Dicle University Journal of Engineering (DUJE)

web: http://dergipark.gov.tr/dumf

Research Article

Wear Resistances of X6Cr17 Ferritic Stainless-Steel Surfaces Coated with Al_2O_3 Powders Using Thermal Spray Method

Hülya DURMUŞ, Mustafa TÜRKMEN, Uğur ÇALIGÜLÜ

[1] Manisa Celal Bayar University,Engineering Faculty,Dept. of Metallurgy and Materials Engineering.Manisa/Turkey. ORCID ID: 0000-0002-7270-562X
[2] Gebze Technical University, Institute of Transport Technology, Kocaeli / Turkey. ORCID ID:0000-0002-9402-2459
[3] Fırat University, Faculty of Technology, Dept. of Metallurgy and Materials Engineering, Elazığ/Turkey. ORCID ID: 0000-0003-4862-7219

ARTICLE INFO

Article history:

Received 21 May 2020
Received in revised form 17 June 2020
Accepted 20 June 2020
Available online 30 September 2020

Keywords:

X6Cr17, Al_2O_3, TiO_2, *Thermal spray coating, Wear resistance.*

Doi: 10.24012/dumf.741145

ABSTRACT

The aim of this study was to improve the surface properties of the X6Cr17 ferritic stainless steels by coating with the Al_2O_3-TiO_2 powders in the thickness of 0-100µm, 100-200µm and 200-300µm by using the plasma spray method, one of thermal spray methods. Wear resistance of the samples was investigated after the coating process. The tests were carried out by pin-on-disc method according to ASTM G133 standard. After examination of the results, it was observed highest abrasion resistance of A3 sample. It was concluded that the abrasion resistance in the high hardness sample does not mean that it will be good due to the high hardness.

* Corresponding author
Hülya DURMUŞ
✉ hulya.durmus@cbu.edu.tr

Please cite this article in press xxxxxxxx Please cite this article in press as H. Durmus, M. Turkmen, U. Caligulu, “Wear Resistances of X6Cr17 Ferritic Stainless-Steel Surfaces Coated with Al2O3 Powders Using Thermal Spray Method ”, DUJE, vol. 11, no.3, pp. 1167-1173, September 2020

Introduction

X6Cr17 steels comprise approximately one half of the SAE-AISI type 400 series of ferritic stainless steels. They are known by their excellent stress corrosion cracking resistance and good resistance to pitting and crevice corrosion in chlorine environments. Welding is known to reduce toughness, ductility and corrosion resistance because of the grain coarsening and carbide precipitations. The grain size gradually increases from the edge of heat-affected zone to the fusion boundary. Welding of 400 the series usually requires preheating and post-weld heat treatment to minimize stress that can lead to cracking [1].

Ceramic materials; due to their superior thermal, mechanical, chemical and electrical properties, they have recently been preferred in critical applications. The most common and easy to apply ceramic coating process; It is based on the principle of spraying powdered ceramic on the substrate surface by heating. Oxide ceramic coatings such as alumina (Al_2O_3), zirconia (ZrO_2) and chromium (Cr_2O_3) produced by thermal spraying methods are widely used in many industrial applications where high abrasion resistance is required. Alumina; often-used in combination with titania (TiO_2). As the amount of TiO_2 increases, the fracture toughness of the coating increases, but the hardness and wear resistance decrease. Therefore, a low amount of TiO_2 is preferred. Plasma sprayed alumina coatings; due to their high hardness and good electrical insulation, they are used in the automotive industry to isolate metal substrates. Electronic circuits are then manufactured on these coatings. Alumina coatings are also used in computer memory discs to provide electrical insulation and to form a wear-resistant surface [2].

Coatings are an engineering solution for improving the material surfaces against wear, corrosion, degradation and other surface events. Since coatings are applied in many fields, there are many coating materials and coating methods. The main distinguishing properties between these coating methods are based on the thickness of the coating obtained in the process and the temperature differences forming on the coated material. These properties are the determining parameters for choosing the coating method by considering the properties of the coating material and the material to be coated. Thermal spray coatings are the most popular and most preferred method among these coating methods since they are versatile due to their wide coating thicknesses and substrate temperatures and have good mechanical properties [3-6].

Thermal spray is the general name of a group of processes in which metallic or non-metallic surface coating materials are molten or semi-molten by a heat source and applied to form a coating on a previously prepared surface. The surface coating material may be in powder, wire or rod form. The thermal spray gun produces the required heat with a flammable gas or electric arc. When heated, the coating materials become semi- molten, accelerated with the help of the gases used in the process and moved towards the surface of the base material. The particles flatten by hitting the surface, form thin plates and stick to the rough surface and to each other. When the particles sprayed hit to the surface of the base material, they cool, solidify and form a lamella structure, which forms the coating. The adhesion of each particle takes place with mechanical bonding or metallurgical bonding or diffusion in some cases. Increasing speed of the particles provides a better adhesion strength and higher density. In order to ensure a good bonding between the base material and the coating, it is extremely important to roughen the surface of the base material by sandblasting and to remove and clean the oil completely before coating [7].

