Lining of cast iron cylinder with copper alloy utilizing high temperature oxidation

Toshinari Yamazaki*, Toshio Kikuta and Yoshinori Murata†
Graduate School of Science and Engineering, University of Toyama, 3190 Gofuku, Toyama 930-8555, Japan
†Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa, Nagoya 464-8603, Japan

Lining the inner surface of a cast iron hydraulic cylinder with copper alloy would generally not be possible. In this study, the surface of a cast iron cylinder was decarburized by high temperature oxidation. The cylinder, after decarburization, was filled with borax anhydride and heated at a temperature of 1203 K. Molten copper alloy was then injected into the cylinder, displacing the molten borax anhydride. After cooling, the embedded copper alloy was drilled along its center axis so that a prescribed thickness of the copper alloy remained. Thus, the cast iron cylinder could be successfully lined with copper alloy.

Keywords: cast iron, copper alloy, decarburization, high temperature oxidation, bonding

* Author for correspondence
e-mail: yamazaki@eng.u-toyama.ac.jp

Introduction

Methods to obtain a junction between iron and copper alloy have been devised by several researchers.[1-7] These methods are utilized, for example, to line the sliding surface of a hydraulic iron cylinder with a copper alloy.[4,7] One method for lining the inner surface of an iron cylinder with a copper alloy is to inject a molten copper alloy into a preheated cylinder filled with molten borax anhydride. This process replaces the molten borax anhydride with the molten copper alloy. After cooling, the embedded copper alloy is drilled along its center axis so that a prescribed thickness of the copper alloy may remain. However, when the cylinder is composed of a cast iron, the copper alloy does not bond to the inner surface of the cylinder.

We had previously solved this problem by filling a cast iron cylinder with a FeO powder and heating it,[7] which decarburized the inner surface of the cylinder.[8] Using this method, we succeeded in lining a cylinder with copper alloy. However, the use of FeO powder not only increases the production cost, but also generates a large amount of waste.

It is well known that when a cast iron is oxidized in air at a high temperature, a decarburized layer is formed beneath a surface oxide.[9-11] In this study, we decarburized the inner surface of a flake graphite cast iron cylinder by heating the cylinder in air at a high temperature and succeeded in lining the inner surface with a copper alloy. The detailed procedure and results of the break test of the cast iron and copper alloy junction are reported below.

Experimental procedure

Several square chips of flake graphite cast iron with an edge length of 10 mm and a thickness of 5 mm were heated in air at 1153, 1203 or 1253 K for various time durations. Structure of the surface oxide and decarburized layers were investigated with a Hitachi 3500H scanning electron microscope (SEM), furnished with an energy dispersive X-ray analyzer (EDX).

For the bonding investigation between the flake graphite cast iron and a copper alloy, 45-mm-deep flake graphite cast iron cylinders with an inner diameter of 16 mm and an outer diameter of 50 mm were utilized, as illustrated in Fig. 1(a). These cylinders were heated at a temperature of 1153 or 1203 K. After cooling at room temperature, the cylinders were filled with borax anhydride as a flux. They were then heated at a temperature of 1203 K, which is higher than the melting point (1151 K) of the borax anhydride. A molten copper alloy having a composition of $Cu_{0.87}Sn_{0.08}Pb_{0.03}Ni_{0.02}$ was heated at 1523 K and was injected into the heated cylinders (Fig. 1(b)). This caused displacement of the molten flux from the cylinders, thereby filling the cylinders with molten copper alloy. After cooling, 2-mm-thick disks were cut out of the copper alloy-embedded cylinders, as seen in Fig. 1(c). A strip specimen, 45 mm long and 6 mm wide, was then cut from the disks, as seen in Fig. 1(d). After polishing the strip specimens with abrasive paper and buffing them, SEM and EDX were utilized to observe the cast iron/copper alloy interface structure. Tensile strength of the strip specimens was also examined by using a tensile stress tester.

Results and discussion

The SEM image as well as carbon, oxygen and iron distributions obtained for the square chip specimen heated at 1203 K for 7.2 ks is represented in Fig 2. Note that the specimen was embedded in polyester resin. A 180-μm-thick oxide layer was observed on the surface. In the early stage of the oxidation, graphite flakes were combusted through reaction with air. Thereafter, graphite flakes in a deeper region were consumed through the diffusion of carbon atoms towards the oxide layer. A decarburized region was thus formed as observed in Fig. 2. While carbon precipitates, appearing black, were observed in the region that was not decarburized, they were not observed in the decarburized region, which had a thickness of 260 μm.

