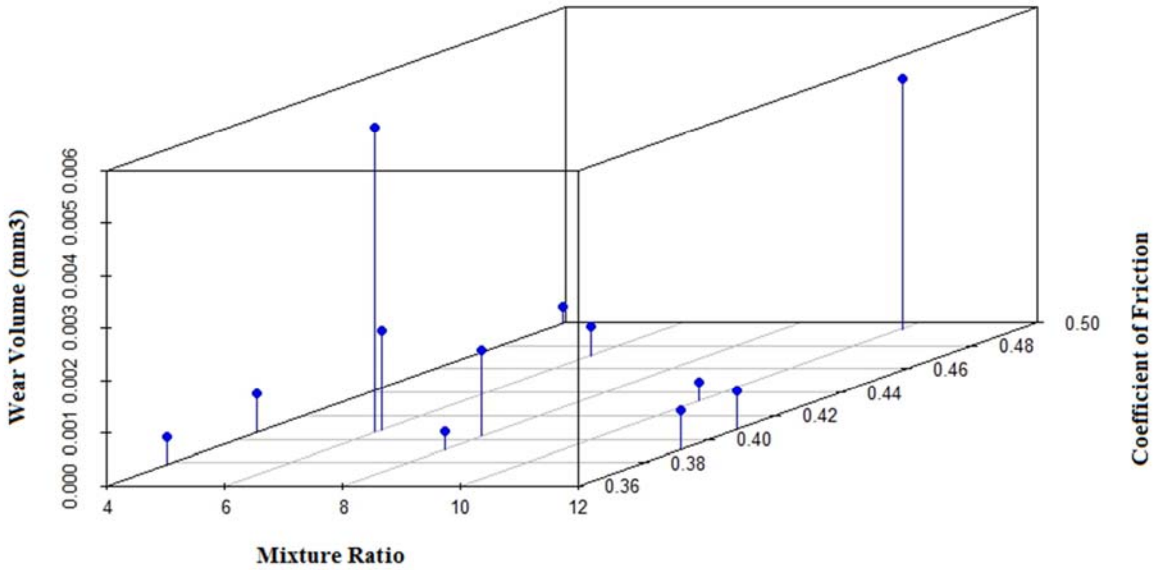


Figure 10. 3D plot of variables.

Inspecting Coefficient of Friction versus Wear Volume Plot at **Figure *11*** shows that N1, N2, C3, E1 and D3 result in best Coefficient of Friction and Wear Volume.

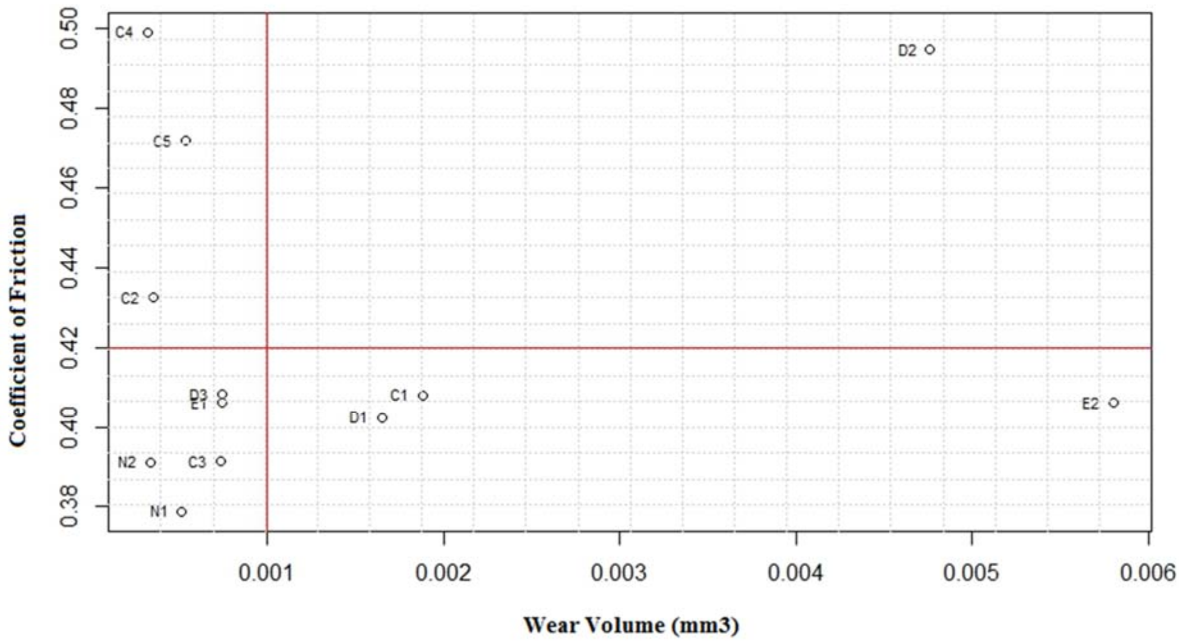


Figure 11. Coefficient of Friction versus Wear Volume Plot

Conclusion

The results show that

- Although B4C in coating increased surface properties, more than 4% B4C causes a decrease in surface properties, thus should be avoided.
- Nickel base shouldn't be used for low temperature environments because of adhesive wear properties. Thus Nickel base should be used in high temperature environments where Nickel Oxides can form.

Acknowledgements

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