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Plastic strain of cobalt-based hardfacings under friction loading

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ABSTRACT

Aeronautic forging dies are subjected to very high loads and temperatures for a long contact time between the pre-heated parts and dies. Cobalt-based hardfacings are commonly deposited on dies and their main wear mechanism is large plastic deformation of the die radii.

This paper deals with the wear damage mechanisms of three different cobalt-based hardfacings: Stellite 21 deposited by a MIG process, Stellite 21 and Stellite 6 deposited by a LASER process. The tribological tests are carried out on a high load Ring on Disc tribometer at room temperature. The post-mortem investigations are undertaken by SEM observations, micro-hardness measurements as well as by X-ray diffraction analyses.

Results show that the increase of the hardness, in order to improve the wear behaviour, can be achieved by a higher carbon content and by a lesser iron dilution that depends on the deposition process. A very important work-hardening, up to 90%, is also observed under sliding conditions and a relationship is established between the increase of the micro-hardness and the plastic strain level. Two different plastic strain mechanisms are observed. For high (MIG) or low (LASER) iron dilution levels, the plastic strain causes respectively a reorientation of grains or a FCC to HCP phase transformation; the latter being associated with a lower friction coefficient.

1. Introduction

Cobalt-based alloys (Stellites®) are commonly used as wear-resistant hardfacings, even at elevated temperature. They present a solidification microstructure composed of a cobalt-rich dendritic matrix surrounded by interdendritic regions containing carbides [1–5]. The predominant alloying element of Stellites is Chromium (around 30 wt%), providing carbide precipitation and solid solution strengthening. Other alloying elements like W and Mo provide additional strength to the matrix and the principal function of carbon (generally between 0.25 and 1 wt%) is the precipitation hardening via carbide formation. The cobalt-rich matrix has a face-centered cubic (FCC) structure; however its thermodynamically stable one is hexagonal close-packed (HCP).

Under plastic straining, the FCC to HCP transformation (strain-induced transformation: SIT) can occur by faulting on every second plane in a stack of close-packed planes and so require the possibility of stacking faults. The stacking fault energy (SFE) of Stellites is low, between 10 and 50 mJ/m^2 and is influenced by the alloying elements [6,7]: Ni, C and Fe tend to increase the SFE and so to stabilize the FCC phase, while Cr, Mo and W tend to stabilize the HCP phase and so to promote the SIT. Plastic strain of Stellites leads to an important work-hardening, this work-hardening ability of Stellites increases with alloying elements reducing the SFE [8]. During the hardfacings deposition process, a part of the substrate is melted and intermixed with the Stellites to insure a good metallurgical bonding. However, this phenomenon, called dilution, modifies the chemical composition of the Stellite, especially increasing his iron content [9] and modifying the SFE of the hardfacing. This has an influence on the initial hardness, the hardening rate under plastic strain and the FCC to HCP strain-induced transformation [8,10–11].

Moreover, Atamert and Bhadeshia [12] have shown that the stacking faults are intrinsic and always contained on FCC-(111) planes and Farooq et al. [13] have observed that the SIT from FCC to HCP phase takes place along FCC-(111) planes in the case of tensile tests. Persson et al. [14] have shown the SIT of a Stellite 21 deposited by the LASER process with the HCP-(0001) planes tilted and aligned parallel to the sliding surface.

Stellite 21 is commonly used as a wear-protective coating on forging dies in the aeronautical field. It is deposited on tool steels, on several millimetres thick, by a Metal Inert Gas process. In this applicative field, hardfacings are under high load and high temperature for a long contact time between the forged piece

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Table 1
Nominal chemical composition (wt%) of Stellite 21 cored wire (data given by Soudokay supplier) for MIG deposited hardfacings and of Stellite 21 and Stellite 6 powders (data given by Höganäs supplier) for LASER deposited hardfacings.

	C	Cr	Mo	W	Ni	Mn	Si	Fe	Co
Stellite 21 cored wire	0.27	28.0	5.0	–	2.4	1.0	1.3	3.5	Bal.
Stellite 21 powder	0.26	27.0	5.6	–	2.4	0.64	0.87	0.1	Bal.
Stellite 6 powder	1.2	28.8	–	4.3	0.7	–	1.1	0.6	Bal.

Table 2
Chemical composition (wt%) of the two substrates used for the elaboration of the tribological samples.

	C	Cr	Mo	Ni	Nb	Ti	Al	Fe
40NiCrMo18	0.40	1.50	0.50	4.50	–	–	–	Bal.
Inconel 718	0.04	18.00	3.00	Bal.	5.20	0.90	0.50	18.50

(aeronautic parts in Inconel grade) and the die. These forging conditions induce large plastic straining in the tool radii where the forged piece is sliding against the die [1].

