Article ID: 1003 - 6326(1999)03 - 0634 - 04

Antifriction and wear resistance of tin diffusion coating on brass[①]

Zhu Weidong(朱维东), Ma Bingxian(马秉先)

Department of Metallurgy, Guizhou University of Technology, Guiyang 550003, P. R. China

Abstract: After brass is coated with tin, heat treatment makes the coating metal Sn and the substrate metallic elements Cu and Zn diffuse with each other. This causes the coating composition to be changed and the interface to be strengthened. The diffusion coating with a multiphase structure formed by this process has excellent properties of antifriction and wear resistance. With the aid of scanning electron microscopy, electronic probe microanalysis and X-ray diffraction, the mechanism of the properties is discussed.

Key words: brass; tin coating diffusion; antifriction and wear resistance; multiphase structure

Document code: A

1 INTRODUCTION

Coating heat diffusion is a compound process combining coating with diffusion. After brass is coated with tin, heat diffusion makes the atoms Sn, Cu and Zn diffuse with each other, thus making the surface alloyed so as to improve wear resistance. This process is called Delsun method. In some domestic literatures[1,2], it is introduced that due to diffusion of Sn towards substrate, a "diffusion layer" of antifriction and wear resistance would be produced. In this paper, the diffusion process of brass sample after hot dip coating with tin, formation of the antifriction and wear resistance layer, and relation between the properties and structure were studied. It was shown that in the process of treament, as Sn atoms diffuse towards substrate, Cu and Zn diffuse more intensely towards coating as well. Tin coating has changed into a multiphase intermetallic compounds of Cu-Sn and Cu-Zn. This makes the ionic combination between coating and substrate change into a firm metallurgical one, and the interface is strengthened and the surface hardness is enhanced.

2 EXPERIMENTAL AND RESULTS

2.1 Diffusion treatment

HPb59 and H62 brasses were selected to be treated with diffusion annealing under protection of carbon powder after hot tinning. The heating temperature was 430 ℃, and the holding time was 6 ~ 12 h.

2.2 Metallographical observation

The microstructures after tin coating diffusion treatment are shown in Fig.1 and Fig.2. The diffusion layers are very bright and hard to corrode. There are a lot of black points

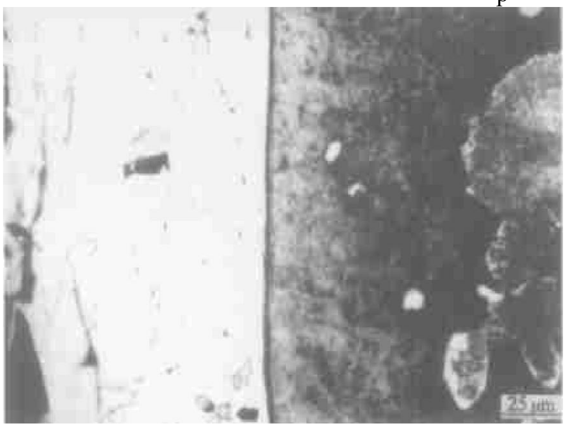

Fig.1 Microstructure of HPb59 substrate and tin coating
(Corroded with aqua regia)

① Received Jul.23, 1998; accepted Dec.5, 1998

dispersively distributed in the main phase(bright field) . There is a black line(HPb59) by the side of coating along the interface , and a " tin diffusion layer" by the side of substrate .

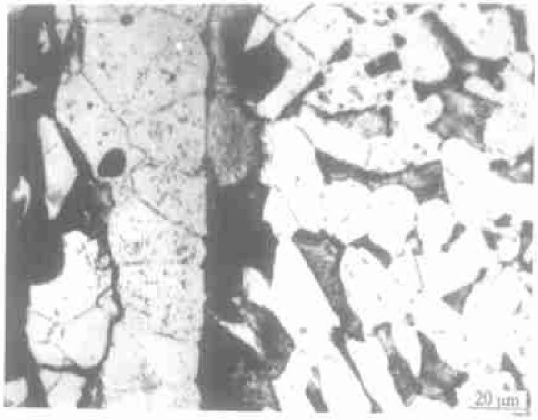

Fig .2 Microstructure of H62 substrate and coating (Corroded with aqua regia)

2 .3 Scanning analysis

At a constant temperature of 430 ℃ , diffusion to coating of Cu and Zn occurs in a liquid phase , but seeping of Sn to substrate is a solid diffusion . The analysis results from SEM(Fig . 3) show the changes in composition . It is indicated that the reverse diffusions of Cu and Zn play a major role in diffusion .

