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Friction and wear behaviour of Ni-Cr-B hardface coating on 316LN stainless steel in liquid sodium at elevated temperature

Hemant Kumar [a, b, *], V. Ramakrishnan [b], S.K. Albert [b], A.K. Bhaduri [b], K.K. Ray [a]

[a] *Department of Metallurgical and Materials Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721 302, India*
[b] *Indira Gandhi Centre for Atomic Research, Kalpakkam 603 102, India*

HIGHLIGHTS

- Wear behaviour of Ni-Cr-B coated stainless steel in flowing sodium is reported.
- Dynamic is lower than the static friction coefficient in liquid sodium at 823 K.
- Wear rate (order of 10^{-12} m^3/m) increases with increase in the contact stress.
- Confocal laser scanning microscopic examinations support the estimated wear damage.
- Estimated friction coefficients and wear rates are well within the design limits for FBR.

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ABSTRACT

The sliding friction and wear behaviour of Ni-Cr-B hardface coating made on 316LN stainless steel were evaluated in liquid sodium at 823 K by using a fabricated reciprocating-type tribometer. The test parameters have been selected based on operational conditions prevailing in the Indian sodium cooled fast breeder reactors (FBRs). Accordingly, the tests were carried out at sliding speeds of 2 and 16 mm/s under contact stresses of 10 and 40 MPa respectively using Ni-Cr-B coated pin and disc specimens. The static and dynamic friction coefficients are found to be in the ranges of 0.03–0.07 and 0.01–0.02 respectively under the imposed test conditions. The estimated wear rates (W_R) are found to be in the range of $0.62 \times 10^{-12} - 3.07 \times 10^{-12}$ m^3/m; the magnitude of W_R increases with increase in the contact stress. The examination of the worn disc specimens by confocal laser scanning microscopy indicated higher damage in specimens tested at 40 MPa compared to that in specimens tested at 10 MPa; the quantitative estimation of damage was made by the number of scars and their depth. These observations corroborate well with the morphological features of the worn surfaces of the pin specimens examined by scanning electron microscopy. The results unambiguously indicate superior friction coefficients and wear resistance of Ni-Cr-B coatings in liquid sodium compared to that in air under identical test conditions.

1. Introduction

Tribological problems are of significance for several engineering components made of austenitic stainless steel used in sodium cooled fast breeder reactors (FBRs). Liquid sodium, used as the coolant in FBRs, removes the oxide films present on the surfaces of these engineering components, leaving these in ultra clean condition [1,2]. This usually promotes adhesive wear, high friction coefficient and the tendency for self-welding between the mating parts of various components. Synergistic occurrences of these phenomena lead to high wear rate and lower service life, which are undesirable for components employed in FBRs. In nuclear reactors taking care of these phenomena is of utmost importance since maintenance, refurbishing or replacement of the worn components are either difficult or sometimes impossible due to high levels of radioactivity that would be present in the vicinity of the components. One of the commonly adopted solutions for these problems is to provide a hard coating on the mating surfaces of the components immersed in liquid sodium. Employment of different types of hardface coatings for such applications naturally demands assessment of their friction and wear characteristics as well as their self-

* Corresponding author. Department of Metallurgical and Materials Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721 302, India.
E-mail address: hemant@igcar.gov.in (H. Kumar).

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welding susceptibility in service conditions. Self-welding susceptibility of Ni-Cr-B hardface coating with and without Ni-Cr-B coating on 316LN stainless steel in flowing sodium has been already evaluated at elevated temperature [3]. This investigation aims to examine the tribological behaviour of Ni-Cr-B hardface coating on 316LN stainless steel in liquid sodium at an elevated temperature.

Hardfacing alloys are commonly categorized as Fe-based, Co-based and Ni-based. However, Fe-based hardfacing alloys cannot be used for high-temperature applications due to their softening at service temperatures. Similarly, Co-based hardfacing alloys become radioactive under nuclear environments, and this phenomenon alone restricts the use of cobalt-based hardfacing alloys for such applications. As a consequence, Ni-based hardfacing alloys [4] find popular use as the coating material. Among the Ni-based hardfacing alloys, Colmonoy, Deloro and Tribaloy are in abundant use with wide range of compositions under AWS A5.21 specification.