Allowing to obtain high heat with plasma makes it possible to use ceramic and metal-based alloy powders with high melting point in coating applications. The ceramics are an important coating material with the advantage of their properties such as high wear and hardness properties, the availability and cheapness of their raw material, corrosion, oxidation and low thermal conductivity and high number of thermal cycles. However, due to their high melting points, their applicability/melting capability in coating applications are only possible at very high temperatures. Plasma spray coating technology depending on the use of plasma energy allows the processability (coatability) of materials with high melting temperature as coating material [8, 9]. Figure 1. shows a schematic view of the plasma spray method.

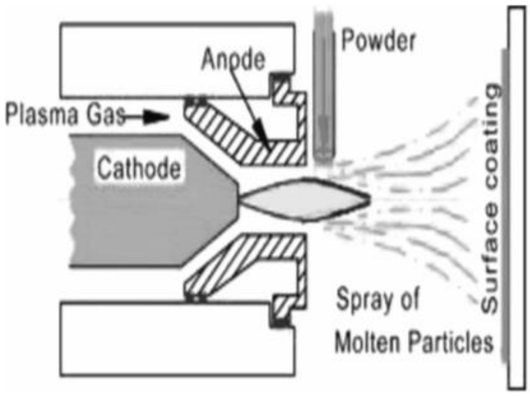


Figure 1. *Plasma spray system [10].*

Plasma spraying technique is the general definition for different metallic or non-metallic coating application group in the molten or semi-molten state on a substrate prepared for spray accumulation. Molten or semi-molten particles are rapidly directed to the previously prepared surface with the gases and atomized jets used. A mechanical bonding occurs at the interface with the hitting of molten or semi-molten particles to the surface. A coating structure forms with repeating hits and bonding of the directed particles. These finely adherent particles suddenly solidify on the surface of the substrate by showing a very rapid cooling regime. Thus, the spraying process is completed [11].

In the study by Aslan (2015), biocompatible coatings comprised of mono and double-layered hydroxyapatite (HAP) and TiO_2 powders were produced with plasma spray coating method on the surfaces of AISI 316L stainless steel materials used as implant material. They observed that the corrosion resistance of AISI 316 L stainless steels coated with HAP improved [12]. In their study, Islak et al. (2019), investigated the microstructure, wear and corrosion properties of Ti_3SiC_2 MAX phase coating produced on AISI 304 stainless steel by plasma spray method. The wear properties of the coating and substrate were determined using the scratch test. The friction coefficient of the coating layer was found to be low compared to the substrate [13]. Irsat (2016) obtained the coating material by accumulating mechanical alloyed composite powder Al-12Si with 100 mm spray distance and Al-12Si/SiO_2 with 150 mm spray distance on surface of Al matrix with plasma spray method on the base material and they observed that the alumina formation increased as coating distance increased [14].

Materials and Methods

Firstly, the X6Cr17 ferritic stainless steel plates were cut, then their surfaces were coated with Al_2O_3 powders, whose properties were shown in Table 1, 2, 3 and 4 to have different coating thicknesses by using a plasma spray coating device setup in a private company in Figure 2. Table 2 shows chemical composition of the material used in the experimental study.

Table 1. *Properties of powders used in coating process*

Oxide Powder	Powder Grain Size	Powder Morphology	Chemical Composition
Aluminum Oxide Al_2O_3 Amdry 6220	-22+5µm	Angular	Al_2O_3 13TiO_2

Table 2. *Chemical composition of X6Cr17 ferritic stainless steels.*

Weight (%) Composition							
Material	**Fe**	**C**	**Si**	**Mn**	**P**	**S**	**Cr**
X6Cr17	Balance	0.055	0.045	0.420	0.031	0.008	17.0

Table 3. *Mechanical properties of X6Cr17 ferritic stainless steels.*

Materials	Tensile Strength (MPa)	Yield Strength 0.2% (MPa)	Elongation. (%)	Microhardness (Rockwell B)
X6Cr17	517	345	25	170

Table 4*. Codes of coated samples used in the experimental study*

Substrate Material ↓ X6Cr17	Al_2O_3 coating thickness		
	0-100µm	**100-200µm**	**200-300µm**
Code →	A1	A2	A3

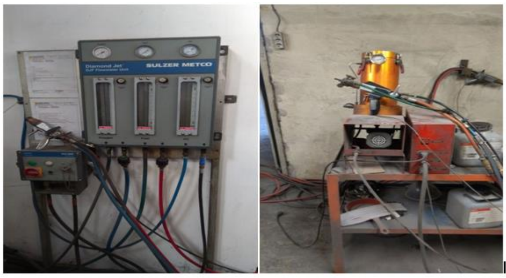


Figure 2. Plasma spray coating system that used for coating

The microhardness of the coatings was measured using Vickers (HV 20) indenter at Futuretech hardness device.

