Wear 376-377 (2017) 1739–1746

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Sliding wear of cobalt-based alloys used in rolling seamless tubes

L.E. Falqueto [a], D.J. Butkus [b], J.D.B. De Mello [c], A.C. Bozzi [a], C. Scandian [a]

[a] Federal University of Espírito Santo, Brazil
[b] Vallourec tubos do Brasil S.A, Brazil
[c] Federal University of Uberlândia, Brazil

ARTICLE INFO

Article history:
Received 3 September 2016
Received in revised form
21 December 2016
Accepted 3 January 2017

Keywords:
Cobalt alloys
Elevated temperatures
Sliding wear
Stellite coatings
Wear mechanism

ABSTRACT

Cobalt alloys are used in several industrial applications due to their good mechanical properties at high temperatures. During manufacturing of 13% Cr super martensitic stainless steel seamless tubes by Mannesmann process, the hot rolling guides made of cast Co30Cr19Fe alloy are currently used, but present severe wear, limiting their service life. Seeking an alternative, three cobalt-based coatings (Stellite 1, 6 and 12) were selected. These coatings were evaluated and compared with the alloy currently used by sliding wear tests performed at room temperature and at 500 °C in a tribometer PLINT TE67 with pin-on-disc configuration, without lubrication and varying the normal load. The pin was made of 13% Cr super martensitic stainless steel. The discs were manufactured with cast Co30Cr19Fe alloy and some of them were coated by laser cladding process with Stellite alloys, that is, a total of four materials. The worn volume of the wear surface was analyzed by 3D profilometry. The micromechanisms were observed with a stereoscopic and scanning electron microscope. To assess the elemental composition of the wear track, analyses were performed using energy dispersive spectroscopy (EDS). The results indicate that the samples coated with Stellite presented better performance than the cast Co30Cr19Fe alloy. Among the coatings, the Stellite 1 showed the best wear resistance, both at room temperature and at 500 °C. The Co30Cr19Fe, Stellite 6 and 12 alloys, presented predominantly plastic removal mechanisms. Whereas Stellite 1 presented micro-cutting and oxidative wear.

1. Introduction

In oil extraction, among others uses, seamless tubes are used as their pipelines. The advances in oil extraction in deep waters, such as pre-salt regions of the Brazilian coast, require a more corrosion resistant material. Therefore, new steels with high chrome content, such as 13% Cr stainless super martensitic steel, were developed to producing these tubes.

One of the methods of manufacturing such tubes is the Mannesmann process. The process consists of piercing bars through a cross-roll piercing mill, composed of two cross work rolls, a stationary piercing mandrel and a pair of rolling guides [1]. During the rolling of the seamless tubes, the components are subjected to extreme wear. It occurs due to the high loads and elevated temperatures (around 1200 °C) involved. The excessive wear can lead to an excessive number of production stops and a poor quality of the final product, leading to a major economic loss to the companies.

During the super martensitic stainless steel tubes manufacture, the rolling guides are subjected to severe wear problems like galling. Consequently, its lifetime is reduced. According to Davis [2], such guides can wear out due to sliding of material, mechanical shock and abrasion.

Cobalt super alloys present a potential manufacturing option for producing this component. The cobalt-based alloys, especially the Stellites®, are widely used in high temperature wear situations [2–4]. They are composed mainly of cobalt, chromium, carbon, tungsten or molybdenum. Most of their properties come from the crystallographic nature of the cobalt and the hardening effect of the solid solution and the precipitations of chromium, tungsten and molybdenum carbide [5].

The Stellite microstructure is formed basically by hard dispersed carbides in a tough and ductile matrix. Adding such properties to its resistance to oxidation and its ability to resist plastic deformation and fatigue [5], these alloys are considered resistant to sliding wear.

Kapoor [6] presents a study of various cobalt alloys in sliding wear and associates the result with the percentage of carbon. Among the studied alloys (Stellite 3, 6, 12 and 21 for example), the higher the carbon content is, the greater is the resistance to sliding wear. This is acceptable, once the amount of this element determines the fraction volume of carbides; which are the main constituents that impart wear resistance to these alloys.

Many authors relate the resistance to sliding wear at elevated temperature of Stellites with the formation of the glaze layer [4,7,8]. Furthermore, a great resistance to oxidation provided by

http://dx.doi.org/10.1016/j.wear.2017.01.009
0043-1648/

the large amount of chrome and other characteristics, such as the presence of hard phases and maintenance of mechanical properties at high temperatures, help to give a good performance under such conditions. However, at some conditions [9,10], the glaze formation does not occur, which may lead to a severe wear.

This paper aims to evaluate and compare the resistance to sliding wear of the Co30Cr19Fe alloy with the pre-selected coatings of Stellite when slid against super martensistic stainless steel. The first is casted and is the material the rolling guides are currently made of. The coatings were obtained through laser cladding technique.

2. Materials and experimental methods

2.1. Materials

The pin (counter body) material used on all the tests was 13% Cr super martensitic stainless steel. Its nominal composition is shown on Table 1. The geometry used was a truncated cone with an initial radius of 1 mm.

Table 1
Pin nominal composition.

Element	Fe	C	Cr	Ni	Mo
Composition (wt %)	Bal.	< 0.02	13.0	8.0	2.0

The nominal chemical composition of the discs is presented on Table 2. Four different materials were used. The Co30Cr19Fe discs were obtained by casting. The coated samples were obtained by laser cladding technique using pre-selected Kennametal powders and Co30Cr19Fe disc as substrate.

