IN SITU GRADIENT DOUBLE-LAYER COMPOSITES OF Al-Fe ALLOY BY CENTRIFUGAL CASTING①

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ABSTRACT In situ double-layer composites of Al-Fe alloy, which possess the microstructure of primary Fe-phase with gradient distribution in outer layer and no primary Fe-phase in inner layer, have been achieved by preheated metal mould centrifugal casting. The structural characteristics were investigated, the distributions of the primary Fe-phase and the hardness of the composites along radius were tested, and the wearability of the composites was also analyzed.

Key words in situ composites gradient composites double-layer composites Al-Fe alloy centrifugal casting

1 INTRODUCTION

It is often expected that the two sides of a part possess different properties or function, and that the two sides are soundly joined so that the part will not fail in use because of their unmatched properties.

For the purpose above, the concept of gradient composites was suggested for the first time by a few Japanese scholars[1]. Gradient composite is a kind of heterogeneous material whose function varies according to its constituent and structure, which can be acquired by selecting two kinds of materials with different properties and changing their constituents and structure continuously.

In this paper, the in situ composition between primary $Al_{13}Fe_4$ and aluminium matrix has been realized by taking primary $Al_{13}Fe_4$ as the reinforced phase and making it precipitate during solidification, because $Al_{13}Fe_4$ has such characteristics as high hardness, good wear resistance and corrosion resistance, and low thermal expansibility.

On the other hand, with the help of the density difference between primary $Al_{13}Fe_4$ and melt, the broad temperature interval in two-phase zone and the steep liquidus, under the condition of centrifugal force and a given solidification, primary $Al_{13}Fe_4$ was accumulated to the outer layer of the cast pipes, and the in situ double-layer composites were achieved by centrifugal casting, which are composed of outer layer of good wear resistance with gradient distribution of primary $Al_{13}Fe_4$ and inner layer with eutectic or hypoeutectic microstructure.

2 EXPERIMENTAL

Fig. 1 shows the vertical centrifugal casting apparatus. The rotation rate is 1000 r/min. The outer diameter of the cast pipe is 60 mm, the inner diameter 30 mm, and the height 80 mm. The Al-5% Fe, Al-10% Fe and Al-15% Fe alloys were prepared with commercially pure aluminium and ferrum in an intermediate frequency induction furnace.

The melt was refined and degassed before pouring, and the superheat temperature of which was 80~ 100 ℃. The inner wall of the metal mould was applied with graphite coating, and it was held at a required temperature before pour-

① Supported by the National Natural Science Foundation of China (No. 59471051)
Received Oct. 16, 1995; accepted Oct. 5, 1996

ing. The heating furnace was shut immediately after pouring.

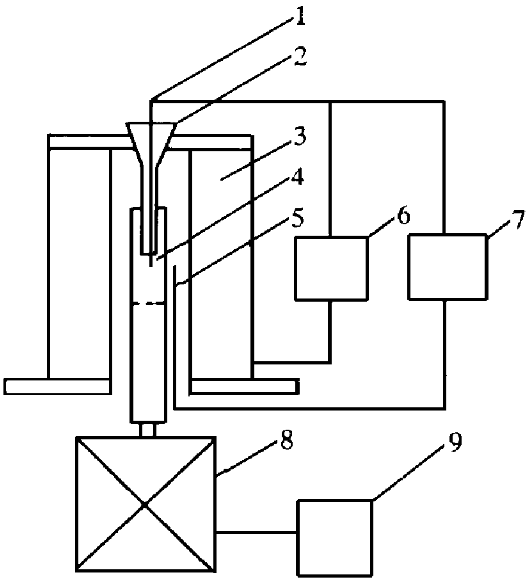

Fig. 1 Schematic diagram of vertical centrifugal casting apparatus

1 —thermocouple; 2 —pouring cup; 3 —heating furnace; 4 —metal mould; 5 —thermocouple; 6 —temperature controller; 7 —temperature recorder; 8 —motor; 9 —inverter

The specimens were eroded separately by 2%, 0.5% HF aqueous solution so that their macrostructures and microstructures could be observed. The amount of primary $Al_{13}Fe_4$ was measured by section method, and the radial hardness distribution in the transverse section of the cast pipe was determined by HV1-10A type Vickers. The wear rates of the composite pipes in different radial positions under the condition of dry sliding friction are surveyed by CPM-III type pin-and-disc wearing tester. The wearing surface of the specimen was 10mm × 10mm, the counterpart disc was 45 steel with hardness HB220, rotation rate 200r/min, and the friction diameter was 40mm, the load 23N.

