

Effect of Coating Thickness on Wear Performance of Inconel 625 coating

R R Phiri ¹, O P Oladijo ^{1,2*}, N Maledi³, E T Akinlabi ²

¹ Department of Chemical, materials & Metallurgical Engineering, Botswana International University of science and technology, Palapye, Botswana

² Department of Mechanical Engineering science, University of Johannesburg, Auckland park , Kingsway Campus, Johannesburg, Gauteng, South Africa.

³ School of Chemical and Metallurgical Engineering, University of Witwatersrand, South Africa

corresponding author: Tel. +27716143884 E-mail: seyiphilip@gmail.com

Abstract. INCONEL® nickel-chromium alloy 625 is widely used for its high strength, excellent corrosion resistance and creep resistance on prolonged exposure to aggressive environment. However, despite its properties and industrial application, its wear resistance is not entirely satisfactory. The article investigates and presents the tribological performance of Inconel 625 coating using reciprocating scratch test. High velocity oxyfuel (HVOF) method was used to deposit Inconel 625 film onto 304 stainless steel surfaces. The frictional behavior and wear data were studied in order to observe the effect of coating thickness on wear failure. The results revealed that coatings of higher thickness showed lower coefficient of friction, better adhesion and good wear resistance in comparison to the low coating thickness.

1. Introduction

Superalloys are complex metallic alloys with the ability to retain their mechanical integrity and surface stability even at elevated temperatures. [1]. These alloys have been extensively used for extreme engineering environments including but not limited to, aerospace systems, sea water applications, gas turbines and nuclear facilities. The aerospace industry's technological and application evolution all over the world is mainly due to advancement in the high temperature materials field. Inconel alloys have traditionally been used for their good corrosion and high temperature resistance[2]. Inconel 625 is a material of interest in the reduction of wear degradation in erosive corrosive environments. Typical application of Inconel 625 are gas turbines, pressure vessels, chemical processing plants, heat shields and special marine application[3]. The high strength of alloy 625 was due to the stiffening effect of molybdenum and niobium on the nickel chromium matrix. Investigations of Inconel 625 on wear and applications are becoming a growing area in hard coating research.

The deposition of Inconel 625 by means of HVOF spraying represent an alternative way for producing quality coatings of higher thickness and improved adhesion on metal substrates. This deposition method of deposition involves particles dispensing at high combustion pressures and

supersonic speed resulting in excess impacting force creating a mechanical adhesion of powders to the solid surface [4].

Several researchers **have worked** on the HVOF coating performance of the Inconel alloys. However, the previous studies [2], [4], [5] were mostly concerned about the coating's wear performance with respect to alloy composition, temperature effects and loading conditions. An in depth understanding of the wear characteristics and mechanisms have yet to be fully achieved in respect to coating thickness. Wear is basically the undesirable removal of solid from a sliding or rolling component. The majority of engineering materials lose their durability and reliability due to wear thereby incurring both important economic and technical consequences[6], [7]. There are two major types of wear mechanisms likely to take place on Inconel coatings, adhesive wear and abrasive wear. In this study, the effect of Inconel coating thickness on wear rate and mechanism is investigated.

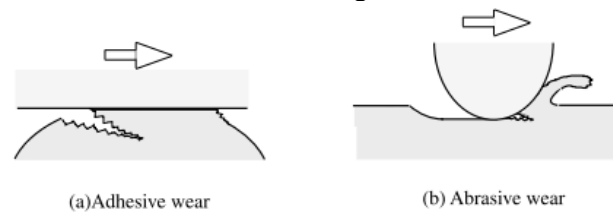


Figure 1. Schematic of Adhesive wear mode and abrasive wear mode [7].

Table 1. Chemical composition of Inconel alloy 625.

