Wear 376-377 (2017) 1489–1501

Contents lists available at ScienceDirect

Wear

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

Sliding wear analysis of cobalt based alloys in nuclear reactor conditions

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ARTICLE INFO

Article history:
Received 5 September 2016
Received in revised form
1 December 2016
Accepted 8 December 2016

Keywords:
Sliding wear
Cobalt-based alloys
Contact mechanics
Pin on disc
Wear prediction

ABSTRACT

The study of the wear behaviour of cobalt based alloys in nuclear reactor environmental conditions is the focus of this work. The alloys are used in components within reactors due to their excellent wear and corrosion resistance and their high hardness in the high pressure and temperature water facing environment. In the nuclear reactor core, cobalt is irradiated producing a highly penetrative gamma emitting isotope, cobalt 60 from stable cobalt 59. Wear of the cobalt alloys, producing wear debris, exacerbates this problem as it may be transported and deposited at various locations throughout the primary loop increasing the potential of radiation exposure. Removing this problem will require the removal of cobalt from the system.

In order for suitable replacement materials to be identified, a better understanding of the behaviour of these alloys in the prototypical working conditions must be obtained. This work focuses on two cobalt based alloys used in the ball and race components of rolling element bearings in the reactor core, Stellite 20 and Haynes 25, respectively. The sliding wear behaviour of the alloys in an environment designed to replicate reactor conditions is examined using a bespoke pin on disc tribometer. Wear measurement and microstructural and compositional analysis of the samples tested over a range of conditions are presented and discussed.

Concurrent to the experimental work is the development of a wear prediction model using a semi analytical method. The model employs Archard's wear law as the method of predicting wear using data obtained through experimentation. The accuracy of the semi analytical model is limited however it does give a good estimation for maximum wear depth of the test specimens.
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1. Introduction

Cobalt-based alloys offer very good resistance to wear and chemical corrosion, and, thanks to their exceptional properties in water lubricated environments, they are often used in different bearing surfaces in nuclear applications. In reactor environments, stable cobalt-59 is bombarded with thermal neutrons producing a radioactive isotope cobalt-60 [1]. Cobalt-60 has a relatively long half-life of 5.3 years and is a penetrative gamma emitter. Wear debris generated in bearings containing cobalt-60 is transported, suspended in the coolant, becoming deposited at locations around the loop. Exposure to cobalt-60 containing wear debris, produced due to different wear mechanisms, is a leading contributor to occupational radiation exposure of maintenance personnel [2].

Therefore, in order to reduce exposure to these isotopes, a leading contributor to occupational radiation exposure, there is a trend to reduce and ultimately remove cobalt based materials to facilitate decommissioning. It is necessary to find an alternative to cobalt based alloys which has suitable tribological properties in water; this can only be achieved by exploring the tribological behaviour of these alloys for bearing applications in more detail and unravelling the mechanisms responsible for their superior performance so that they can be mimicked using Co-free alloys.

The excellent oxidation and corrosion resistance of cobalt-based alloys have made them ideal candidates for application in extreme environments, as already observed by the survey produced by Amateau and Glaeser in the early '60s [3] on the selection of bearing materials for high temperatures. These alloys are widely used in high temperature engineering applications as their resistance to wear and corrosion is often paired to their maintenance of strength at elevated temperatures [4]. These favourable

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http://dx.doi.org/10.1016/j.wear.2016.12.018
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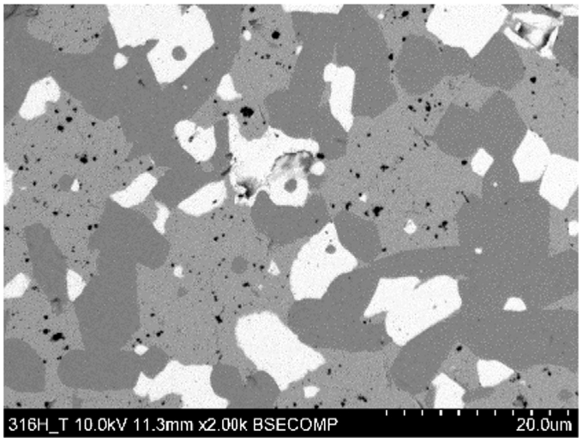

Fig. 1. Microstructure of an undamaged Stellite 20 ball.

Table 1
Material composition.

