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# Laser Boronizing of Copper Alloy†

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## Abstract

*Surface hardening of Cu-Ni alloy has been successfully achieved by laser alloying with boron powder. Powder was preplaced in a groove on the plate surface of the base metal, and irradiated by a defocused $CO_2$ laser beam with 2.5-3.5 kW at a travel speed of 100 mm/min under Ar shielding. The structure of the alloyed layer consisted of very hard boron particles, hard Ni boride (mainly NiB) and a soft Cu-Ni solid solution phase. With an increase of Ni content, the volume fraction of boride increased but that of boron particles decreased. Hardness of the alloyed layer increased to Hv 400-500 up to 30 mass% Ni and increased monotonicaly with the increase of Ni content and reached to Hv 1400 at pure Ni plate, which corresponded to the hardness of Ni boride. Wear resistance of the alloyed layer improved to 40 times as that of base metal for each Cu-Ni alloy.*

**KEY WORDS:** (Copper) (Laser alloying) ($CO_2$ laser) (Boron) (Cupronickel) (Monel) (Nickel) (Boride) (Surface hardening) (Hardness) (Wear)

## 1. Introduction

There are no convenient methods of surface hardening Cu alloy such as carburizing or nitriding for steels. The authors have already proposed the diffusion penetration process of boron as one of the possible methods for Cu alloy to form a boride-dispersed layer[1,2]. However, in conventional boronizing processes, the hardened layer is rather thin, less than several tens of micro-meters even with long treatment times at high temperature 850℃[1,2].

On the other hand, it is well known that the laser alloying process, which involves surface melting and simultaneous alloying, has a high potential to make a thick alloying layer on base metals, especially in steels and cast irons. However, there have been a few reports of the laser alloying of Cu alloy base metal with Cr[3] and Ni, Al, Si, Sn and Pb[4].

Therefore, in order to produce thicker hardened layers the laser alloying process with boron powder as an alloying element, that is laser boronizing, has been attempted, and the applicability of this process to Cu alloy was investigated. Effects of the process parameters of laser irradiation on the formation of the alloyed layer and its structure, hardness and wear resistance were examined.

## 2. Materials and Experimental Method

As the base plate, Cu-Ni binary alloys with different Ni contents as 10Ni(9.6 mass%), 20Ni(20.1 mass%), 30Ni(30.2 mass%), 50Ni (50.5 mass%) and 65Ni(63.5 mass%) and pure Ni were used. 10Ni and 65Ni are commercial cupronickel and monel, respectively. Chemical compositions of these materials are shown in **Table 1**. Boron powder (97 mass% purity) with 0.1 to 1 $\mu$m in powder size were used as an alloying element. According to the equilibrium phase diagram[5] as shown in

Table 1 Chemical compositions of base metal plates used.

| Base metal | Chemical composition (mass%) | | | |
|---|---|---|---|---|
| | Cu | Ni | Fe | Mn |
| 10Ni | 88.53 | 9.58 | 1.21 | 0.44 |
| 20Ni | Bal. | 20.07 | — | — |
| 30Ni | Bal. | 30.17 | — | — |
| 50Ni | Bal. | 50.51 | — | — |
| 65Ni | 33.06 | 65.53 | 2.08 | 1.14 |
| Ni | — | 99.7 | — | — |