The context of this study is the wear improvement of hardfaced forging tools. In this paper, a MIG welding process and LASER cladding are considered to examine the influence of chemical composition and of the deposition process on the plastic straining of cobalt-based hardfacings under friction loadings. High load tribological tests have been performed at room temperature on Stellite 21 and Stellite 6 deposited by MIG and LASER processes. Post-mortem investigations have been performed to identify wear rates, plastic stain, work-hardening and crystallographic evolutions of the studied hardfacings.

2. Materials and experimental methods

2.1. Materials and test specimens

Three different cobalt-based hardfacings are studied in order to compare their wear mechanisms: one Stellite 21 (ST21-MIG) hardfacing deposited by the MIG (Metal Inert Gas) process, one Stellite 21 (ST21-LASER) and one Stellite 6 (ST6-LASER) hardfacings deposited by the LASER process. The nominal chemical compositions are given in Table 1.

The three hardfacings are deposited on tempered martensitic tool steel plates 40NiCrMo18 (Table 2) and are then machined to obtain roughness-controlled surfaces. The contact geometry of the hardfacings parts is cylindrical type with a hemispherical contact radius equal to 10 mm. During the deposition, the steel base plate was preheated. After the deposition, the deposits are cooled with a warm cover to ensure slow cooling to avoid cracking. For the multilayer deposits, the inter-pass temperature was maintained at less than a defined temperature so as to ensure identical cooling.

During triblogical tests, hardfacings are sliding against a disc in Inconel 718® Nickel superalloy (Table 2) machined with a flat contact surface.

2.2. High load Ring on Disc tribometer

The tribological tests are conducted using a Ring (hardfaced part) on Disc (Inconel 718 part) tribometer in a cylinder on plate configuration in air [15] (Fig. 1).

A constant normal load, measured by a deformation gauge sensor, is applied to the ring via dead weights and a lever arm. The tangential forces are measured using two deformation gauge cells located in the friction plane. A thermocouple is spot welded near the contact surface of the ring in order to monitor the temperature during the friction test. All the sensors are continuously recorded during the friction tests by an acquisition system, written in the LabVIEW® software.

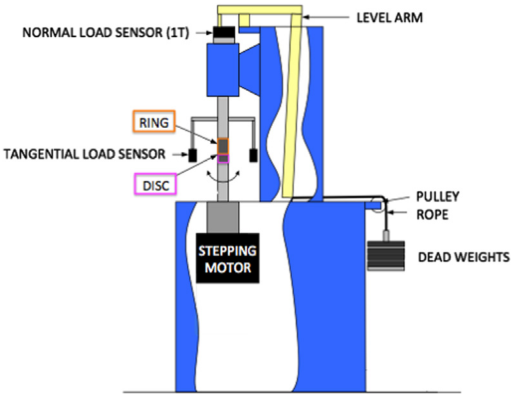

Fig. 1. Scheme of the high load Ring on Disc tribometer.

Table 3
Tribological test parameters of the reference test.

Initial contact temperature (°C)	Room temperature (RT)
Normal load (N)	5000
Hertz contact pressure (MPa)	472
Sliding velocity	60 rpm (rotate) or 0.08 m/s (linear)
Sliding distance (m)	144

Table 4
Tribological test parameters of the long duration test.

Initial contact temperature (°C)	Room temperature (RT)
Normal load (N)	5000 (for 120 min) then 3000 (for 360 min)
Hertz contact pressure (MPa)	472 then 365
Sliding velocity	50 rpm (rotate) or 0.07 m/s (linear)
Sliding distance (m)	480 then 1440

Before testing, the specimens are thoroughly degreased using acetone and ethanol solutions with an ultrasonic cleaner.

2.3. Friction test parameters

To assess the effect of the cobalt-based hardfacings on the tribological behaviour, a reference test with constant parameters has been defined (Table 3). An additional room temperature test has been performed to define wear resistance and plastic strain under a long duration test (8 h) (Table 4). The repeatability and reproducibility of the tribological device has been verified on these cobalt-based hardfacings with slightly different parameters as those presented in this study, namely a normal load of 8000 N and a sliding velocity of 0.05 m/s. These latters are comparable to the ones used in this study as the *PV* values (with *P*=normal load and *V*=sliding velocity) are the same.

2.4. Characterization of wear

An extended field confocal microscope (AltiSurf520 from Altimet), based on the principle of chromatic coding was used to measure the surface profile of the worn specimens. Prior to scanning, the specimens are cleaned in an ethanol ultrasonic bath to remove any debris not adhered to the surface. As the wear scars do not extend over the full width of the flat (disc) or hemispherical (ring) specimens, profiles are taken over an area completely spanning the wear scar. In order to estimate the wear volume, the reference (unworn) surface has been