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Surface alloying of aluminium using plasma transferred arc welding with powder addition

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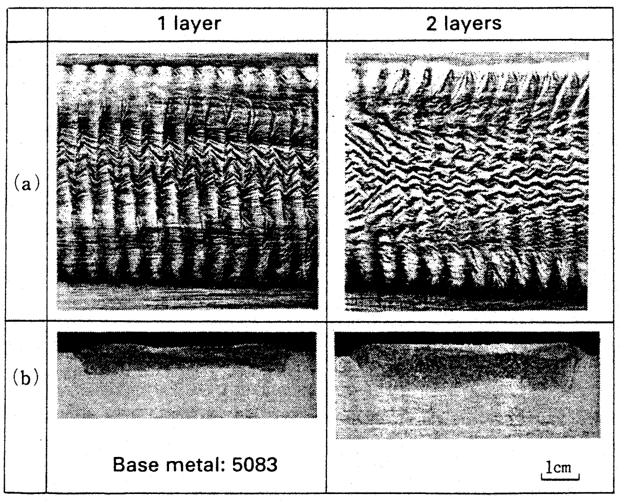
Introduction

Aluminium and its alloys (referred to below as Al and Al alloys) have a high strength/specific gravity ratio as well as superior workability and corrosion resistance. For these reasons they are used in a number of products. However, as these products become highly developed and are required to fulfil complex functions, abrasion resistant properties have become a more common requirement for Al and Al alloys. Thus, it has become highly desirable to establish techniques for obtaining superior abrasion resistant properties and formation of a thick film on the surface of Al and Al alloys.

In this work plasma transferred arc (PTA) welding with powder additions was applied; carbide (NbC) and metal (Ni or Cu) were added to the Al alloy surface and became alloyed. Then the various properties of the surface, such as the superior abrasion resistance, were investigated. The results are described below.



1 Bead appearance and cross section of macrostructure of NbC build-up layer: a) Bead appearance; b) Cross section of macrostructure.

Alloying with carbide (NbC)

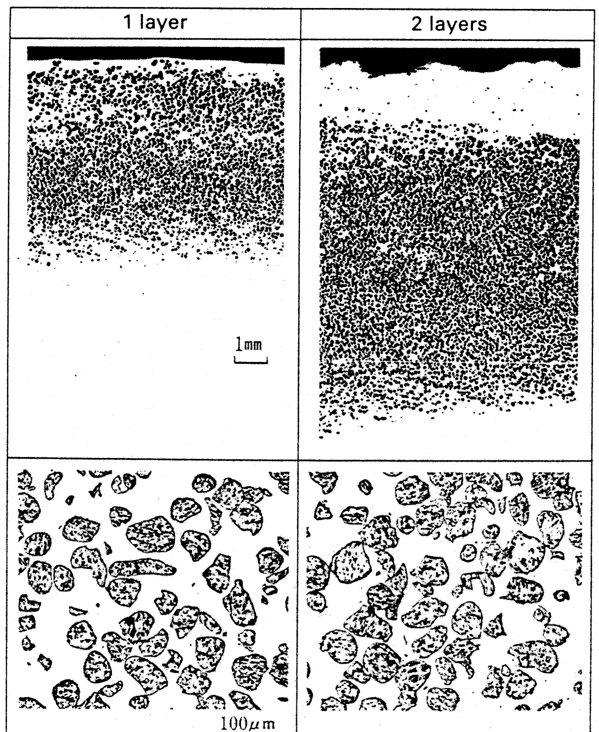
NbC powder (100 - 250 mesh) was used with 5083 Al alloy plate and the various properties of the build-up metal manufactured using the PTA method (direct current, straight polarity) are described. In addition, the chemical composition of 5083 is shown in Table 1.

Figure 1 shows the bead appearance and cross sections of the macrostructure for one and two layer deposits. Flaws could not be seen either on the bead surface or in the cross section.

Figure 2 shows the microstructure of one and two layer deposits. NbC, in its non-molten condition, was dispersed into the Al alloy matrix. The boundary zone between the build-up layer and Al alloy was sound and, in addition, the surface of the build-up layer was covered by an Al alloy layer. In the two layer case, the thickness of Al alloy layer increased.

Figure 3 shows the relationship between carbide area ratio and hardness for an NbC surface layer. For more than approximately 20% carbide area ratio, the hardness of the build-up layer increased compared with that of the Al alloy base layer and, at about 45%, the hardness of the build-up layer reached an HV of approximately 140.

