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Mechanistic studies on degradation in sliding wear behavior of IN718 and Hastelloy X superalloys at 500 °C

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ABSTRACT

This technical paper deals with high temperature dry sliding wear behavior and its mechanism of Inconel 718 and Hastelloy X alloys. The sliding wear behavior of the Inconel 718 alloy and Hastelloy X was investigated using a pin on disc equipment at 500 °C with varying normal load. Hastelloy X has shown the higher coefficient of friction in comparision to IN718. SEM features of worn samples reveal that delamination, ploughing and deep grooving are the dominant wear mechanisms for IN718, while for Hastelloy X, it is shear band, cleavage formation, debris generation.

1. Introduction

Wear is a removal of material from the operating surfaces under the mechanical action of the two surfaces rubbing together [1]. Relative motion between machine components almost inevitably leads to changes in the surface of engineering components which degrades the performance and lifetime of mechanical components and results in economic loss [2]. Wear may occur in a number of modes, that includes abrasion, adhesion and erosion encompassing the field of tribology [3].

In particular, wear at 400–500 °C is a serious problem in a large number of industrial applications such as power generation, high temperature bearings, valve and valve seats in internal combustion engines, moving assemblies for hypersonic aircraft and missiles [4–7].

Wear at elevated temperatures brings further complications in engineering materials, due to loss of mechanical strength of materials and alterations in the surface conditions leading to changes in adhesion between the surfaces caused by the joint action of temperature and tribological parameters [8]. It degrades the performance and lifetime of mechanical components and results in catastrophic failures in many cases.

A typical example is relevant to the aerospace industry, where a variety of degradation problems exist in aircraft engines as a result of metal to metal wear and fretting. Thus mechanical components operating in aerospace often require strength to withstand the synergetic attack combining wear and high temperature [9]. Nickel based superalloys provide solutions to systems which are subjected to stress at high temperatures for prolonged periods. In recent times, gas turbine technology for power generation and for aeroengine applications places an increasing demand on the use of Ni based superalloys [10,11].

IN718 and Hastelloy X alloys are used in a wide range of applications including power generation equipment, aircraft engines, space shuttle main engine, land-based and marine turbines [12,13].

The crucial characteristics of Nickel base superalloys include superior tribological properties, excellent mechanical strength, outstanding resistance to loading under static, fatigue, and creep conditions; good surface stability, good oxidation and corrosion resistance, and good phase stability at high temperatures[14–16].

Friction and wear characteristics of various superalloys have been investigated by various researchers [17–21]. However, there is only little tribological data available in the literature about friction and sliding wear behavior of IN718 and Hastelloy X alloys.

Regarding mechanisms with which sliding wear phenomenon happens, virtually no report is available in literature on IN718 and

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Hastelloy superalloy. Thus main objective of this work is to study the friction behavior and sliding wear mechanisms of IN718 and Hastelloy X alloys using a pin on disc universal tribometer at 500 °C, by varying the normal load. Further it is well known that mechanism only always determines the wear rate and vice versa is not true. Hence this paper lays more emphasis on mechanistic aspects only.

2. Materials and methodology

In the present study, Inconel 718 and Hastelloy X are chosen as the substrates and their nominal chemical compositions (in wt%) are summarized in Table 1. Hardness of Inconel 718 and Hastelloy X are 40 HRC and 31 HRC respectively. Samples with dimension of 8×8 mm sliced mm sliced using wire electrical discharge machining (wire–cut) were employed for the dry sliding wear tests. Dry Sliding wear tests were carried out at 500^{o}C as per ASTM G76 standard on specimens using pin on disc tribometer, to simulate sliding friction and wear behavior of IN718 and Hastelloy X alloys. The temperature was elevated by setting the furnace temperature in the tribometer and it was measured by attaching the temperature sensor to the specimen holder. The testing conditions is summarized in Table 2. Scanning electronic microscope (Hitachi, S-2000H) was used to observe the surface morphology of the worn samples to investigate the mechanisms of degradation.

3. Results and discussion

Figs. 1 and 2 illustrate the variations of the coefficient of friction of the IN718 and Hastelloy X samples with increasing distance at normal loads of 10, 20 and 30 N. The coefficient of friction (COF) was recorded throughout each pin-on-disk test by utilizing the tangential and normal load sensors of the tribometer. When two contacting surfaces slide against each other, a frictional force is generated opposite to the direction of sliding. During sliding, the friction force is considered to be exerted in a direction perpendicular to the normal load. The ratio of these forces is equal to the coefficient of friction. The variation of coefficient of friction with sliding distance provides the basic data for understanding the friction behavior of a material.