%wt	Co	Ni	Cr	W	Fe	Mn	Si	C
Stellite 20	Balance	3 **	30-34	13	3 *	0.5 *	1 *	2.8-3
Haynes 25	Balance	10	20	15	3 *	1.5	0.4 *	0.1

* = Maximum.

characteristics are attributed to a number of factors. Chromium, tungsten and molybdenum contribute to the solid solution strengthening of the alloys. Chromium also contributes to the corrosion resistance with tungsten promoting the high hardness of the alloys. The oxidation behaviour and the resistance of alloys to deformation are the main reasons behind their excellent wear performance [4].

In the past decades the use of cobalt-based alloys as bearing material has been widely accepted and a number of examples can be found in the literature where researchers have been investigating friction and wear properties of such materials in severe

Table 2
Test conditions.

Test Setup	Description					
Time	180 minutes					
Speed	200 rpm					
Sliding distance	2295.95 m					
Test conditions	**Test number**					
	1	2	3	4	5	6
Normal load [N]	10	10	10	35	35	35
Temperature [°C]	20	100	200	20	100	200

testing conditions (see e.g. [5–17]). In particular, an interesting review of the level of understanding of the elevated temperature wear resistance of various metals and alloys, including many Co-based materials, was reported by Pauschitz et al. [10]. The formation of a “glaze” under different alloying, temperature and sliding conditions was identified as a salient feature in a systematic review of all results reported in the recent literature. Different classifications of the “glaze” formed on the surface of metal components that underwent sliding wear tests in elevated temperatures are identified either as transfer layers, mechanically mixed layers and composite layers. Scenarios where no layer was formed were also mentioned but it was indicated that most studies reviewed, identified the formation of a layer, its classification depending on the salient features mentioned above. The comparative chemical composition of the wearing and mating surfaces versus that of the worn surface are described as identifying features for each classification. It is pointed out that in the case of the transfer and mechanically mixed layers the oxygen content of the worn surface is low where as a high oxygen content is anticipated in the presence of a composite layer. The wear conditions of the test will also influence how these layers are formed. A series of studies was also conducted by Yu et al. [15,16,18] to study the influence of manufacturing process and alloying element content on the tribomechanical properties of cobalt-based alloys. The aim was to comprehend the structure-property relationships of a wear resistant cobalt-based alloys (Stellite 20 and Stellite 6) produced

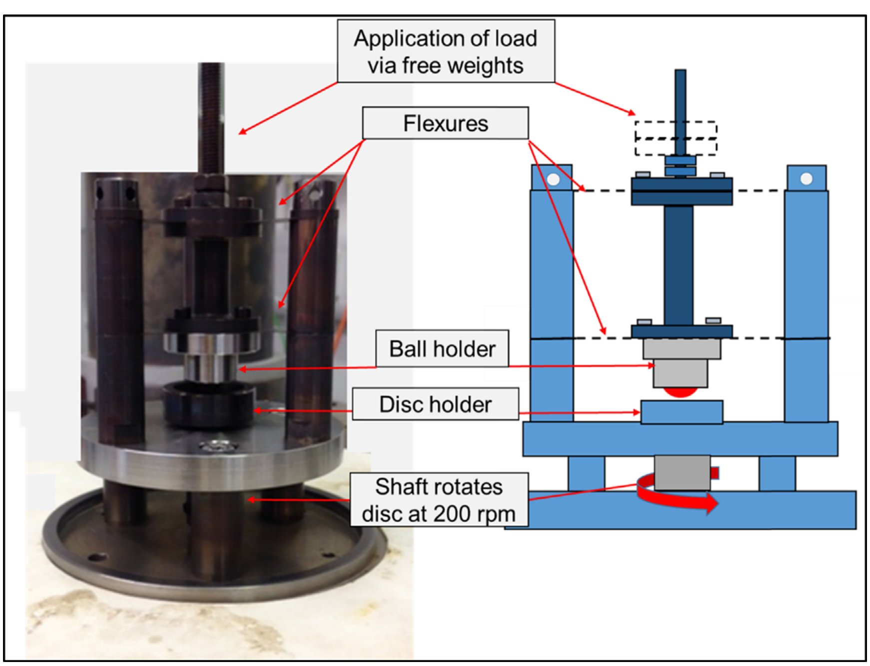

Fig. 2. Pin on disc tribometer developed at the University of Nottingham adapted to accommodate a Stellite 20 ball as a pin in the sliding wear test configuration.

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