A few investigations are found reported on Ni-based hardfacing alloys to understand the friction and wear behaviour in sodium environment. The report by Kanoh and his co-workers [5] on Colmonoy-5 hardfacing alloy indicates lowest static and dynamic friction coefficients at temperatures above 340 °C during wear tests conducted at contact stress of 20 MPa with the maximum sliding speed of 7.2 m/s in liquid sodium. In another study, Depierre and Raffailhac [6] showed that Ni-based hardface coatings in liquid sodium exhibits mean wear rates of 3×10^{-16}, 3×10^{-16} and 25×10^{-16} m^3/N-m for Colmonoy-5/Colmonoy-6, Colmonoy-4/Colmonoy-5 and Plasma Transferred Arc-deposited Colmonoy-5/Colmonoy-6 pairs respectively. The tests by Depierre and Raffailhac were conducted in liquid sodium at 560 °C with speed ranging from 0.5 to 5.0 cm/s at contact stresses between 0.5 and 10 MPa. The existing reports on the tribological behaviour of Ni-based hardfacing alloys in liquid sodium appear to inherit several limitations from the point of view of applicability. These are (i) the tests do not corroborate to evaluation of tribological properties of the hardfacing alloys in flowing sodium, (ii) the purity of the sodium mainly the oxygen level is often not reported, which can affect the tribological properties considerably and (iii) the reported test conditions do not always corroborate with the service conditions in various nuclear reactors.

Ni-based hardfacing alloy Ni-Cr-B has been chosen as the hardfacing alloy for the components of the nuclear steam supply system of Indian prototype fast breeder reactor (PFBR). It is of utmost importance to understand the friction and the wear behaviour of this Ni-Cr-B hardface coating under test conditions which simulate closely the operating conditions prevailing in this nuclear reactor. This investigation is an attempt to achieve understanding and generate information related to tribological properties of Ni-Cr-B hardface coating with emphasis on obtaining these in flowing sodium.

2. Experimental

2.1. Selected materials

Ni-Cr-B hardfacing alloy conforming to AWS A5.21 specification was deposited on 316LN stainless steel substrate using tungsten inert gas (TIG) welding process. The welding parameters employed for the deposition process are given in Table 1. Disc and pin specimens for wear tests were then machined from the hardface coated blanks of 316LN stainless steel. The thickness of the coating on these specimens was typically between 1.5 and 2.0 mm after machining. The coated specimens were ground to achieve the surface finish of <0.8 μm as estimated by the digital surface profilometer. Table 2 shows the chemical composition of the Ni-Cr-B hardface alloy, as analyzed by optical emission spectrometer (Model: ARL 3460 Metal Analyser, Switzerland). Specimens of an approximate dimension of 12 mm × 12 mm were cut from the hardface coated blanks, and were ground and polished up to 0.25 μm finish following the standard metallographic procedures. These were etched using HCl:HNO_3:H_2O (0.4:1:1) solution to reveal the microstructures. The microstructures of the specimens were examined by optical (Leica, DM-IRM, Germany) and scanning electron microscope (CamScan, 3200, UK). The hardness of the hardface coating was determined on cylindrical specimens (~15 mm diameter and ~10 mm height) by a Vickers Hardness Tester using a load of 5 kgf for a dwell time of 15 s.

Table 1
TIG welding parameters used for the deposition process.

Current (A)	120–140
Voltage (V)	22
Shielding Gas	Ar
Flow rate (lpm)	5–6
Polarity	DC
Tungsten electrode diameter (mm)	3 (2% Thoriated)

2.2. Wear test

Wear tests were carried out with the help of a reciprocating type pin-on-disc tribometer in flowing sodium in which the pin is static, and the disc reciprocates. A schematic diagram of the tribometer along with the sodium test chamber is shown in Fig. 2 of Ref [7]. The tribometer is provided with an inner cylindrical shaft, load lever, load cells and provision for holding the pin and the disc specimens at the bottom. The pin specimens were placed and tightened to the pin holders of the load lever. The disc (as shown in Fig. 1) was suitably placed and fixed within disc holder of the reciprocating lever. The configuration of the pin and the disc specimens along with assembly are shown in Fig. 1. The test set-up was inserted in a cylindrical chamber in which arrangement was made to flow liquid sodium at a temperature of 823 K. The purity of the flowing sodium in the chamber was maintained by passing sodium continuously through a series of pre-filters and cold trap purification systems. The temperature of the cold trap was maintained between 396 and 406 K.

The friction and wear tests were carried out at two stress levels of 10 and 40 MPa and for all the tests, a stroke length of 6 mm was used; two different sliding speeds of 2 and 16 mm/s were used during these tests for a total sliding distance of 200 m. The contact surfaces were flat-on-flat at the mating junction. Additional friction and wear tests on 316LN stainless steel were also carried out using the same tribometer at ambient temperature in air, prior to similar tests in sodium environment to check the performance of the tribometer.

All pin specimens and discs were thoroughly cleaned with acetone and these were weighed, before assembling these in the tribometer for testing. A blank test was performed before the actual one in which the tribometer was calibrated without any applied load along with the disc and the pins. This load obtained during the blank tests (originating from seal friction) was subtracted from the ones recorded during the actual tests to compensate the seal friction present in the tribometer. Load is applied pneumatically through load levers and is measured by load cells mounted along the load levers to pneumatic cylinders. Air to the pneumatic cylinder is supplied from a compressor through air header, online regulator and solenoid valve. During the tests, air pressure corresponding to a given load, is set on the online regulator and is