3 RESULTS AND DISCUSSION

3.1 Macrostructures of the composites

The macrostructures of Al-5% Fe alloy composite by centrifugal casting at the mould temperature of 600 ℃ are shown in Fig. 2. It can be seen that in situ double-layer composite has been obtained, which is composed of outer layer with accumulated primary Fe-phase and inner layer without primary Fe-phase. Furthermore, primary Fe-phase in outer layer behaves like gradient distribution: its distribution is the densest and its amount is the most in the outermost layer, while from outer to inner layers the distribution becomes more and more sparse and the amount reduces along radius until primary Fe-phase can not be seen from a certain position inwards. The primary Fe-phases in outer layer are needle-like, and they tend to be arranged radially, but with some deflection angle from radial direction. Primary Fe-phases perpendicular to radial direction are seldom found; this arrangement is more evident especially for bulky needle-like Fe-phases, and their branches and overlaps can also be seen.

In situ double-layer composites of Al-10% Fe, Al-15% Fe alloys have also been achieved by centrifugal casting at the mould temperature of 700 and 800 ℃ respectively, with primary Fe-phase of gradient distribution in outer layer and no Fe-phase in inner layer.

3.2 Microstructures of the composites

Fig. 3 shows the microstructures of Al-5Fe alloy composite. Its outer layer consists of primary Fe-phases and eutectic between them, and the macroscopic long primary Fe-phases in outer layer are often joined microscopically by a few sections. There are branches on the trunk of primary Fe-phase, which results from the variety of growth directions of $Al_{13}Fe_4$ with the help of its twins[3]. The primary Fe-phases which broke and collided together can also be seen. The amount of primary Fe-phase reduces and eutectic increases along radius from outer to inner layers, and there is no primary Fe-phase in inner layer, where its microstructure is flake eutectic or hypoeutectic with eutectic between α-Al dendritic structures.

Fig. 4 shows the microstructures of double-layer composite of Al-15Fe alloy. It is experimentally found that, with the increase of Fe content the amount of primary Fe-phase in outer layer increases, its shape becomes more bulky, and the amount of the primary Fe-phases

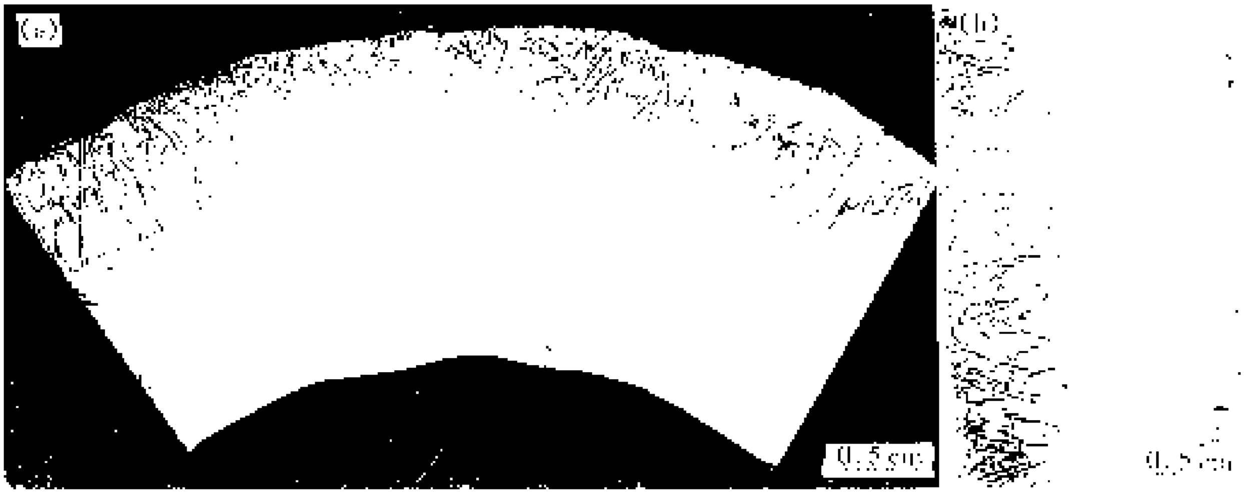

Fig. 2 Macrostructures of double-layer composite of Al-5%Fe alloy
(a) —transverse section; (b) —longitudinal section