Since a decarburized layer is formed beneath an oxide layer, a copper alloy should bond to the inner surface of a cast iron cylinder if only the surface oxide formed on the inner surface is dissolved into the molten borax anhydride. Figure 3 illustrates examples of the SEM and EDX images observed for the cast iron/copper alloy interface of a strip specimen cut out of the copper alloy-embedded cylinder that was decarburized for 3.6 ks at 1203 K. The copper alloy was uniformly bonded to the cast iron. Note that the copper alloy penetrated the cast iron in spots to a depth of about 50μm, which indicated that the voids formed near the surface of the cast iron by decarburization were embedded with the copper alloy.

A break test for the strip specimens cut out of the cylinders embedded with the copper alloy was then performed. The specimens, after the break test, are shown in Fig. 3. In the sample that was oxidized for 1.8 ks at 1153 K, in which the thickness of the decarburized region t_{dc} was 40 μm, we failed to form a junction between the copper alloy and cast iron; the junction was broken in the process of cutting a strip out of a disk. On the other hand, in the sample oxidized for 3.6 ks at 1153 K (t_{dc}=70 μm), the strip specimen was easily divided at the cast iron/copper alloy interface by a tension as low as about 4 MPa with a strain of 0.13%. In the sample oxidized for 7.2 ks at 1153 K (t_{dc}=120 μm) and that oxidized for 3.6 ks at 1203 K (t_{dc}=120 μm), the strip specimens were broken in the region of the copper alloy. The stresses and strain upon rupture for the former sample were 164 and 4.2%, while they were 139 MPa and 4.7% for the latter sample. These values were comparable to 156 MPa and 4.0% for the specimen formed for a pure iron cylinder without decarburization process. Therefore, it was concluded that cast iron could be lined with a copper alloy if oxidation conditions produced a decarburized layer with a minimum thickness of 120 μm.

In the previous study[7], we poured molten copper alloy into a cast iron cylinder without decarburization filled with molten borax anhydride. Because the copper alloy was not bonded to the cast iron, we detached the copper alloy from the cast iron cylinder. We observed the surface of the copper alloy that had been in contact with the inner surface of the cylinder and found many semispherical holes with a diameter from a few hundred micrometers to a few millimeters[7]. These holes suggest that gas bubbles were incorporated at the cast iron/copper alloy interface. Since molten copper at a high temperature of 1523 K can dissolves oxygen atoms as much as 10 at.%[12], carbon atoms dissolved in the cast iron near the interface as well as graphite flakes at the interface react with oxygen atoms in the molten copper alloy. This results in the formation of CO_2 gas bubbles at the interface, inhibiting the copper alloy being bonded to the cast iron. Thus, it is reasonable that decarburization is essential to bond a copper alloy to cast iron.

Conclusion

A method to obtain a cast iron/copper alloy junction was developed. In this method, a cast iron cylinder is oxidized by heating in air at a high temperature. This cylinder is filled with molten borax anhydride and is heated at a high temperature, and then molten copper alloy is injected into the cylinder. After cooling, a reliable junction is obtained. While the previously reported method requires FeO powder upon heating of a cast iron cylinder for the decarburization of its inner surface, this method requires only borax anhydride. This method is therefore economical and generates less amount of waste material, making it desirable in practical applications such as the production of hydraulic cylinders lined with a copper alloy.

References

1.H. Wang, K. Wang, R. Zheng, K. S. Prasad and S. P. Ringer: Mater. Charact., 2008, 59, 542-546.

2. S. Lv, J. Song, H. Wang and S. Yang: Mater. Sci. Engin. A, 2009, 499, 347-351.

3. M. V. Suresh, B. V. Krishna, P. Venugopal and K. P. Rao: Trans. Indian. Inst. Met. 2003, 56, 375-381.

4. H. Ono and T. Mori: Materia Jpn., 1995, 34, 471-473. (in Japanese)

5. C. B. Lin and J.-S. Ho: J. Mat. Eng. Perf., 2000, 9, 81-87.

6. J. Wang, J. Cao and J. Feng: Mat. Des., 2010, 31, 2253-2258.

7. T. Yamazaki, T. Shibuya, C. Jin, T. Kikuta and N. Nakatani: J. Mat. Proc. Tech., 2006, 172, 30-34.

8. S. Yamada, S. Goto, S. Aso, Y. Komatsu and T. Konn: J. Jpn. Found. Eng. Soc., 2001, 73, 219-224. (in Japanese)

9. Y.-J. Kim, H. Jang and Y.-J. Oh: Metall. Mater. Trans. A, 2009, 40, 2087-2097.

10. M. Muscalu and D. Fatu: J. Therm. Anal., 1998, 52, 425-438.

11. A. R. K. Rashid and D. V. Edmonds: Surf. Interface Anal., 2004; 36, 1011-1013.

12. H. Okamoto: ‘Desk Handbook Phase Diagram for Binary Alloys’, (ed. M. A. Fleming), 303; 2000, Materials Park, ASM.

Figure captions

Fig. 1. Preparation of the specimen for the break test and the observation of the cast iron/copper alloy interface. (a) Cast iron cylinder oxidized at the surface. (b) Injection of molten copper alloy into the cylinder filled with molten borax anhydride. (c) Disc sample cut out of the copper alloy-embedded cylinder. (d) Strip specimen cut out of the disk sample.