The chemical composition analysis of Co30Cr19Fe alloy was obtained using plasma spectrometry techniques, atomic spectrophotometry absorption and carbon and sulfur chemical analysis by LECO. The chemical composition of the Stellite coatings was obtained using energy dispersive spectrometry technique (EDS).

For the microstructural compositions, every specimen underwent a standard metallographic procedure followed by electrochemical or chemical etch. For the Co30Cr19Fe alloy an

Table 2
Nominal chemical compositions of Co30Cr19Fe alloy as cast and selected Stellite powders used for laser cladding deposition.

Material	**Composition (% wt)**								
	Co	**Cr**	**W**	**Mo**	**C**	**Fe**	**Ni**	**Si**	**Others**
Co30Cr19Fe alloy	Bal.	28	0.2	0.3	< 0.15	22	–	< 1.2	–
Stellite 6	Bal.	28.5	4.6	< 1	1.2	< 2	< 2	< 2	< 1
Stellite 12	Bal.	30	8.5	< 1	1.45	< 2	< 2	< 2	< 1
Stellite 1	Bal.	30	13	< 1	2.5	< 2	< 2	< 2	< 1

Table 3
Chemical composition of alloys.

Material	**Composition (% wt)**								
	Co	**Cr**	**W**	**Mo**	**Fe**	**Ni**	**Mn**	**Si**	**C**
Co30Cr19Fe alloy	47.7	29.8	0.2	0.3	19.1	–	–	1.0	0.2
Stellite 6	57.4	29.7	4.5	0.2	4.4	2.1	0.6	1.2	–
Stellite 12	53.3	30.5	8.6	0.4	3.5	1.8	0.6	1.2	–
Stellite 1	47.8	31.9	13.7	0.2	3.7	1.4	0.5	0.8	–

Table 4
Vickers hardness measured at room temperature.

Material	**Pin**	**Co30Cr19Fe**	**Stellite 6**	**Stellite 12**	**Stellite 1**
Vickers Hardness (HV 1)	284 ± 4				
Vickers Hardness (HV 0,1)		310 ± 11	466 ± 18	546 ± 21	690 ± 29

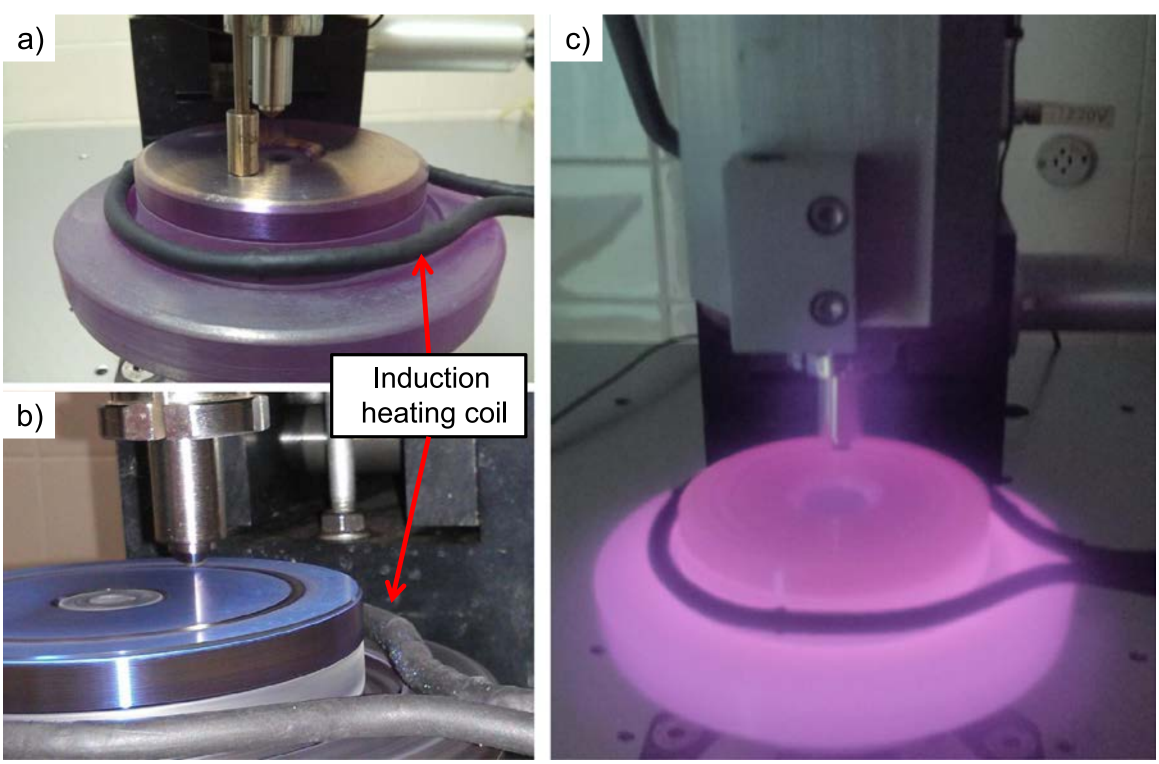

Fig. 1. (a) Heating setup used for tests at 500 °C. (b) Positioning of the induction heating coil close to the disc. (c) Example of the heated setting.