2 .4 X-ray diffraction analysis

Fig .4 shows the X-ray diffraction pattern of the tin coating diffusion layer of a HPb59 sample , from which the phases , $Cu_6Sn_5(\eta')$, $Cu_5Zn_8(\gamma')$ and $CuZn(\beta')$ can be identified , and Cu_6Sn_5 constitutes the main phase in the diffusion layer .

2 .5 EPMA micro-area composition analysis

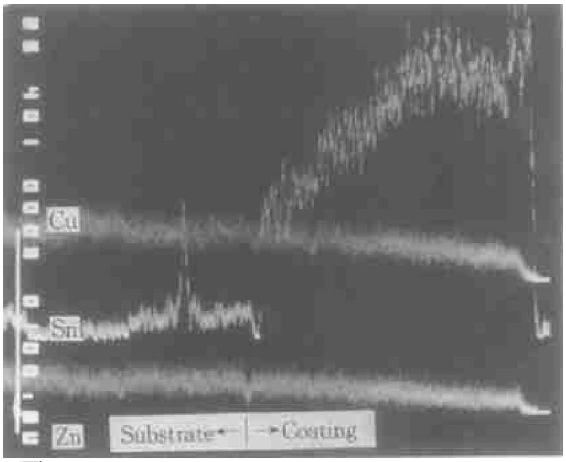

Fig .3 d_k linear scanning analysis for Cu , Zn and Sn in H62 substrate and coating

Fig .4 X-ray diffraction pattern for HPb59 tin coating diffusion sample

EPMA micro-area composition analyses for Sn layer , black points and black area (affected layer) have been done respectively , and the results are shown in Table 1 .

2 .6 Hardness test

After diffusion treatment , owing to the

Table 1 EPA micro-area compositions of Sn layer , black points and black area (mole fraction , %)

Group number	Sn layer			Black points			Black area		
	Sn	Cu	Zn	Sn	Cu	Zn	Sn	Cu	Zn
1	10.08	54.41	34.40	11.77	51.00	37.62	1.80	56.10	41.41
2	7.98	56.40	34.63	10.60	50.86	36.47	1.94	56.83	41.62
3	8.14	54.54	37.23	11.15	50.55	37.12	2.00	55.81	40.71

formation of intermetallic compounds Cu_6Sn_5 and Cu_5Zn_8, the hardness of coating increased over 400 HV from original 3.3 HB of tin (see Table 2), and greatly exceeded the hardness of brass.

Table 2 Hardness values of tin coating diffusion samples

Sample material	Diffusion layer hardness ($HV_{0.02}$)	Substrate hardness ($HV_{0.02}$)
HPb59	678, 580, 458, 428	156 184, 143, 133
H62	538, 378, 580, 458	241, 162, 115, 104

2.7 Friction and wear test

Two wear samples of 40 mm in diameter (ID 10 mm) and 10 mm in height were made from H59 brass. One was treated and the other was not treated. The opposition friction piece sample was GCr15 quenched and tempered with a hardness of 60 HRC.

The friction and wear test shows that under the conditions of air atmosphere and no lubricant, the untreated sample got rubbed and adhered after friction running for a short time, and worn heavily, due to adhesion, but under the same conditions property of anti-rubbing and adhering of the treated one was improved obviously. The coating was not easy to peel off (see Table 3).

Table 3 Results of friction and wear test

Test conditions	Test results
1. MM200 wear test machine 2. Upper sample was fixed to do sliding friction 3. Rotational speed 200 r/min 4. Normal pressure 490 N 5. Environment: non-lubrication, in air	1. When untreated sample had run for 45 s, rubbing and adhering happened. Friction moment was 6 kg·cm before adhering; when adhering occurred, friction moment changed in the range of 8.5 ~ 9.5 kg·cm. 2. Adhering did not occur yet after the treated sample had been tested for 30 min. Friction moment was averagely kept at 4.7 kg·cm.