Fig. 2. Cross section SEM image (a) and EDX images showing carbon (b), oxygen (c) and iron (d) distributions.

Fig. 3. SEM image (a) and EDX images for a cast iron/copper alloy interface showing carbon (b), iron (c) and copper (d) distributions.

Fig. 4. Strip specimens after the break test.

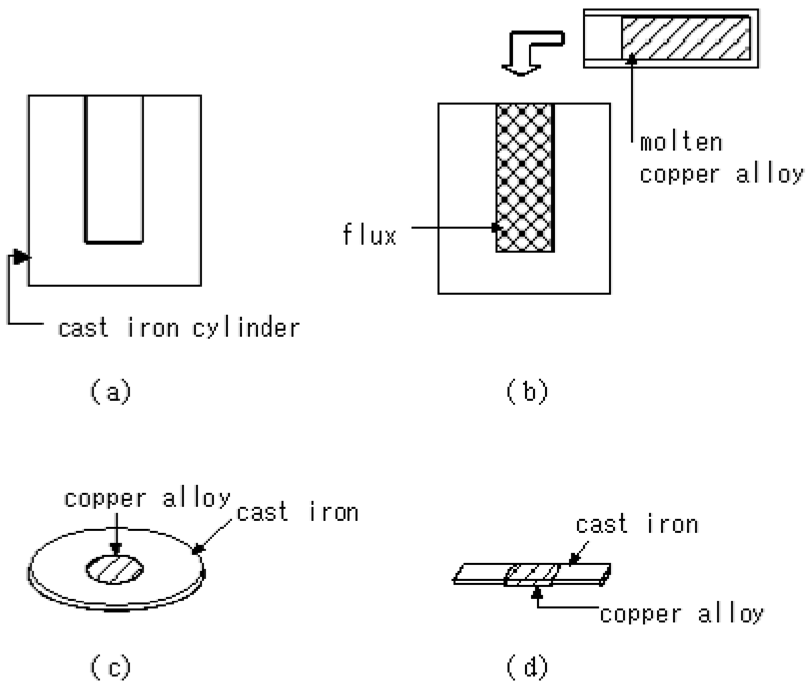
cast iron cylinder
(a)
flux
molten
copper alloy
(b)
copper alloy
cast iron
(c)
cast iron
copper alloy
(d)

Fig.1

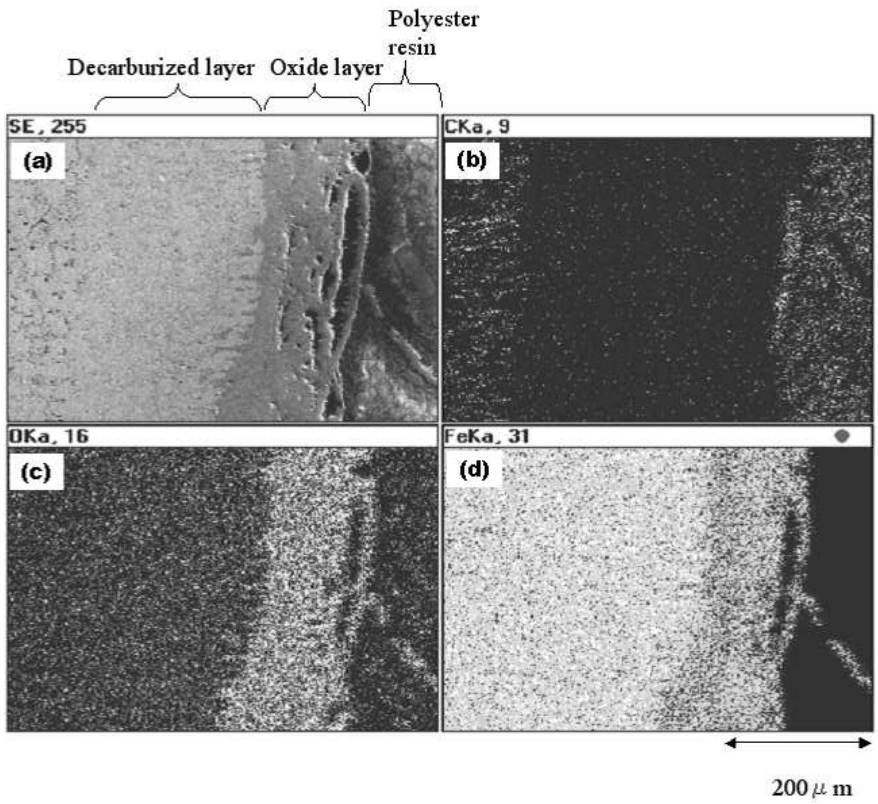
Polyester
resin
Decarburized layer
Oxide layer
SE, 255
(a)
CKa, 9
(b)
OKa, 16
(c)
FeKa, 31
(d)
200 μ m