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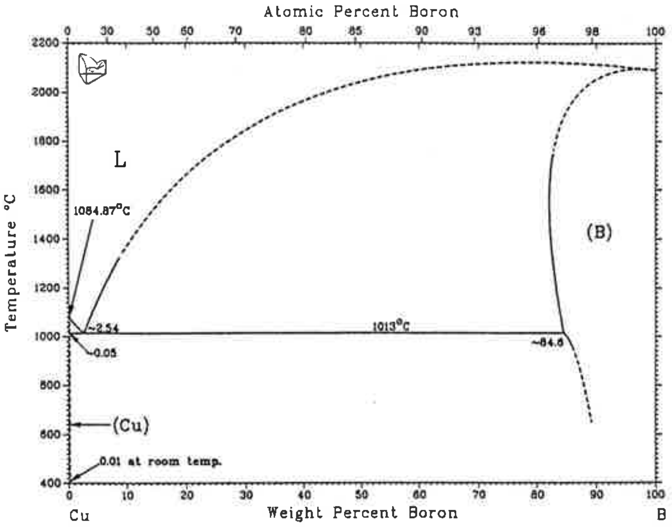
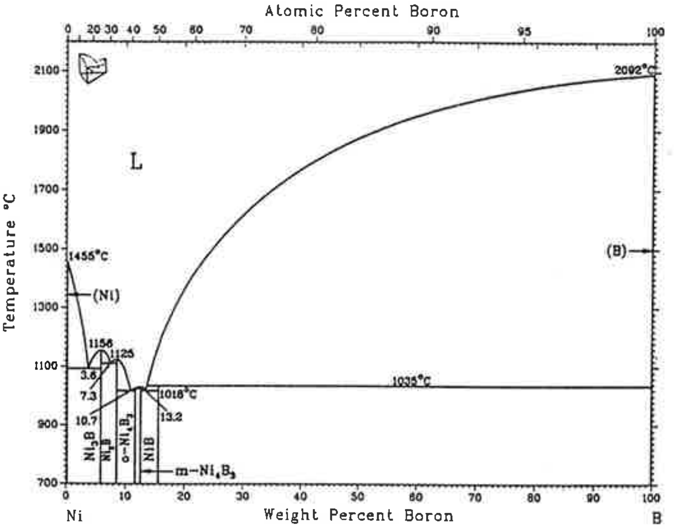


(a) B-Cu binary system



(b) B-Ni binary system

Figure 1 Equilibrium phase diagrams.

**Figure 1** (**a**) and (**b**) for Cu-B and B-Ni, respectively, boron is expected to form a primary-solidified boron phase in Cu-rich alloy and Ni boride phase in Ni-rich alloy, respectively.

**Figure 2** shows the schematic illustration of laser alloying process. Boron powders mixed with ethyl alcohol as a binder were preplaced in a groove of 0.5mm depth x 6mm width cut on the surface of a base plate of 50mm width x 100mm length x 5mm thickness. Approximate quantity of boron powder placed in the groove was 0.4 mg. mm$^{-2}$. After natural drying, a CW CO$_2$ laser beam with a ring mode(TEM01*) was irradiated onto the groove surface filled with boron powder under Ar shielding. Laser power and defocused distance (Ddf) between plate surface and beam focusing point were varied

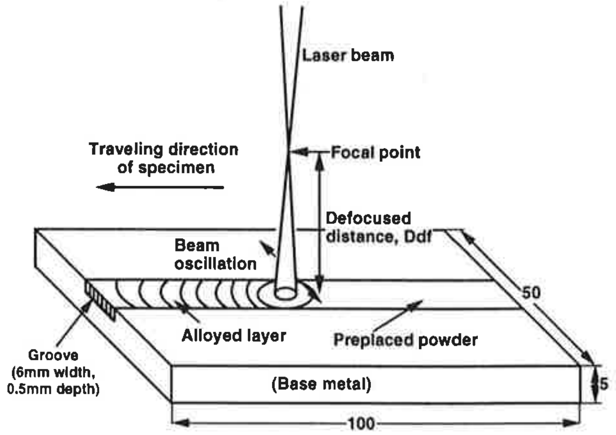


Figure 2 Schematic illustration of laser alloying process.