3 DISCUSSION

3.1 Formation of antifriction and wear resistance layer

In the process of tin coating diffusion, when the temperature reaches the melting point of tin, the tinning layer is in a melting state, with large energy fluctuation and increased vacancy concentration. After a short time of dissolving, Cu begins to diffuse towards the Sn layer[3]. At the diffusion temperature (430 ℃), the compound produced is Cu_3Sn (ε)[4]. At the same time, seeping of Sn to substrate is a diffusion in solid state. The radius of atom Sn being bigger than those of Cu and Zn (r(Sn) = 1.41 Å, r(Cu) = 1.28 Å and r(Zn) = 1.33 Å)[5] makes it difficult for Sn to seep and diffuse to substrate. Fig.3 qualitatively reflects the distribution of Cu and Sn concentrations on two sides of the interface. So, reverse diffusion as a dominant factor is a main feature in the treatment of "tin coating diffusion"[6]. In studying the coating structure, it can be seen with the aid of Cu-Sn phase diagram[7] that when diffusion ends, in the process of cooling, while temperature drops down to 415 ℃, a peritectic reaction occurs: $L + \varepsilon \rightarrow \eta$. When the temperature of the remains of tin-rich part in melting liquid gradually drops down to its crystallization temperature, a eutectic reaction happens: $L \rightarrow \eta + \theta(Sn)$. Since that eutectic point is very close to the Sn end, the structure obtained should be a hypoeutectic structure (η + Sn), in which Cu_6Sn_5 is a main phase. Besides, because of the big electronegative difference between Zn and Cu, Zn atoms diffusing to Sn layer tends to produce a compound with Cu. So, with temperature dropping down a Cu-Zn compound Cu_5Zn_8 (γ) is precipitated and dispersively distributes in the diffusion layer. Finally, with temperature dropping down continuously, ordering transformation of η and γ will occur, that is, the final hypoeutectic structure is (η' + Sn), and the dispersive phase is γ'.

3.2 Effects of Cu_6Sn_5, Cu_5Zn_8 and Sn on friction and wear resistance

The strength and hardness of Cu_6Sn_5 and Cu_5Zn_8 in diffusion layer are much higher than those of the substrate. In these phases, Cu_6Sn_5 belongs to a deformed structure of close packed hexagonal NiAs type[8]. In a frictional couple in which one piece is made with ferrous metal, the material with a hexagonal crystal structure is the most ideal one. It can reduce the friction coefficient effectively and restrain " metal transfer" caused by adhering and burning between frictionizing surfaces to mitigate wear. This phase has a complicated cubic structure, and is hard in character. This structure in which hard particles distribute in matrix is exactly like that of the typical tin-based antifriction material. That is, while frictionizing, γ', as the hard particles, may bear a high load, but the matrix, η' as a main phase in it, can make the pressure well-distributed on each particle. A trace of Sn(difficult to observe metallographically) produced in eutectic reaction also has its special contribution to antifriction, good conformability and embedability. Suitable amount of the low-melting point element existing in the material composition will meet by the high temperature caused by the real contacts during friction, spread flatly on the frictional surface along with the friction force acting, and make temperature well-distributed.

3.3 Friction and wear characteristcs of diffusion layer

The diffusion layer with a multiphase structure not only strengthens the coating and enhances its properties, but also reduces the adhesive tendency[9]. Firm combination within multiphase structure is advantageous to bearing high fatigue stress and improving fatigue wear. Moreover, because the tin diffusion layer formed through seeping and diffusion of Sn into substrate is under the hardened layer, and located within the range of a gradual drop of the matrix' s hardness distribution, it makes a continuous chain from surface to substrate. This will keep a full malleability for tracing to matrix' s plastic deformation. And this kind of firm metallurgical combination is also very important to prevent the coating from crumbling.

4 CONCLUSIONS

(1) After brass is treated with tin coating diffusion, the coating will transform into a structure with ordered η' as main phase, in which Cu_5Zn_8 phase precipitates on solid state, and also goes through an ordering transformation. A small amount of Sn phase exists as a single phase, which is produced from eutectic reaction.

(2) The increase of the hardness of whole diffusion layer greatly strengthened the antiadhesion of the material. Hardness distribution changes continuously from surface to inner layer, approaching an ideal one of antifriction and wear resistance material.

(3) The improvement of friction and wear resistance of diffusion layer is due to that the structure of surface layer corresponds actually to a thin antifriction layer composed of multiphase alloy.

REFERENCES

1 Editorial Committee of Machinery Engineering Manual. Machinery Engineering Manual, (in Chinese). Beijing: Mechanical Industry Press, 1979: 45 ~ 37.

2 Dai Xiongjie. Elements of Tribology,(in Chinese). Shanghai: Shanghai Science and Technology Press, 1984: 219.

3 Zhang Qiyun *et al*. Acta Metallurgica Sinica,(in Chinese), 1989, 25 (6): 347.

4 Zhang Qiyun *et al*. Acta Metallurgica Sinica,(in Chinese), 1992, 28 (9): 380.

5 Ying Yongjia. Concise Manual of Physical Chemistry, (in Chinese). Beijing: Higher Education Press, 1988: 583.

6 Zhu Weidong. Modern Machinery, (in Chinese), 1994, (1): 28.

7 Massalski T B. Binary Alloy Phase Diagrams. Ohio: Metals, Park, ASM, 1986.

8 Hansen M. Constitution of Binary Alloys. New York: McGraw-Hill, 1958: 636.

9 Ma Bingxian. Jounal of Guizhou Institute of Technology,(in Chinese), 1989, 18 (3): 16.

(Edited by Peng Chaoqun)