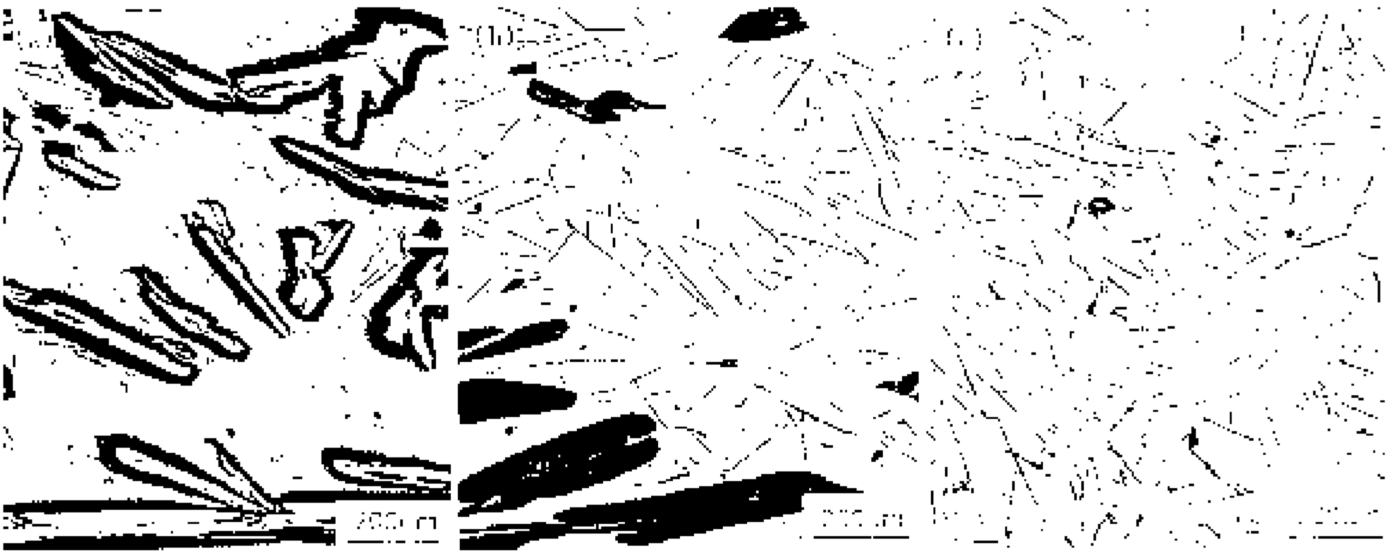

Fig. 3 Microstructures of double-layer composite of Al-5Fe alloy
(a) —outer layer; (b) —transitional layer; (c) —inner layer

broken by colliding increases. For the inner layer without primary Fe-phase, its microstructure remains eutectic or hypoeutectic.

Fig. 5 shows the distribution of primary Fe-phase along radius. It can be seen that, in-situ double-layer composites of three kinds of Al-Fe alloys have been achieved, which are composed of outer layer with primary Fe-phase of gradient distribution and inner layer without primary Fe-phase. The primary Fe-phases in the composites increase gradiently from inner to outer layers in the position corresponding to the macrostructure. The thickness of outer gradient layer and the amount of primary Fe-phase increase with the increase of Fe content, which results from the increase of the temperature interval in solid/liquid two-phase zone and the total amount of primary Fe-phase as Fe content increases. It will cause: (1) the amount of primary Fe-phase moving outwards increases; (2) the solid fraction in outer solidifying layer becomes more than the critical solid fraction, retarding primary Fe-phase to move outwards when primary Fe-phase

