



Effects of molybdenum content on the wear/erosion and corrosion performance of low-carbon Stellite alloys



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ABSTRACT

The strengthening agents of Stellite alloys are commonly various carbides, but intermetallic compounds may play a similar role to the carbides. In this research two low-carbon Stellite alloys with high molybdenum content are developed and studied, which are modified version of Stellite 21. This particular elemental content combination results in large amounts of Co_3Mo intermetallic compound precipitated in these alloys. The microstructures of the alloys are analyzed using SEM/EDX/XRD and DSC. The dry sliding wear resistance and solid-particle erosion resistance of the alloys are evaluated experimentally. The corrosion performance of the alloys in 3.5 wt.% sodium chloride (NaCl) aqueous solution is investigated under electrochemical tests. It is shown that the intermetallic compounds enhance hardness and wear resistance as the carbides do in Stellite alloys, but do not favor solid-particle erosion resistance due to their brittleness. The presence of the intermetallic compounds does not worsen corrosion resistance, compared to Stellite 21.

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1. Introduction

Stellite system is cobalt-based alloys, which contain mainly alloying elements chromium (Cr) and tungsten (W) or molybdenum (Mo) as well as a certain amount of carbon (C), addition to cobalt (Co) [1]. With unique chemical compositions, these alloys display exceptional properties including high-temperature strength, excellent wear/erosion and corrosion/oxidation resistance. Chromium is the main alloying element of Stellite alloys; it is added for resistance to corrosion and oxidation; it is also the predominant carbide former, that is, most of the carbides in Stellite alloys are Cr-rich, in the meanwhile, it provides strengthening to the solution matrix. Tungsten and molybdenum provide additional strength to the solution matrix as solute atoms in Stellite alloys because of their large atomic size that impedes dislocation flow [1], and also promote formation of W-rich carbides [2–5], for example, in Stellite 12 and Stellite 3, and formation of Mo-rich carbides [6], for instance, in Stellite 712 and Stellite 720, when present in large quantities (>5 wt.%). Molybdenum can also improve general corrosion resistance of Stellite alloys [1].

In the CoCrMo Stellite alloy system, Stellite 21, which contains very small amount of C (0.25 wt.%), has a wide range of application mainly involving high temperature and corrosion, owing to its unique properties, such as creep resistance and mechanical strength at elevated temperatures, good resistance to corrosion [1,6–9], for example, valve trims for high pressure steam, oil and petrochemical processes, forging or hot stamping dies. It is also used on a large scale in medical implants and prosthetics [10–14] because of its good mechanical and corrosion properties, excellent compatibility with human body environments, and better wear resistance than stainless steels. However, in some applications, for example, hip implants, which require metal-on-metal bearing, Stellite 21 is found deficient in wear resistance. Therefore, a modification on Stellite 21 with improved wear resistance and meanwhile maintaining good corrosion resistance was proposed, which motivated this research.

As mentioned above, Mo is an important alloying element of Stellite alloys. It provides strengthening to the solution matrix as a solute and can also form Mo-rich carbides when present in large quantities (>5 up to 11 wt.%). In addition to these functions, Mo was reported to form intermetallic compounds Co_3Mo in low-C Stellite alloy, which improved the wear resistance of the alloy [8]. The effects of Mo on the performance of Stellite alloys have been studied by some researchers [15–20]. For example, the wear and corrosion behavior of Stellite 6 hardfacing with addition of

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different contents of Mo was investigated experimentally and the results demonstrated that with increasing the Mo content the wear and corrosion resistance of the hardfacing was enhanced, which was attributed to the formation of Mo_6C carbides [17]. The comparative studies between W-containing Stellite alloys and Mo-containing Stellite alloys found that the latter exhibited unusual combination of excellent abrasive, adhesive and erosive wear resistance and corrosion resistance in reducing environments. The Mo-containing Stellite alloys also had adequate cracking resistance compared with the W-containing Stellite alloys [18]. Because of these advantages of Mo, in this research, attempt was made to add large amounts (>11 wt.%) of Mo in low-C Stellite alloys to create new alloys which were expected to have better wear resistance than and comparable corrosion resistance to Stellite 21. These alloys were investigated under dry-sliding wear, solid-particle erosion, electrochemical corrosion tests, Stellite 21 and Stellite 6 were also tested under the same conditions for comparison.

2. Materials and methods

2.1. Microstructure characterization

The chemical compositions of the new alloys, together with those of Stellite 21 and Stellite 6, are given in Table 1. The new alloys have similar Cr and Mo contents, and contain very small C content. Alloy 2 contains slightly high C content than alloy 1 and additional element of niobium (Nb). Addition of Nb is to enhance the strength of the alloy by forming niobium carbide [21]. The alloy specimens are cast products. The microstructural analyses of the alloys were conducted on the IGMA HV-01-043 (Carl Zeiss SMT Pte Ltd, Germany) SEM, equipped with the Bruker Nano Xflash Detector 5010 EDX system (Bruker, Germany) for elemental analysis and quantitative mapping. The phases in the microstructures were identified using the X'Pert PRO X-ray photoelectron spectroscopy (PNAlytical Ltd, Holland) with Cu $K\alpha$ radiation, which was operated at 40 kV and 40 mA to generate monochromatic Cu $K\alpha$ radiation with a wavelength of 0.154 nm.

