Tribological properties of solid lubricants (graphite, MoS₂) for Ni based materials

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Tribological properties of solid lubricants (graphite, MoS$_2$) for Ni based materials

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Abstract. Ni based materials with solid lubrication of 0%, 10% MoS$_2$, 10% graphite, 5% MoS$_2$+5% graphite at weight fractions were fabricated by a P/M hot press method, respectively. The effects of graphite and MoS$_2$ on tribological properties of Ni based materials were investigated on a pin-on-disk tester. Worn surfaces, microstructures of materials were characterized by scanning electron microscopy(SEM). Results indicate that lubrication effects of MoS$_2$ are superior to that of graphite, and the materials with 10% MoS$_2$ has a low and stable wear rates and friction coefficient.

1. Introduction

There is a high demand to anti-wear performance of friction materials with the growth of applications, especially in the condition of high load and temperature. The Nickel has high melting point, high-temperature strength and stable crystal texture, so it have the characteristic as friction materials for working in harsh environments. In recent years, the anti-wear performance of Ni matrix has been studied extensively[1~5]. Solid lubricants, such as graphite, MoS$_2$, h-BN etc., were added to Ni matrix for improving wear performance. Solid lubricants-rich film which was beneficial to improve wear resistance[6] was produced between contact surfaces in the friction process because of lamellar structure and softness of these solid lubricants[7]. It has been shown by Jianliang Li and Dangsheng Xiong that the anti-wear performance of Ni matrix can be improved significantly through added graphite and the matrix with 12wt.% graphite has the best anti-wear performance[1]. The similar conclusion was got through added MoS$_2$ to the Ni matrix by Jian Liang Li and Dang Sheng Xiong[3,4]. The combination of different solid lubricant can improve anti-wear performance of the Ni based materials effectively because of synergistic effect, such as the combination of graphite and MoS$_2$[5], and it was indicated that the combination of 3wt.%C+5wt.%MoS$_2$ can enhance anti-wear performance of the Ni based materials better than single solid lubricant of 3wt.%C or 5wt.%MoS$_2$. The synergistic effect of solid lubricants has also been verified in some references[7,8]. In the reference[5], the total content of solid lubricants of combination of 3wt.%C+5wt.%MoS$_2$ is more closer to 12% than 3%C and 5%MoS$_2$, and the material with 12% solid lubricant content has the best anti-wear performance[1,3-4], so the synergistic effect of the combination of graphite and MoS$_2$ is need to be further investigated.

The aim of this study is to analyze the effects of graphite and MoS$_2$ on the tribological properties of the Ni based materials. The followings are the main works of this study: (1)fabricate four kinds of Ni based materials incorporated 0 , 10%graphite, 10%MoS$_2$, 5%graphite+5%MoS$_2$, respectively; (2)
investigate the synergistic effect of graphite and MoS₂, (3) analyze and compare the lubricating mechanisms of four Ni based composites.

2. Materials and experiment procedure

2.1 preparation of samples
Source powders were Ni(~90µm, 99.7% purity), Cr(~100µm, 98% purity), graphite(~30µm, 99% purity), MoS₂ (cauterant residua < 0.15%, moisture-bearing is below 0.5%, 99% purity). The constituent of four materials is listed in Table 1. The matrix is 80wt.%Ni+20wt.%Cr, and three different ratio of graphite and MoS₂ are 10wt.%graphite+0%MoS₂, 0%graphite+10wt%MoS₂, 5wt.%graphite+5wt.%MoS₂, respectively. For comparison, the friction properties of the matrix was also tested. The ingredients were mixed for 8 hours by a planetary-type mixer with stainless steel milling balls, the weight ratio of ball-to powder is 4:1 and the rotational speed is 220r/min. Then the powders were hot pressed in a graphite mold in a vacuum sintering furnace. The hot press pressure is about 18.5 MPa, the sintering temperature is 1250 °C for 30 minutes, and the heating-rate is about 10°C/min. The hardness was measured by a Brinell hardness tester at a constant load and dwelling time of 10s. The hardness values were the average of three times tests of each sample.

| Sample designation | MoS₂ | Graphite | Ni           | Cr           |
|--------------------|------|----------|--------------|--------------|
| 00                 | 0    | 0        | 80           | 20           |
| M10                | 10   | 10       | Bal.(80%Ni+20%Cr) |              |
| C10                | 0    | 10       | Bal.(80%Ni+20%Cr) |              |
| MC                 | 5    | 5        | Bal.(80%Ni+20%Cr) |              |