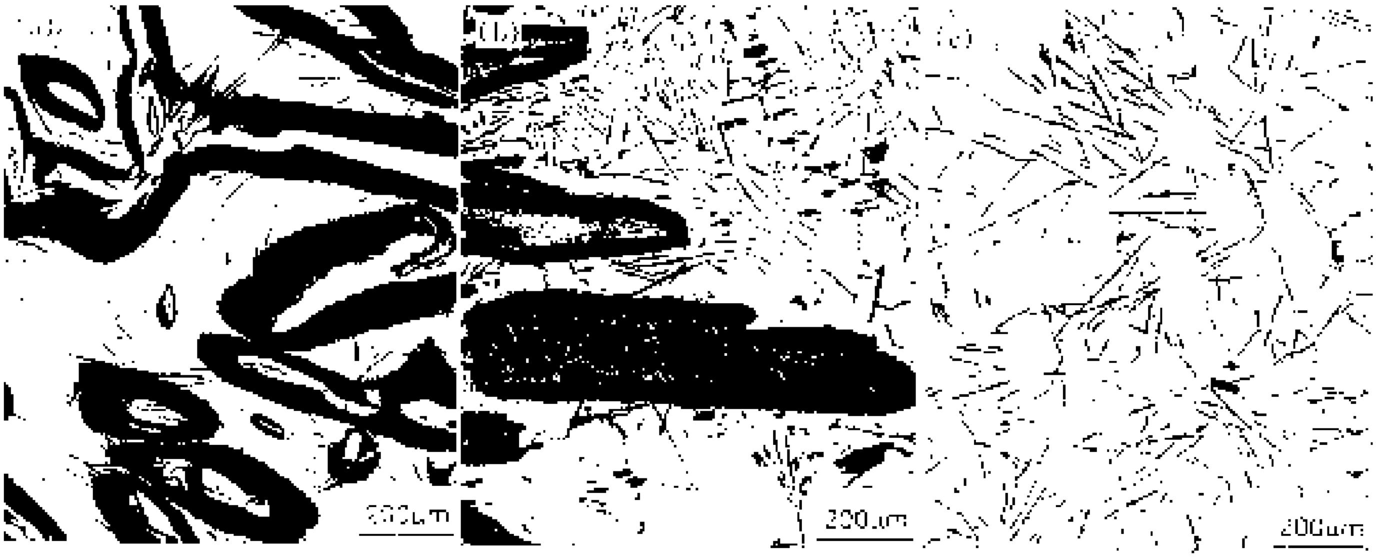

Fig. 4 Microstructures of double-layer composite of Al-15Fe alloy
(a) —outer layer; (b) —transitional layer; (c) —inner layer

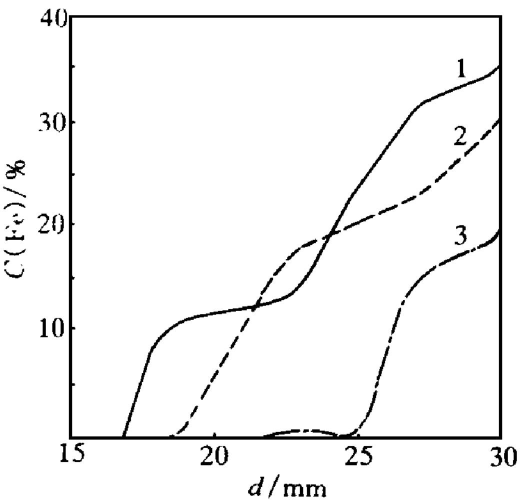

Fig. 5 Distribution of primary Fe-phase along radius
(C(Fe) —fraction of primary Fe-phase; d —distance from center)
1 —Al-15Fe; 2 —Al-10Fe; 3 —Al-5Fe

is still precipitating in inner layer. As a result, the outer layer thickens and the amount of primary Fe-phase in outer layer increases.

3.3 Hardness distribution

Fig. 6 shows the distribution of Vickers hardness along radius for the double-layer composites of Al-Fe alloy. In the figure, it is shown that for the composites with different Fe content the Vickers hardness is about 32 in the inner layer without primary Fe-phase. The hardness of the composites changes along radius from inner to outer layers. In the first section from inner wall, the hardness increases little. Up to a certain position where the primary Fe-phase appears, the hardness increases greatly, then it increases gradiently to the largest value at the outmost wall.

Compared to Fig. 5, it can be found that the distribution of hardness is entirely consistent with the distibution of primary Fe-phase along radius, demonstrating that the hardness of the composites is mainly dependent on the amount of primary Fe-phase.

