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THE TRIBOLOGICAL BEHAVIOR OF INCONEL 718 IN SODIUM COOLED REACTOR ENVIRONMENTS

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INTRODUCTION

This paper summarizes the results of friction and wear tests performed on Inconel 718 against itself under conditions prototypical of various Liquid Metal Fast Breeder Reactor (LMFBR) component operations. Testing was performed in a flowing sodium environment having a controlled impurity content and flow rate. Dynamic friction behavior, self-bonding tendency and wear are discussed.

EXPERIMENTAL FACILITIES AND TECHNIQUES

MASTER

The friction and wear test machines employed in this program permit prototypic testing in sodium at temperatures up to 1200°F (922K) under controlled impurity contents (0.5-1.0 ppm, oxygen) and flow rates (1 fps; .3 mps). The basic experimental approach is to press two diametrically opposed horizontal specimens (pins) against mating specimen surfaces (plates) mounted on a vertically reciprocating rod(1). Tests are run under as prototypic-as-possible conditions of load and motion simulating those anticipated in the reactor system. The contact loads (normal static loads), the force necessary to move the plates (frictional load), and the displacement are continuously measured and recorded on magnetic tape. Wear data are obtained from weight changes and measured height changes of the pin and from quantitative analysis of wear scars on the plate specimens using a surface profile instrument.

EXPERIMENTAL RESULTS

The Inconel 718 material utilized in these studies had a typical heat analysis as follows (all values in weight percent):

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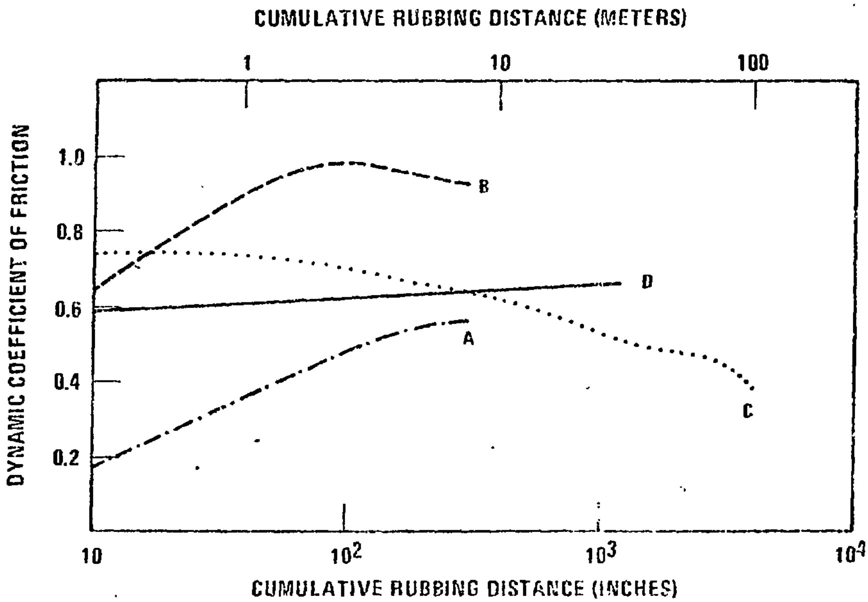
53.05 Ni, 18.35 Cr, 18.18 Fe, 5.29 Cb+Ta, 3.08 Mo, 0.95 Ti, and 0.59 Al. The material was in a precipitation heat treated condition and had an average hardness of Rc 45.

Typical dynamic friction results for Inconel 718 rubbing against itself in high purity sodium (0.5-1.0 ppm oxygen) under various test conditions, are shown in Figure 1. During initial rubbing in 450°F (505K) sodium, friction coefficients were found to increase with cumulative rubbing. This increase was attributed to a gradual wearing away of initially present surface films (oxides, etc.). Friction coefficients were considerably greater for stroke amplitudes $\leq$ one-half the test pin diameter (test B); this probably being the result of entrapped wear debris which could not escape the rubbing interface region. Following an 1100°F (866K) static soak period initial friction coefficients in 450°F (505K) sodium were again low but rapidly increased to values experienced prior to the high temperature exposure. This decrease in friction most probably resulted from the presence of a stable boundary lubrication film which formed at the higher temperature. For chromium containing materials, most investigators now accept this lubricative film to be sodium chromite; a double-oxide of sodium and chromium having a stoichiometry of $NaCrO_2$(2,3).