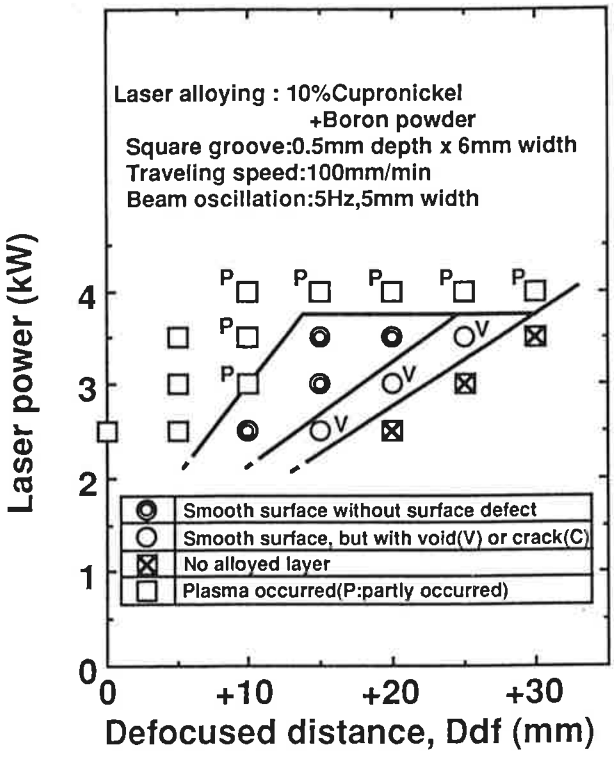


Figure 3 Effect of laser power and defocused distance on surface condition of the alloyed layer.

from 2.5 to 4.0 kW and 0 to +35 mm, respectively at a constant travel speed of 100 mm/min. Beam oscillation at 5 Hz with 5mm amplitude was applied to get an uniform composition of boron in the alloyed layer. At first, the optimum laser irradiation condition to get a good alloyed layer with smooth surface and no defects of porosity or cracking was examined. Then, the structure of the alloyed layers obtained were revealed by X-ray diffractometry and EPMA analysis. An Ogoshi-type wear tester was employed with the conditions of sliding speed : 4 m/s, wear load : 9.8 N, sliding distance : 100m with a counter disc of SUJ2 high Cr cast iron (HV650) under a dry air condition.

## 3. Results and Discussions

### 3.1 Surface morphology

**Figure 3** shows the combined effect of laser power and Ddf on the surface morphology of the alloyed layer on 10Ni plate. Typical photos are shown in **Figure 4**. The smaller Ddf promotes the occurrence of plasma which prevents smooth formation of the alloyed layer. In addition, the larger Ddf also prevents smooth formation because of an insufficient fusion of base metal due to low energy density. Melt depths achieved were changed from about 300$\mu$m for 10Ni to 1300$\mu$m for 65Ni, increasing with an increase in Ni content.

### 3.2 Structure

**Figure 5** shows the structure of a cross section of the alloyed layer formed with an optimum condition of 3.0 kW in (a) and (b) for 10Ni and (c) for 65Ni. The structure of the alloyed layer of 10Ni consisted of comparably large boron particles dispersed in a Cu-Ni solid solution phase matrix along with fine Ni boride (mainly NiB). Boron particles which contained small amount of Cu detected by EPMA analysis are considered to be formed by the eutectic reaction between Cu and boron according to the phase diagram in Fig.1 (a). As the Ni content increased, however, volume fraction of boron particles decreased and that of boride increased. At more than about 50 mass% Ni, Ni borid formed a matrix in the alloyed layer where the Cu-Ni solid solution phase with spherical or dendrite shapes dispersed, and boron particle almost disappeared, as shown in (c).