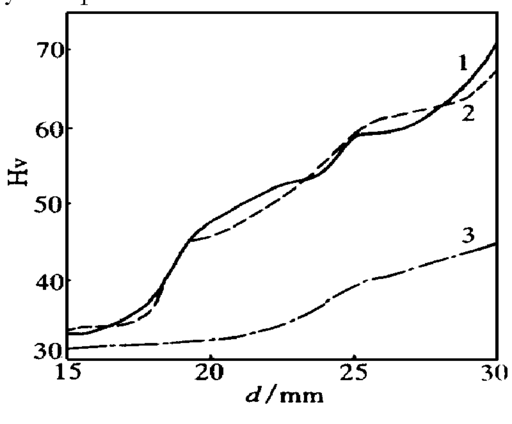

Fig. 6 Hardness distribution of double-layer composites of Al-Fe alloy
(d —distance from center)
1 —Al-15Fe; 2 —Al-10Fe;
3 —Al-5Fe

3.4 Wearability

Three wearing specimens were taken separately from the inner, the transitional and the outer layers of the composites, the wearing capacities of which in 30 min were tested. The results are shown in Fig. 7. It can be seen that the wear rates increase from outer to inner layers, and they are distinctly lower in outer layer than in inner layer. With the increase of Fe content, the wear rates in outer layer become even lower, while those in inner layer are near. The results of wear test indicate that the wearability of the composites mainly depends on the amount of primary Fe-phase. That proves the composites are promising to be applied to the parts which demand high wearability in outer surface.

Fig. 8 shows the scanning electron micrographs of the wearing surface of Al-Fe alloy composites. It is shown that the wear process of the composites includes the breakdown and detachment of Fe-phase from the wearing surface