Element	Ni	Cr	Mo	Fe	Nb+Ta	Ti	Al	Si	Mn	Co	C
%wt.	Balance	21.7	8.8	3.9	3.9	0.23	0.17	0.15	0.14	0.08	0.05

2. Experimental Details

Inconel 625 powder was used for this research work with their composition listed in Table 1. Four rectangular (100x100x3mm) 304 stainless steel plates **were used** as substrates for the deposition of Inconel 625 by High Velocity Oxy-Fuel technique using the Sulzer Metco HVOF hybrid DJ-2600. Prior to deposition, all the substrates were grit blasted and degreased. Kerosene was used as the fuel for the deposition system used. The process parameters were kept constant and the coating thickness of 250 μ m, 300 μ m, 400 μ m and 500 μ m were achieved through number of passes of the spray gun at a transverse speed of 1m/s. Table 1 below shows the coating parameters used.

Table 2. Process parameters of the Inconel 625 coating

Oxygen flow rate (m ³ /h)	(Kerosene) flow rate (m ³ /h)	Powder feed rate (g/min)	Chamber Pressure (bar)	Stand-off distance (mm)	Nozzle length (mm)
52.39	0.03	80	7.8	375	101.6

Dry sliding wear tests were carried out at room temperature using the Rtec universal tribometer. The ball used was E52100 Alloy steel, grade 25 with a diameter of 6.35mm configured for the ball-on-disk mode. The sliding speed was set to 1mm/s for a period of 30 seconds reciprocating on a distance of 5mm with the load of 150N applied to the surface of the samples. Studies of the sliding contact between the samples flat surface and the tribometer ball were conducted on four different Inconel 625 coated samples of coat thickness of 250 μ m, 300 μ m, 400 μ m and 500 μ m respectively. The wear resistance of as-received 304 substrate stainless steel was also analyzed.

3. Results and Discussion

3.1. Coefficient of Friction

The coefficient of friction was recorded for all Inconel coated samples. Results were taken from time 0 seconds which is when the test began until 5 seconds when it decelerated to reverse the direction of travel (Figure 2). As expected, it is observed that the friction coefficient increases with time and distance for all coating thickness. This behavior is attributed to the interaction of the ball material and the coating surface. The fluctuations observed are due to the breakage and detachment of the hard Inconel layer from the surface during sliding under the occurrence of abrasive wear behavior. Generally, the μ value observed was more pronounced for the 300 μm coating thickness and the least μ was observed for the 500 μm thickness. This depicts that the tangential movement faced more resistance from the 300 μm coating as compared to the 500 μm coating thickness. This difference in friction coefficient is primarily due to the mechanical interlocking of asperities on the substrate material during coating hence influencing different wear failure mechanism susceptibility.

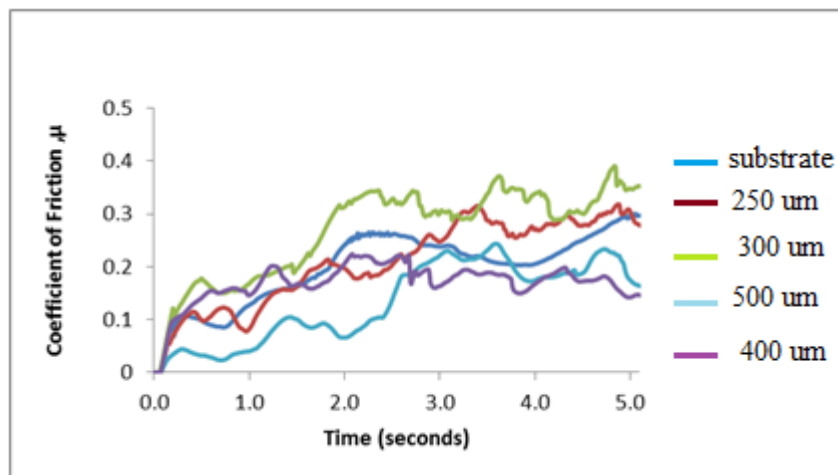


Figure 2. Friction Coefficient as a function of time for Inconel alloy 625 coatings.