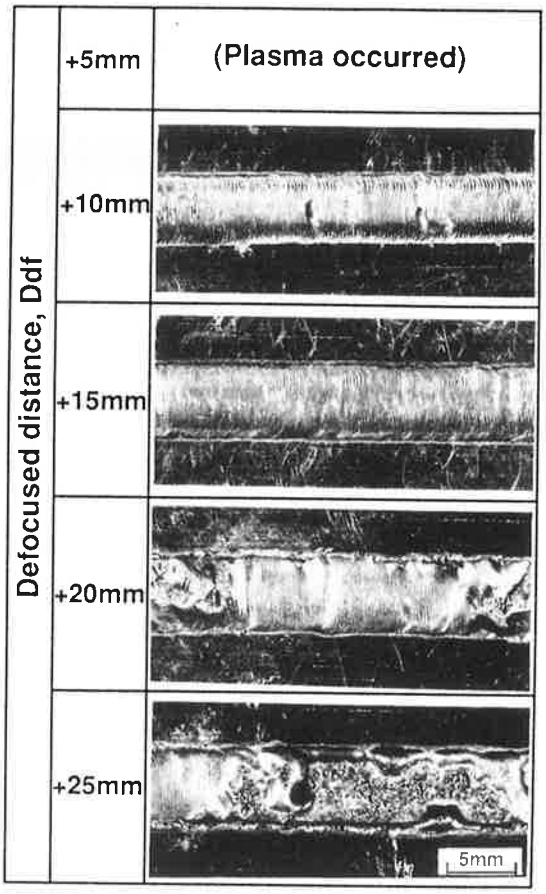


Figure 4 Typical changes in surface morphology of the alloyed layer formed on10% cupronickel at 3.0 kW laser power with different Ddf values.

### 3.3 Hardness

**Figure 6** shows the hardness distributions on the cross section of the alloyed layer from top surface to the base metal. Almost uniform distribution in the hardness through the alloyed layer was obtained. The layer thickness increased with increasing Ni content and the maximum thickness appeared at 65Ni even with the same irradiation conditions. This relationship is similar to the change in thermal conductivity of the Cu-Ni binary alloys, which decreases with Ni content and shows a minimum at about 50 to 60 mass%Ni[6]. It seems that this change in thermal conductivity caused the change in the layer thickness.

**Figure 7** shows the relation between the hardness of the alloyed layer and the Ni content of base metal at an optimum condition of 3.0 kW. The hardness of the alloyed layer increased to HV 400 to 500 due to the dispersion of very hard boron particles of about HV 2100 to 2600 in the Cu-Ni phase matrix up to 30 mass%Ni. With more Ni the hardness increased almost linearly with the increase of volume fraction of Ni boride and reached about HV 1400, which corresponds to the hardness of Ni boride.