. The average hardness values of three measurements were calculated. Coating thickness and width of wear scar of samples were calculated by using Clemex Software of Nikon Optical Microscope. Wear test; Manisa Celal Bayar University, Faculty of Engineering was carried out with wear tester. The abrasion tester used is shown in Figure 3. Wear tests; it was carried out by using 10 mm diameter ceramic ball at a speed of 15 cm/sec, under a load of 5 N and at a temperature of 20 ^oC over a shear distance of 1000 m.

Figure 3. Wear test aparatus

Results

Coating Thickness

The results of coating thickness measurement of the samples are given in the Figure 4. There is a difference of 100 microns between each coated sample. In Figure 4.1., the stereo microscope images of the coatings made by plasma spray spray method are given. Oxide coatings on X6Cr17 ferritic stainless steels adhere homogeneously to the substrate. No cracks were observed in the coatings and the substrate material, and no negativity was observed which could cause the coating to detach from the sample. There are laminated structures and porosities on the oxide coated surfaces. The lamellar structure observed is the deformation of the Al_2O_3 alloy in the molten state by hitting and solidifying the substrate.

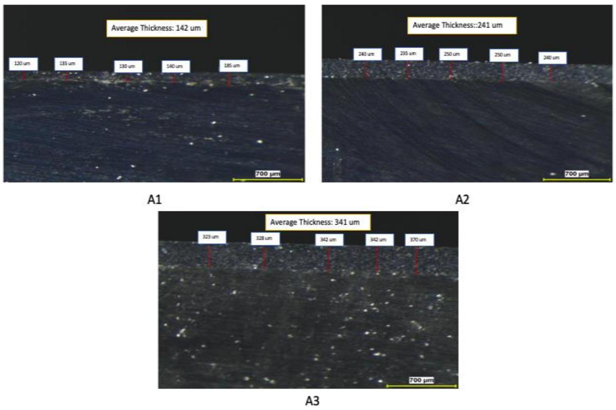


Figure 4. Images of coating thickness of A1, A2 and A3 samples

Hardness Test Results

Results of microhardness measurement of A1, A2, A3 samples were summarized in Table 5. The hardness results were obtained close to each other. While the lowest hardness was obtained in the A1 sample with the thinnest coating layer, the highest hardness was not obtained due to the effects such as gaps in the A3 sample with the thickest coating. The highest hardness value is in A2 sample.

Table 5. *Microhardness test results of coated sample*

Sample Code	Microhardness (HV)
A1	540±85
A2	880±88
A3	740±78

Wear Test Results

All samples were exposed to 1000 meters of wear road. The volume loss graph of all samples on the 1000 meters wear road is given in Figure 5. Here the volume loss is given in mm^3. Volume loss was calculated based on the wear scar depth obtained from the roughness tester.In Figure 6 and Table 6, informations of wear track wides of A1, A2 and A3 samples was given.

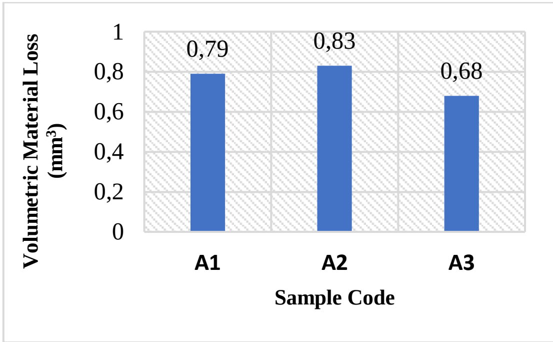
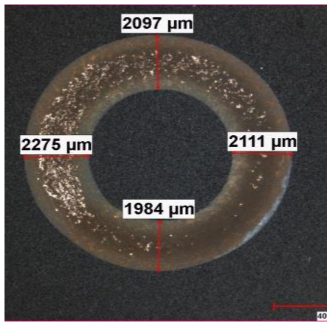
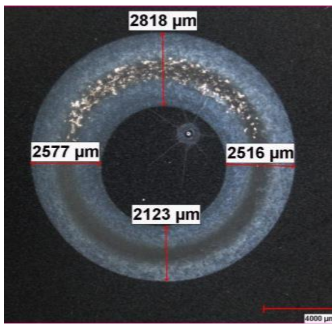