3.2. Wear Track and Profiling

In order to have a better understanding of the thickness effect during wear testing the scratches were imaged using x10 magnification lens. Figure 3 shows scratch images of the coatings with their corresponding surface profiles. From the images, layer removal, chipping, and delamination of the coating were observed. The results suggest that as the coating thickness is increased, less material is scrapped off the surface. Scratch test on the uncoated substrate shows a uniform wear track and a uniform wear profile as expected. This is owing to the surface being squeezed out of the contact region inducing plastic deformation. As previously stated, the ball used was E52100 alloy steel, this is a very hard material compared to the 304 stainless steel substrate hence making it easier to scrape out a large groove observed. The coated samples images however show random dark and light regions indicating regions of lower and higher depths respectively, suggesting that as the coating thickness is increased, the wear rate of the material is reduced. Evidently from the images, the regions of lower and higher depths are becoming less apparent and the worn surface is non uniform indicating that the more the thickness the more the substrate is protected against wear. Tiny lighter regions indicative for the ball debris can be seen for the coating thickness of 500 μm , the wear of the coating was dominated by the abrasive and adhesive wear, that's is why the ball used had to be changed every now and then. It is highly likely that the debris generated from the ball would act as hardening grits in the Inconel coating. The surface profile of the coated samples depicts a non-uniform surface on the wear track, the wear track becomes more arbitrary with increased thickness, and furthermore, at higher thickness the groove

is not clearly visible except for smidges of cracks, pores and chips of the film worn. The average depth of the wear tracks on different thicknesses shown in Figure 4. The wear track depth was decreasing with increase in coating thickness. Overall, there was a correlation between the surface profile and optical scan data.