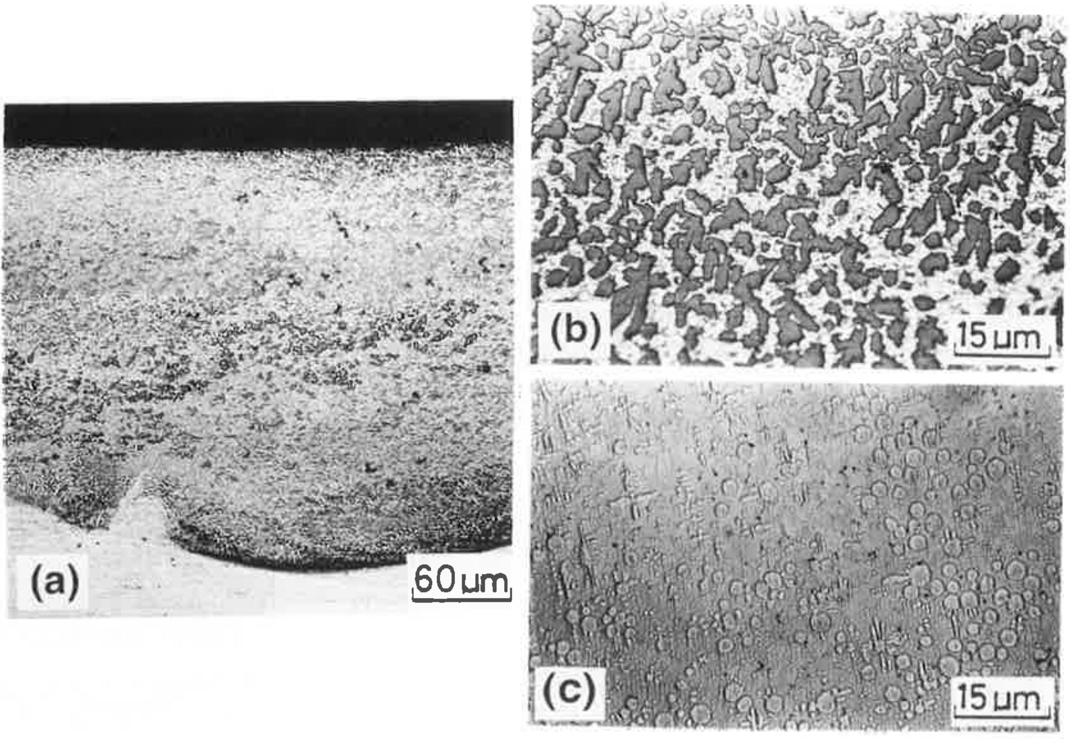


Figure 5 Microstructure of the alloyed layer formed on 10% cupronickel of (a) Low mag. and (b) High mag., and on Monel (65Ni) of (c) High mag., with an optimum condition (3.0kW, + 15mm).

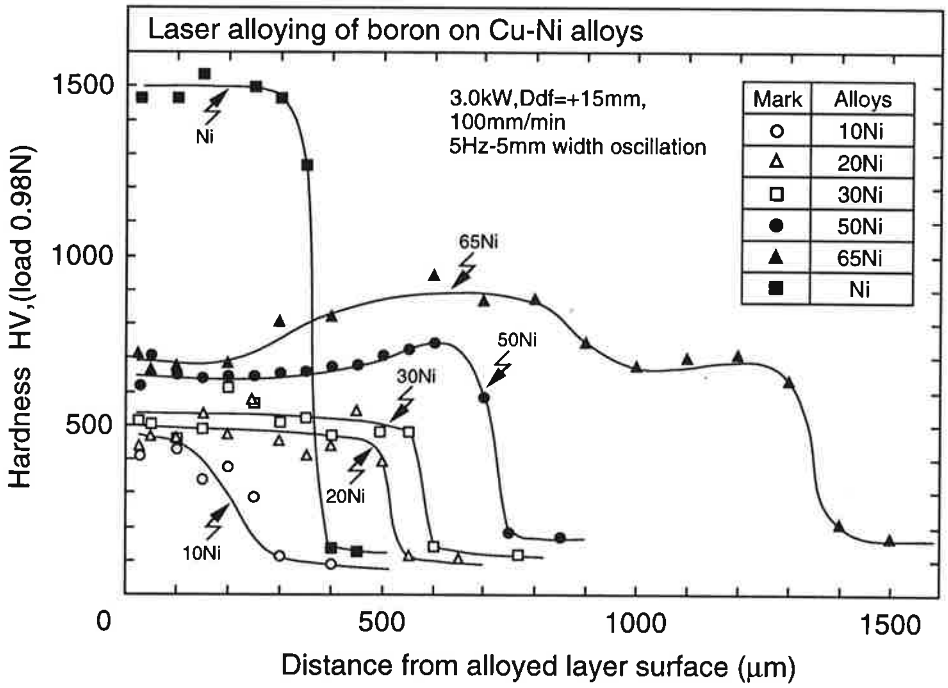


Figure 6 Hardness distributions on cross sections of the alloyed layer formed with an optimum condition (3.0kW, + 15mm).