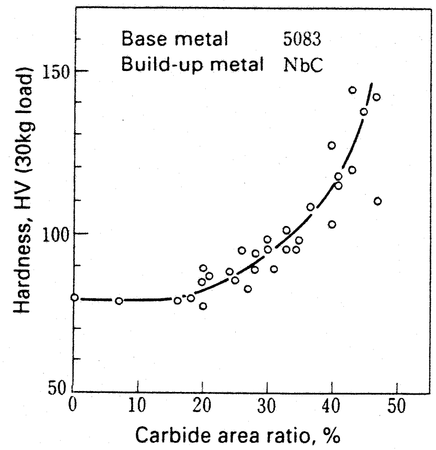
Figure 4 shows the abrasion resistant properties of an NbC build-up layer. At low friction rates, the abrasion resistant performance of the NbC build-up hardly differed from that of the Al alloy base metal; however, at increased



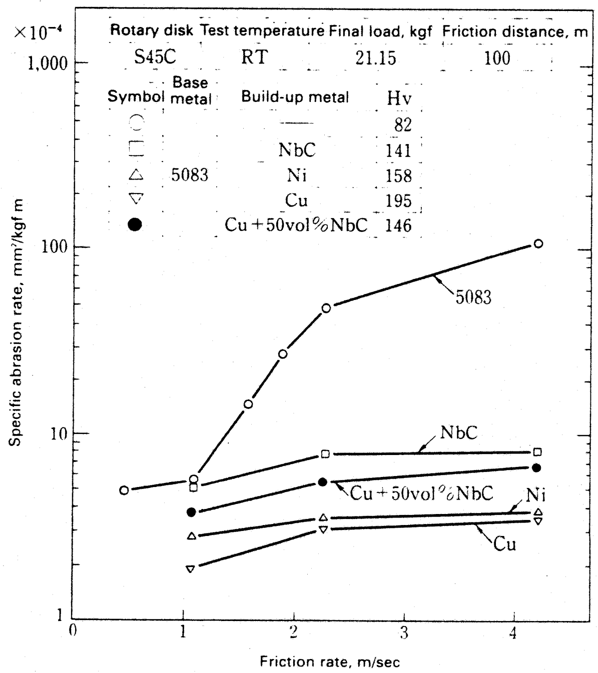
2 Microstructure of NbC build-up layer (base metal: 5083).

Table 1 Chemical composition of 5083 base metal, wt%

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.35	0.23	0.09	0.47	4.15	0.16	0.19	0.01	Bal.

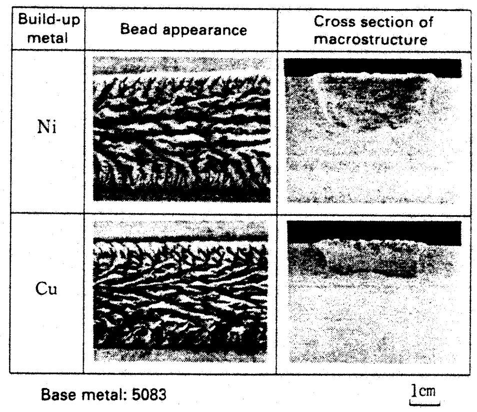


3 *Relationship between carbide area ratio and hardness of NbC build-up layer.*

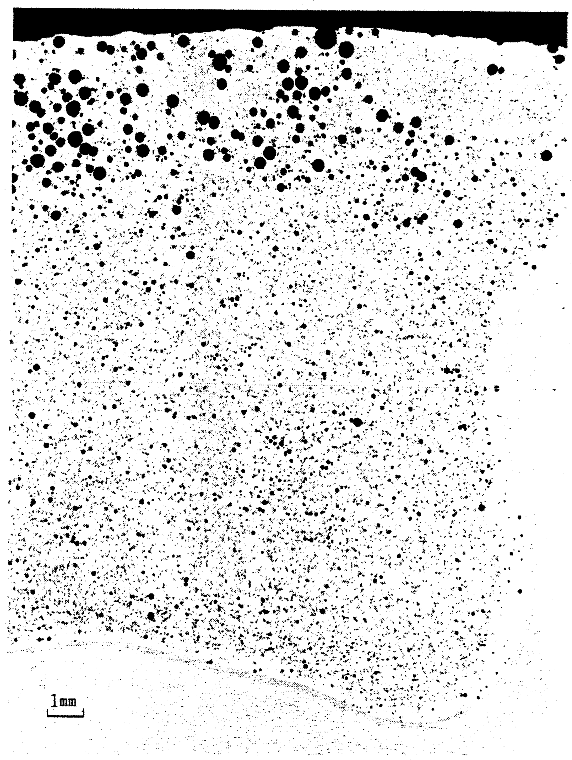


4 *Abrasion resistant properties of build-up metal.*

friction rates, the abrasion resistant performance of the NbC build-up became highly satisfactory compared with the Al alloy base metal. This is because the NbC build-up did not develop cohesion with the partner material S45C.