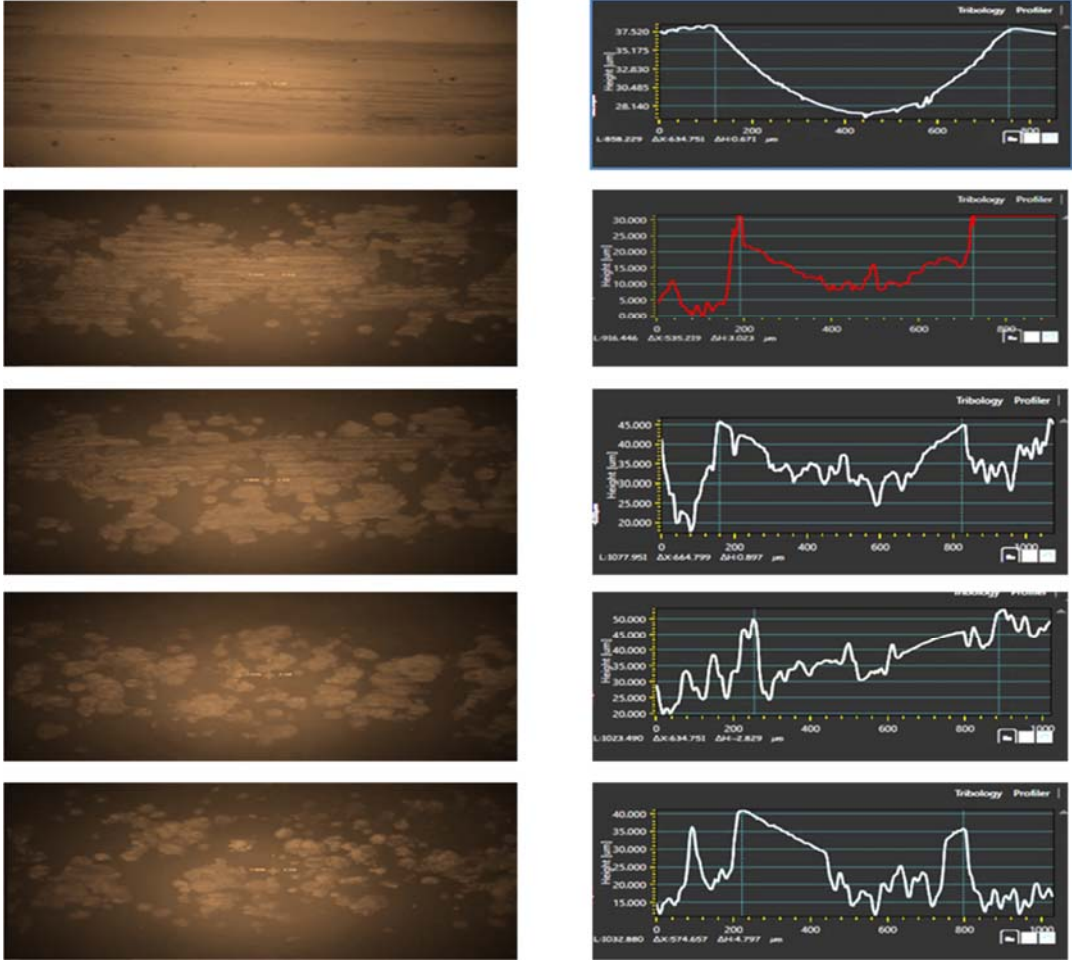


Figure 3. Optical Images of wear track and corresponding surface profiles.

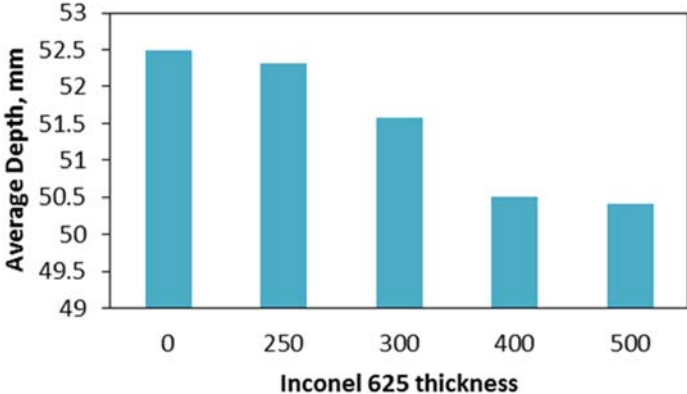


Figure 4. Average depth on different coatings

4. Conclusion

The wear behavior of HVOF sprayed Inconel 625 coating of different coating thicknesses was studied on 304 stainless steel substrate. The universal tribometer was used to quantify coefficient of friction and wear tracks on the different coating thickness. The friction coefficient results indicate that the 500 μ m coating thickness experienced lower friction hence lower wear rate. Wear track images, surface profile and depth bar graph shows that better wear resistance is achieved through thicker coatings of Inconel 625. The prominent wear mechanisms experienced on this study are adhesive and abrasive wear due to the interaction of the hard steel ball, Inconel 625 coating and a softer 304 stainless steel substrate. The study showed that tribological properties are a function of temperature, testing variables as well as coating thickness.

Acknowledgement

The authors wish to thank the South Africa Thermal Spray Industry for the production of this coating. Authors also wish to acknowledge the financial and technical support from Botswana International University of Science and Technology (BIUST), Palapye.

References

- [1] B. Geddes, H. Leon, and X. Huang, *Superalloys: Alloying and Performance*. 2010.
- [2] G. R. Fox and H. Liang, "Wear Mode Comparison of High-Performance Inconel Alloys," *J. Tribol.*, vol. 132, no. 2, p. 021603, 2010.
- [3] S. Vezzù, "Characterisation of Inconel 625 coatings deposited by cold spray," no. September, 2011.
- [4] A. A. Boudi, M. S. J. Hashmi, and B. S. Yilbas, "HVOF coating of Inconel 625 onto stainless and carbon steel surfaces: Corrosion and bond testing," *J. Mater. Process. Technol.*, vol. 155–156, no. 1–3, pp. 2051–2055, 2004.
- [5] V. Podgursky, A. Gregor, E. Adoberg, and P. Kulu, "Wear of hard coatings , evaluated by means of kaloMax," *Tallinn Univ. Technol.*, vol. 12, pp. 419–426, 2006.
- [6] J. K. Lancaster, "Fundamentals of wear," *Tribol. Int.*, vol. 22, no. 4, pp. 301–302, 1989.
- [7] K. Kato and K. Adachi, "Wear Mechanisms," *Mod. Tribol. Handbook. Vol 1*, p. 28, 2001.