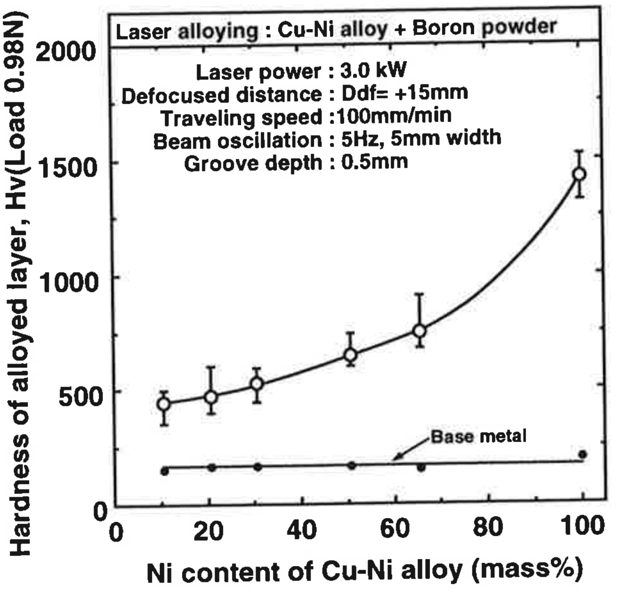


Figure 7 Relation between hardness of the alloyed layer and Ni content of base metal.

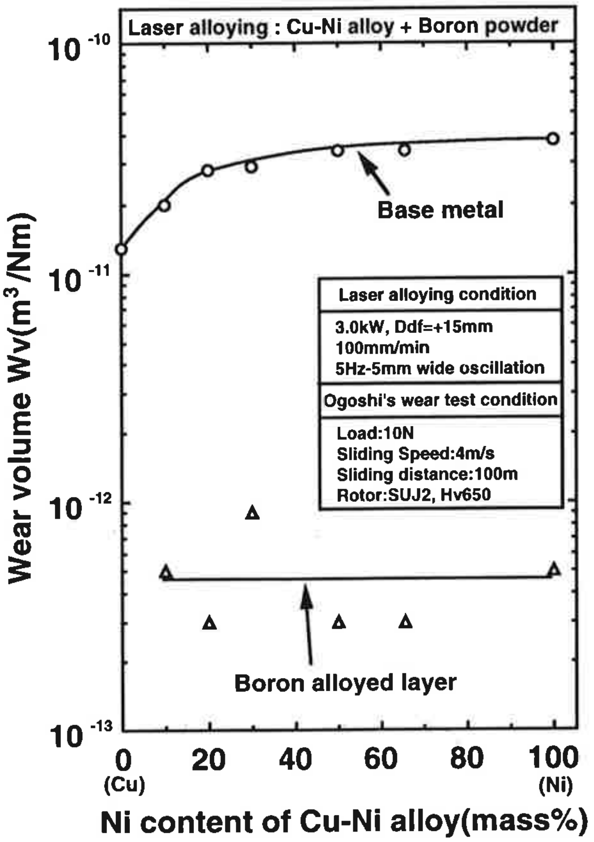


Figure 8 Relation between wear volume of the alloyed layer and base metal and Ni content of base metal.

### 3.4 Wear resistance

**Figure 8** shows the relation between wear volume of the alloyed layer and Ni content compared with base metal. The wear resistance of the alloyed layer is much improved, approximately 40 times that of base metal irrespective of Ni content. These improvements in wear resistance are thought to be due to the dispersion effect of very hard boron particles in the Cu-rich alloys, even with comparably lower hardness of the alloyed layer, and as well as the hard matrix of the alloyed layer consisted of Ni borides in the Ni-rich alloys.

## 4. Conclusions

It has been established that surface hardening of Cu-Ni alloys with different Ni contents can be achieved by applying the laser alloying process with boron powder as alloying element and irradiation using a CW $CO_2$ laser beam. Hardness of the alloyed layer formed on Cu-Ni alloy increased to HV 400 to 800 due mainly to the formation of hard boron particles up to 30 mass%Ni and Ni boride phases at higher Ni contents. Wear resistance of the laser alloyed layer was improved to about 40 times that of base metal, irrespective of Ni content.

## 5. Acknowledgments

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