Figs. 1 and 2 shows that the friction coefficient of the IN718 and Hastelloy X specimens under dry sliding condition, increases with increasing normal load. As the applied load increases, the number of asperities interactions between the rubbing surfaces increases, resulting in increased friction coefficient. The gradual increase of the friction coefficient can be associated to the real contact area between the rubbing surfaces.

Fig. 1 illustrates that the friction coefficient of the IN718 specimens for all different loads that initially increased with increasing sliding distance until a peak value was reached, and then it gradually approached steady state. This is the so-called running-in stage. The initial running- in corresponds to the contact of the asperities between the rubbing surfaces. At the beginning of sliding the asperities of the surface limit the sliding speed. Meanwhile the friction leads to removal of some of the asperities during running-in stage.

Table 2
Sliding test parameters.

Specimen size (Cylindrical) mm	8×8
Pin material	IN718 and Hastelloy X
Disc material	EN 31
Sliding velocity (m/s)	2
Normal load (N)	10, 20, 30
Temperature	500 °C

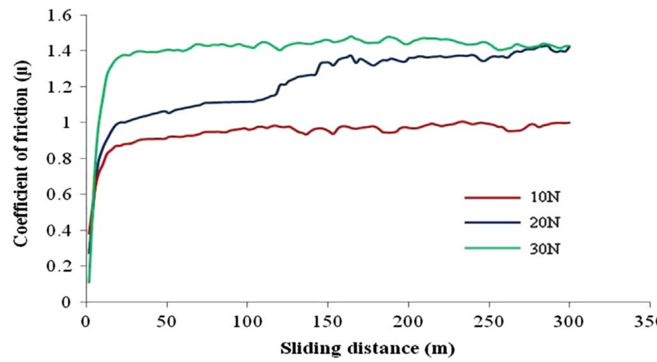

Fig. 1. Variation of coefficient of friction of IN718 with distance at 2 m/s.

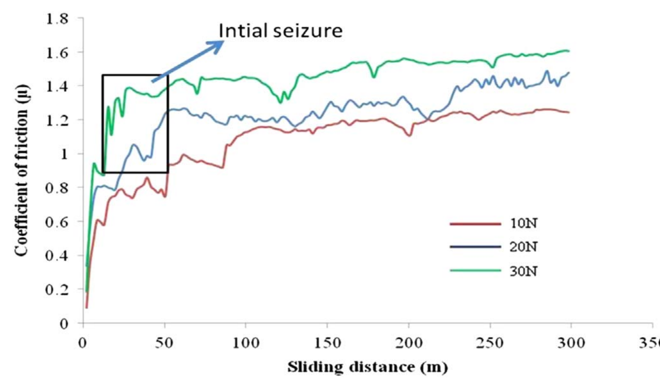

Fig. 2. Variation of coefficient of friction of Hastelloy X with distance at 2 m/s.

The effect of wear debris retained within the interface can play an important role in the wear mechanism and its coefficient of friction [22–24]. The effect of 'third bodies' on coefficient of friction is complex phenomena and it may give rise to a higher or lower coefficient of friction. This was attributed to the type of motion of wear particles trapped within the wearing interface [25]. The wear particles may skid over each other, act as rollers or become interlocked and undergo fracture. Based on type of motion of wear particles at sliding interface, the applied stress on the worn surface, would change the friction coefficients involved in the wear process.

Fig. 1 shows the oscillations in the friction coefficient behavior of the IN718 specimens, this should be attributed to the entrapment of wear particles at the interface. Some wear particles may undergo rolling between the surfaces, which lower the friction coefficient. Some wear particles may act as an abrasive, giving rise to an abrasive-type mechanism which is generally considered to increase the coefficients of friction. This was attributed to the

Table 1
Materials chosen and their nominal chemical compositions (in wt%).

Material	Ni	Fe	Cr	Mo	Co	Mn	W	C	Si	S	Cu	Al	Ti	Cb+Ta
Hastealloy X	49.4	18.4	20.9	8.7	0.8	0.6	0.3	0.06	0.2	–	–	–	–	–
Inconel 718	52.5	18.5	19	3.05	–	0.8	–	0.04	0.18	0.008	0.15	0.5	0.9	5.03