To help understand the microstructures, DSC analysis was conducted on the new alloys with a DSC 404C instrument which can detect and qualify almost all calorimetric effects occurring in materials. The maximum heating temperature used in this experiment was 1500 °C which was determined based on the melting point of Co. The alloy samples were heated to 100 °C at a rate of 10 °C/min and kept for 20 min, then heated again up to the ultimate temperature, kept for 10 min, and finally cooled down to room temperature with the same rate. The phase transformation behavior of the material during the heating and cooling process is characterized by the DSC curve that can be obtained in the test.

2.2. Pin-on-disk wear test

Wear tests of the alloys were performed on a Neoplus pin-on-disk tribometer in dry sliding condition, according to ASTM: G99 – 05(2010). This apparatus used a rotating pin that was pressed

under a normal force of 10 N against a static disk that was the specimen with dimensions $12 \times 12 \times 4$ mm. The pin used was a ball having a radius of 2.5 mm and was made of a composite containing 94 wt.% WC and 6 wt.% Co, with the hardness of HV1534. During the test the specimen disk was placed horizontally with the center at a distance of 3 mm away from the vertical axis of the pin shaft. The pin (ball) was spinning at a speed of 350 rpm, corresponding to a linear speed of 110 mm s^{-1} . As the result of friction/wear, a 6 mm diameter circular wear track was generated on the specimen surface, which represents the wear loss of the specimen material. The test duration of each specimen was set to 2.5 h, leading to a total sliding length of 990 m. Three specimens were tested for each alloy to verify the wear loss results.

For each alloy, the wear loss was evaluated by calculating the volume of the wear track. Four locations were selected uniformly along the wear track to calculate the average cross-sectional area. The cross-sectional profiles of the wear tracks were simulated utilizing a D150 Surface Profile Measuring System. The plots in Fig. 1 are the examples of the cross-sectional profiles of wear track for the new alloys. The cross-sectional areas of the wear tracks at the selected locations were calculated automatically by the associated software of the D150 Surface Profile Measuring System. The volume of each wear track was then calculated using the average cross-sectional area multiplied by the periphery length of the wear track, πD ($D = 6$ mm).

The worn counterparts (pins) were also examined. The unused pin had a sphere shape with a radius (R) of 2.5 mm. The wear in the test resulted in an approximately circular area on the pin surface. By measuring the diameter (d) of the circle, as illustrated in Fig. 2, using the DEKTAK 150 Surface Profile Measuring System, the volume or wear loss of the pin can be estimated by the following equations:

$$V = \pi h^2 \left(R - \frac{h}{3} \right)$$

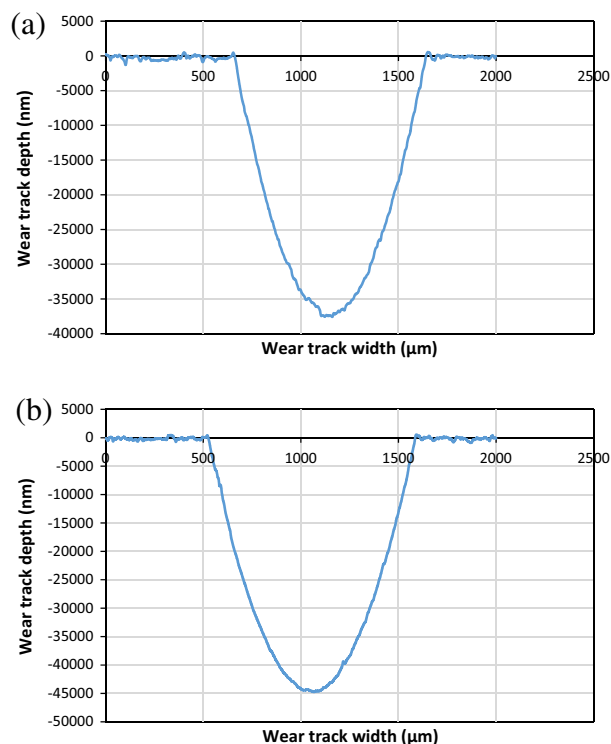


Fig. 1. Cross-sectional profiles of wear track: (a) alloy 1 and (b) alloy 2.

Table 1
Chemical compositions (wt.%, Co in balance) of the new alloys and existing Stellite alloys.

Alloy	Element								
	Cr	W	Mo	C	Fe	Ni	Si	Mn	Nb
Alloy 1	27		11	0.25	3	2.75	1	1	
Alloy 2	24.2		11.8	0.35	1	3.8	0.45	0.52	2.07
Stellite 21	27		5.5	0.25	3	2.75	1	1	
Stellite 6	28.5	4.5	1.5	1.2	3	3	1.5	1	

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