Fig.2

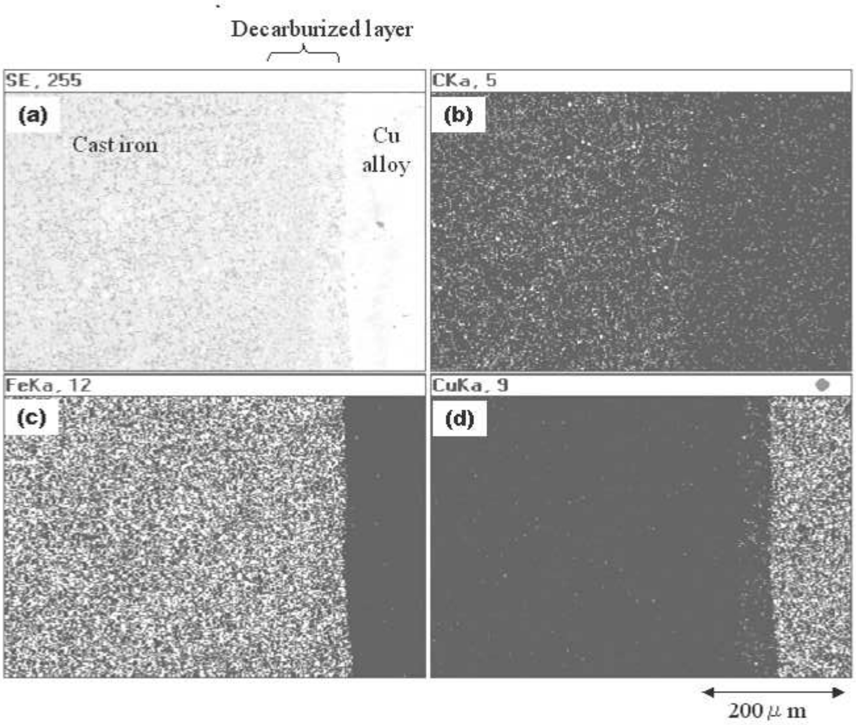
Decarburized layer
SE, 255
(a)
Cast iron
Cu
alloy
CKa, 5
(b)
FeKa, 12
(c)
CuKa, 9
(d)
200 μ m

Fig.3

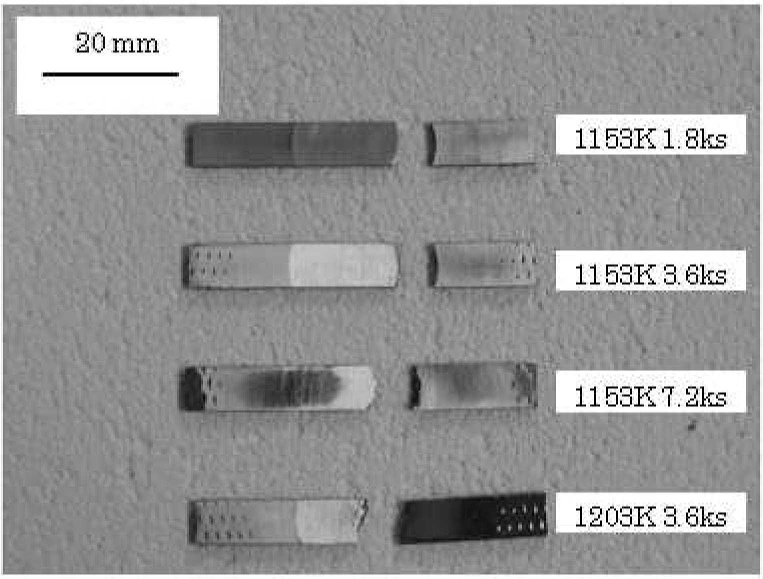

Fig.4