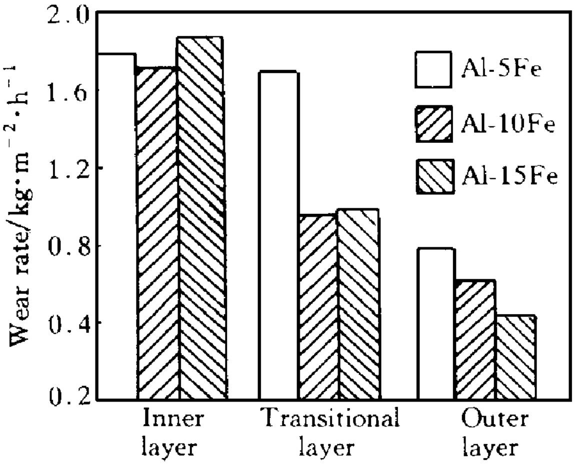

Fig. 7 Wear rates of the composites

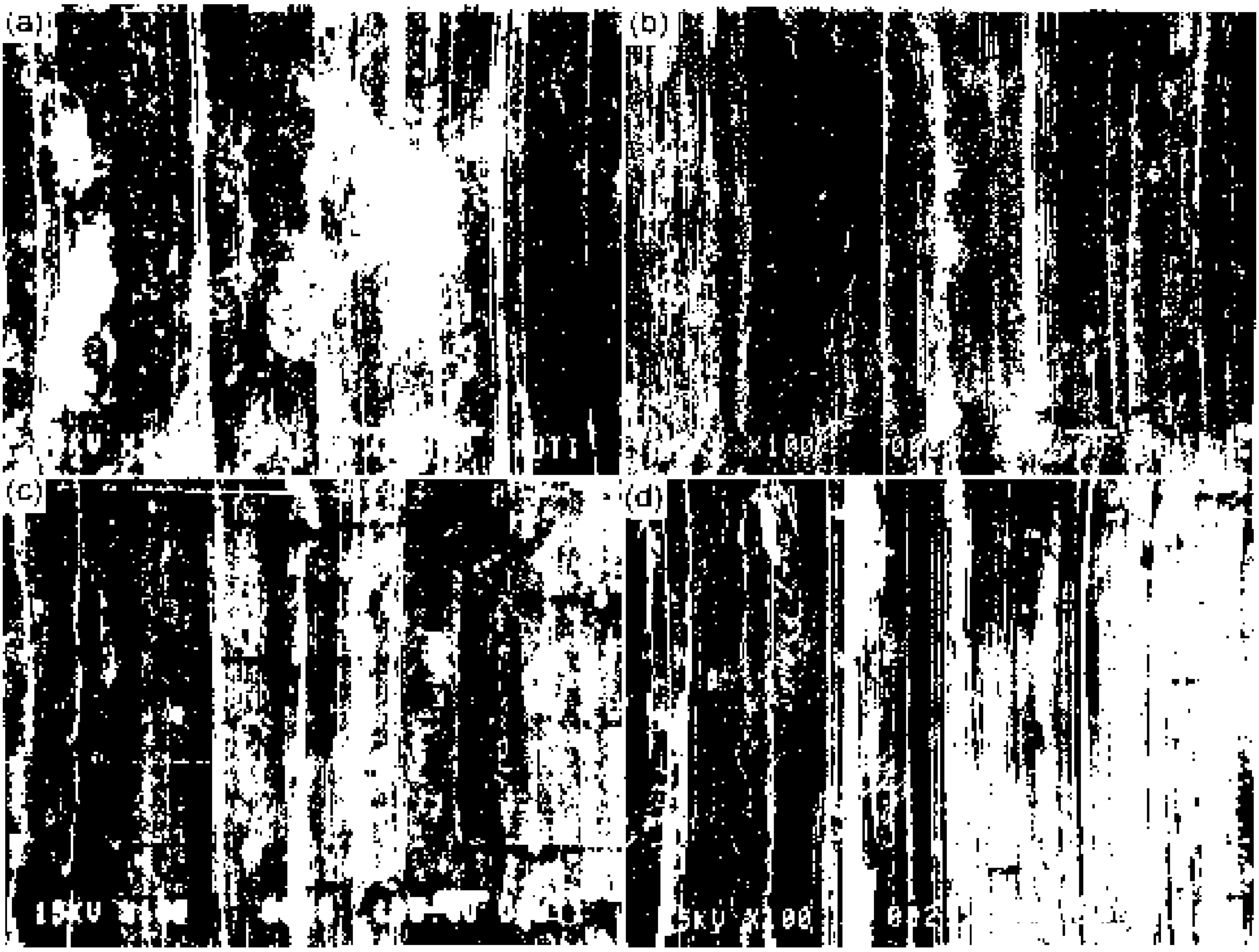

Fig. 8 SEM micrographs of the wearing surface of Al-Fe alloy composites

(a) —Al-5Fe, outer layer; (b) —Al-5Fe, inner layer;
(c) —Al-10Fe, outer layer; (d) —Al-10Fe, inner layer

and the wear of aluminium matrix[4]. Fig. 8 shows the following results.

(1) The wearing grooves on wearing surface in outer layer are more shallow than those in inner layer. The reason is that the depth of the grooves depends on the load and the intrinsic ability of plastic deformation of a material; if the shear strength of the material is lower, the grooves are deeper. For the outer layer of the composites, since the amount of aluminium matrix is less and its deformation is retarded by Fe-phase, the grooves are relatively shallow.

(2) More scraps adhere to the wearing surface of outer layer than to that of inner layer. It is because the hardness in outer layer is higher than in inner layer, which increases the probability of protruding spots to plough into the wearing surface of the counterpart disc, and the outer layer leads the counterpart disc to produce more scraps, thus the amount of the scraps adhered to the outer layer increases.

(3) The wearing surface is rougher and more uneven with increasing Fe content. It is because that primary Fe-phases become more bulky with increasing Fe content, and the holes resulting from their breaking are bigger.

4 CONCLUSIONS

(1) The in situ double-layer composites of Al-Fe alloy have been achieved by centrifugal casting. They possess the microstructure of primary Fe-phase with gradient distribution in outer layer and no primary Fe-phase in inner layer.

(2) The hardness and wearability of the composites depend mainly on the distribution of primary Fe-phase along radial direction.

(3) The wear process of the composites includes the breakdown and detachment of the Fe-phase on wearing surface and the wear of aluminium matrix.

REFERENCES

1 Masayuki Niino, Toshio Hirai *et al*. Journal of the Japan Society for Composite Materials, (in Japanese), 1987, 13(6): 257-262.

2 Mondolfo L F. Aluminium Alloys: Structure and Properties. Boston: Butterworths, 1976: 216-222.

3 Adam C M, Hogan L M, Acta Met, 1975, 23: 345-354.

4 Wang Qudong. PhD Thesis, (in Chinese). Dalian: Dalian University of Technology, 1995: 76-78.

(Edited by Li Jun)