2.2 wear tests
The wear tests were carried out on the pin-on-disc test machine under the dry condition. The sample with sizes of φ4 mm×15mm in the holder was rotated with a wear track of diameter of 22mm against the hardened steel disk (Cr12MoV) with Rockwell hardness of about 55HRC with size of φ36 mm×3 mm on which the load was applied automatically. The temperature and friction coefficient were recorded by a computer interfaced with the test machine. The duration of wear test was determined according to the time of about 5mm long of the pin which was out of the holder has been worn out. The wear tests were carried out at load of 20-50N with sliding speeds of 0.23– 0.58m/s(200-500rpm). All experiments were conducted in air with temperature and relative humidity maintained between 19-23°C and 55-67%, respectively.

Before each test experiment, the samples were polished with metallographic abrasive papers and then cleaned with acetone. Each specimen was cleaned with acetone and weighed before and after test by an electronic balance with accuracy of ± 0.1mg.

Wear rate was calculated by following formula:

\[ w = \frac{m}{s \times N} \]  

Where \( w \) is the wear rate(g/(N.m)), \( m \) is the wear mass loss of the specimen(g), and \( N, s \) is the normal load applied(N) and sliding distance(m), respectively. The value of each wear test condition is the average of three times tests.

Scanning electron microscopy (SEM) observations were carried out for viewing the worn surfaces.
3. Results and discussion

3.1 hardness

The Brinell hardness of four materials are shown in Tab. 2. It can be seen that the hardness of 00 sample and M10 are 50 and 51, respectively, but the hardness of C10 sample is only 13 which is the lowest value and the hardness of MC sample is 141 which is the highest value. Obviously, the graphite and MoS2 have different influences to Ni based materials although they have similar crystal structure and total content, namely, the MoS2 has enhancing effects and graphite has weakening effects to the Ni matrix, but the dual-lubricant of MoS2 +graphite has a great strengthening effect to Ni based material[9].

|       | 00  | M10 | C10 | MC  |
|-------|-----|-----|-----|-----|
| Brinell hardness | 50  | 51  | 13  | 141 |

Remark: the load under the C10 sample is 250kgf.

3.2 composition with different solid lubricants

The typical microstructure of Ni based materials are showed in Fig.1. It can be seen from Fig.1b that MoS2 was compacted and integrated tightly with the matrix, on the contrary, the graphite was loose and ease to be erased from matrix, and there are more pits which was formed due to graphite erased in the course of metallographic preparing in the C10 and MC samples. Based on Fig.1 and Tab.2, it can be deduced that integrated tight degree of the solid lubricants with matrix has a great influence to hardness of Ni based materials. From Fig.1b, it can be seen that MoS2 particles is fine and dispersed uniformly in the matrix.

3.3 wear behavior

The variation of wear rate of Ni based materials with loads at sliding speeds of 400-500r/min(0.46-0.58m/s) is shown in Fig.2. It can be seen from Fig.2 that the wear rate of the 00 sample is the lowest at load of 20N, and it is increased to the highest value at load of 30N/40N at sliding speed of 400-500r/min and then decreased with increased load. The wear rates of MC sample has a similar trend to the 00 sample. The wear rates of C10 sample is increased with loads increasing and got to the highest value at load of 30N at sliding speed of 400r/min and then decreased with loads increasing(Fig. 2a). From Fig. 2b it can be seen that the wear rate of the C10 sample are higher at load of 20N and then decreased and keep invariant at load of 30-50N, the wear rate of the MC sample are decreased with load increasing from 20N to 40N and then keep invariant at load of 50N. The wear rate of 00 sample is still the lowest at load of 20N and keep stable at load of 30-50N at sliding speed of 500r/min. Obviously, it can be seen from Fig.2 that the wear rate of the M10 sample are relatively low and stable at load of 30-50N compared with other materials.

The variation of friction coefficient of Ni based materials with time is shown in Fig.3. It can be seen from Fig.3 that the friction coefficient of the M10 sample is the lowest and stabllest than other samples, and the friction coefficient of other sample are higher and unstable.
Fig. 1. Typical microstructure of Ni based materials: (a) C10; (b) MC

Fig. 2. Variation of wear rate of the Ni based materials with loads at sliding speed of: (a) 400r/min, (b) 500r/min.