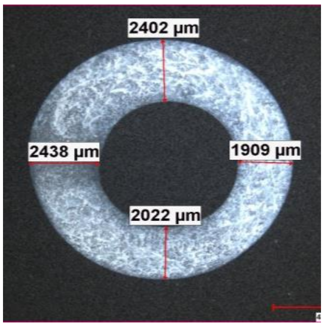
Figure 5. Graphic of volumetric material loss of A1, A2 and A3 samples at end of 1000m wear distance



A1



A2



A3

Figure 6. Images of wear track wides of A1, A2 and A3 samples

Table 6. *Average wear scar wides of A1, A2 and A3 samples*

Sample code	Wear debris wides (µm)
A1	2116.75±120
A2	2508.5±288
A3	2192.75±267

Conclusions

- It was determined because of the conducted tests and investigations that X6Cr17 ferritic stainless steel surfaces were successfully coated with plasma spray method using Al_2O_3-TiO_2 powders.
- When the wear scars of the samples are examined; the widest wear scar is observed in the A2 sample with 2508.5 µm, while the narrowest wear scar is observed in the A1 sample with 2116.75 µm. Due to the high hardness in the A2 sample, it increased the amount of wear in the form of expansion in the upper surface layer instead of in-depth wear in the coating base.
- It was determined that the wear resistance increased as the coating thickness increased. The best wear resistance was obtained in the A3 sample.

References

1. Taskin M.; Caligulu U.; Kolukisa S. The effect of welding speed on the laser welding of X6Cr17 Ferritic stainless steel with AISI 1010 low Carbon steels. *Practical Metallography* **2009**, 46, 11, pp. 598-607.
2. Akın, U. Investigation of Wear Behavior of Ceramic and Ceramic-Polymer Coatings Coated with Thermal Spray Method on Aluminum Base, Master Thesis, Istanbul Technical University, Institute of Science and Technology, 2003.
3. Davis, J.R. Thermal Spray Processes, Handbook of Thermal Spray Technology, International ASM, 329. ASM İnternational, USA, 2004.
4. Aran, A.; Temel, M.A. Production, Use and Standards of Stainless Steels, Saritas Technical Publication, Istanbul, 2004.
5. Kambur, K., The Effect of Different Substrate Temperatures on Coating Properties in Coating of Ti6Al4V alloy with HA. Master's thesis, Manisa Celal Bayar University, Turkey, 2018.
6. Durmuş H ; Çömez N ; Gül C ; Yurddaşkal M . Farklı Kimyasal İçeriğe Sahip Tellerin İki Pasolu Sert Dolgulu Malzemelerin Aşınma Davranışına Etkileri. *Muş Alparslan Üniversitesi Fen Bilimleri Dergisi*. **2018**; 6(2): 561-564.
7. AWS Committee, Thermal Spraying: Practice, Theory, and Application, American Welding Society Inc, 12-15, 1997.
8. Hidalgo, V.H.; Varela, F.J.B.; Martinez, S.P. A comparative study of high-temperature erosion wear of plasma sprayed NiCrBSiFe and WC-NiCrBSiFe coatings under simulated coal-fired boiler conditions, *Tribology International*, **2001,** 24, 161–169.
9. Islak,S.; Ozorak, C.; Kucuk, O.; Akkas, M.; Sezgin, C. Microstructure and Hardness Properties of high velocity oxygen fuel (HVOF) Sprayed WCCo-SiC Coatings, Kastamonu University, *Journal of*

Engineering and Science, **2015,** Vol.1, pp. 1–7.

10. Rajarathnam D. R. P.; Jayaraman M. Investigation of the wear behaviour of an AISI 1040 forged steel shaft with plasma-spray ceramic-oxide coatings for sugar-cane mills. *Materiali in tehnologije*, **2017**. 51(6), 939-944.
11. Sert, Y., Examining Wear Properties of Textile Piece Coated with Plasma Spray Technique, Master's thesis, Sakarya University Institute of Science, Sakarya, 2007.
12. Aslan O., Examining Corrosion Behaviors of Single and Double layered AISI 316L Stainless Steel Coated by Plasma Spray Coating, Afyon Kocatepe University, Afyon, 2015.
13. Islak, S ; Özorak, C ; Eski, Ö . Plazma Sprey Yöntemiyle AISI 304 Paslanmaz Çelik Üzerinde Üretilen Ti_3SiC_2 MAX Fazlı Kaplamanın Karakterizasyonu. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, **2019,** 8 (1), 206-213. DOI: 10.17798/bitlisfen.453085
14. Irsat C., Determining Corrosion Behavior of Al-12Si Plasma Spray Composite Coatings Reinforced with In-Situ Al_2O_3 Phases, Master's thesis, Atatürk University Institute of Science, 2016.