Dynamic friction studies performed in 1000°F (811K) sodium (curves C and D) showed the frictional behavior of reciprocating Inconel 718 couples to be strongly dependent on rubbing velocity. At slow velocities (0.1 in/min; 2.54 mm/min) friction coefficients continuously decreased with increasing rubbing distance while at faster velocities (5.0 in/min; 127 mm/min) friction was constant or slightly increasing with cumulative rubbing. It is believed that at the slow velocity, film formation kinetics are such that the film forms at a slightly greater rate than it is worn away, hence friction decreases. It is also possible that under these conditions of boundary lubrication, the contacting interfaces are being continuously smoothed with the resultant effectiveness of the lubricative film thus increasing. At the faster rubbing velocities, wear processes dominate and there is no opportunity for the formation of effective lubricative films.

Oxygen content of the sodium was found to have no significant influence on dynamic friction characteristics in 450-1160°F (505-900K) sodium. At 450°F, oxygen concentrations of 10 ppm did result in slightly lower friction coefficients



CONDITIONS

TEST	TEMP., °F(K)	PRESSURE, psi (MPa)	STROKE (PIN. DIA)	AVG. VELOCITY, ipm (mm · MIN.⁻¹)
A	450 (505)	5000 (34.47)	6d	10 (254)
B	"	"	d/2	1.0 (25.4)
C	1000 (811)	"	d	0.1 (2.54)
D	"	3000 (20.68)	d	5.0 (127)

Figure 1. Dynamic friction behavior of Inconel 718/self in liquid sodium

(~10 percent) relative to values obtained in the 0.1-2.0 ppm range. Lower normal forces were found to result in slightly higher friction coefficients over the 300-5000 psi (2.07-34.47 MPa) range.

The short-term self-bonding behavior of Inconel 718 was investigated in a series of dwell-breakaway tests. It was found that dwells performed under simultaneously applied normal and tangential interfacial loads resulted in significantly higher $\Delta\mu$ values than dwells performed under normal loads only. This effect is attributed to the increased real area of contact resulting from plastic flow, which occurs under the combined loading. Other investigators(4,5) agree that dwelling under both normal and tangential load results in junction growth. These studies, along with one performed by Huber and Mattes(6), have further demonstrated that adhesion (or breakaway force) increases with increasing real area of contact.

All self-bonding studies performed in this program employed both a normal and tangential interfacial load during dwell periods. It was observed from these data that increasing normal contact pressure resulted in a significantly lower self-bonding tendency. Although increased contact pressure results in increased real area of contact, the area increase is less than the pressure increase(7). Therefore the increase in breakaway force (resulting from the increase in area) was less than the increase in contact pressure. This results in a lower calculated A_μ value for the higher pressure tests.

Additional data obtained from these studies indicate that no significant bonding occurred at temperatures below 900°F (755K). Similarly, changes in sodium oxygen concentration from 0.2 to 4.8 ppm had no effect on bonding behavior. It was also found that A_μ values increased with increasing dwell times at each test temperature (above 900°F; 755K), and with increasing temperature.

The wear damage incurred by Inconel 718 rubbing against itself in all cases was adhesive in nature, with specimen surfaces exhibiting the smeared butter appearance typical of this process. Specific wear coefficients (K) calculated for this material indicate that increasing travel distance results in a decreasing wear rate. This is attributed to an initial rapid wearing-in process of the two contacting surfaces.

The observed maximum wear depth, along with the calculated specific wear coefficient data, imply that Inconel 718 is very resistant to wear damage. This resistance is attributed to the high level of hardness of the material over a wide temperature range, and to the ability of this material to form protective lubricative surface layers in a sodium environment (as previously discussed).

SUMMARY AND CONCLUSIONS

Results of the present study on the tribological behavior of Inconel 718 in a sodium environment are summarized as follows:

a) Stroke lengths ≤ one-half the test pin diameter result in higher friction coefficients.

b) At elevated temperatures, the formation of a lubricative surface film can significantly influence the frictional behavior.

c) Tangential forces present during static dwell periods result in greater bonding tendencies.

d) Increasing contact pressure during static dwell periods results in lower breakaway friction coefficients.

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