Fig. 3. Variation of friction coefficient of the Ni based materials with time at load of 40N and sliding speed of 400r/min.

3.4 Wear surface and analysis

Fig. 4 shows the worn surfaces of Ni based materials at load of 20N and sliding speed of 300r/min (0.35m/s). From Fig. 4a, it can be seen that there are fine and shallow grooves on the worn surface of 00 sample, obviously, the wear mechanism is mild abrasive wear. The worn surfaces of
sample M10 and C10 have a similar morphology, there are more wide and deep grooves on the surfaces than that of 00 sample (Fig. 4b-c). Besides shallow grooves, there are more loose film on the surface of MC sample than that of M10 sample and C10 sample (Fig. 4d). At the low load of 20N, the 00 sample has the lowest wear rate because of no soft lubricant in matrix, among other three materials, the wear rate is in accord with its hardness, the C10 sample has the highest wear rate for it's lowest hardness, the MC sample has the lowest wear rate for its highest hardness and the M10 sample has a medium wear rate.

![Sample Images](image)

**Fig. 4.** worn surfaces of Ni based materials at load of 20N and sliding speed of 300r/min(0.35m/s): (a) 00 sample; (b) M10 sample; (c) C10 sample; (d) MC sample.

Fig. 5 shows worn surfaces of Ni based materials at load of 50N and sliding speed of 500r/min(0.58m/s). It can be seen from Fig. 5a that there are fine particles, deep grooves and cracks on the wear surface of 00 samples. Because there are no solid lubricant in the matrix of 00 sample, the friction pair is metallic contact directly, so its wear surface is more ragged. It can be seen from Fig. 5b that the worn surface of M10 sample is more smooth than that of other samples due to produced lubrication film on the wear surface, and there are shallow grooves and fine decries on the surface. Compared Fig. 4b and Fig. 5b, it can be seen that both of worn surfaces and wear rates of M10 sample at load of 20N and 50N are similar, all of these owe to good lubricating properties of MoS2. From Fig. 5c and 5d, it can be seen that the worn surfaces of C10 and MC sample are similar, there are pits and fine particles on the surfaces, although the surface of MC sample is a little smooth than that of C10 samples. From Fig. d1-d2, it can be seen that the graphite is loose and aggregated in local area. Because of aggregated graphite is difficulty to form uniform lubricant film on the wear surface, so the friction coefficient of C10 and MC samples are unstable.

Both graphite and MoS2 are excellent solid lubricants for they ease to form lubrication film which can alleviating friction and wear of friction pair [6]. The density of MoS2 is 4.80g/cm³, which is more than 2 times density of graphite(2.25g/cm³). So the volume content of total solid lubrication of C10 sample is twice times more than that of M10 sample. At the same time, the graphite is loose and aggregated in the matrix, the local area where graphite gathered is like the cavity of matrix, and these ‘cavity’ can greatly reduced the strength of matrix[10], so the anti-wear resistance of material would also be cut down. It can be seen from Fig. 2and 3 that the wear rate and friction coefficient of MC and C10 samples are high and unstable. In contrast to loose and aggregated in the matrix of graphite, the MoS2 is compacted, dispersed uniformly, highly closed combination with matrix, those characteristics is beneficial to the anti wear performance of the materials. Uniformly dispersed and tight combined with matrix of MoS2 particles can not only enhancing the strength of matrix but also alleviating wear of matrix for producing stable lubrication film between friction pair surfaces. As can be seen from Fig.2 and Fig.3 that, the M10 sample has a low and stable wear rate and friction coefficient almost at different loads and sliding speeds.
4. Conclusions

Tribological properties of four Ni based materials with different content of solid lubrication of graphite and MoS$_2$ were investigated using a pin-on-disk wear tester. Results showed that the effects of graphite and MoS$_2$ to Ni based materials were different. Important conclusions obtained from this work can be summarized as follows:

1) The Ni based material with 10% graphite has a lowest hardness, the material with 5% MoS$_2$+5% graphite has a highest hardness, and the material with 10% MoS$_2$ has a hardness similar to that of the material with no solid lubricant.

2) The wear rate and friction coefficient of the Ni based material with 10% MoS$_2$ were relatively low and stable at different loads and sliding speeds for uniformly dispersed and tight combined with matrix of MoS$_2$.

3) The materials with 10% graphite and 5% MoS$_2$+5% graphite have high and unstable wear rates and friction coefficient because of loose combined with matrix of graphite lead to reduction strength of materials.

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