5 *Bead appearance and cross section of macrostructure of Ni, Cu build-up metal.*



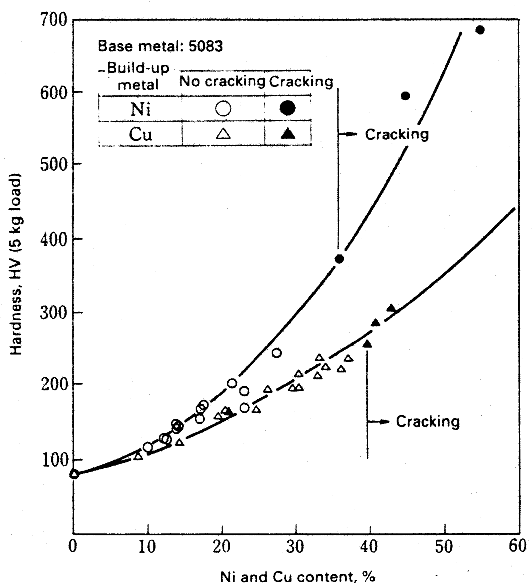
6 *Porosity developed in Cu build-up metal (base metal: 5083).*

Alloying with metal (Ni or Cu)

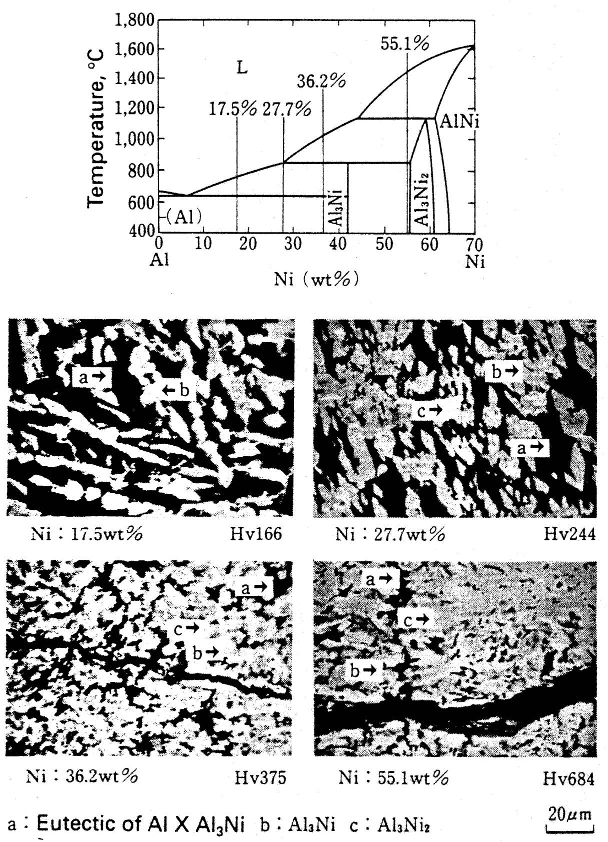
Ni or Cu powder was used with 5083 Al alloy plate and the build-up metal was produced using the PTA method. Table 2 shows the chemical composition of the Ni and Cu powders. Figure 5 shows the bead external appearance and cross sections of the macrostructure of the Ni and Cu build-up metal. Flaws could not be identified on the bead surface but porosity was found in the bead cross sections. Porosity in the Cu build-up metal is shown in Fig.6.

Table 2 Chemical composition of Ni and Cu powder, wt%

Powder	Chemical composition (%)									
	Ni	Cu	Si	P	As	Sb	Bi	Pb	S	Te
Ni	88.7	7.9	2.3	1.2	–	–	–	–	–	–
Cu	–	299.96	–	–	≤0.003	≤0.005	≤0.001	≤0.005	≤0.010	≤0.010



7 *Relationship between Ni and Cu content, hardness and cracking of build-up metal.*



8 *SEM structure of Ni build-up metal (base metal:5083).*

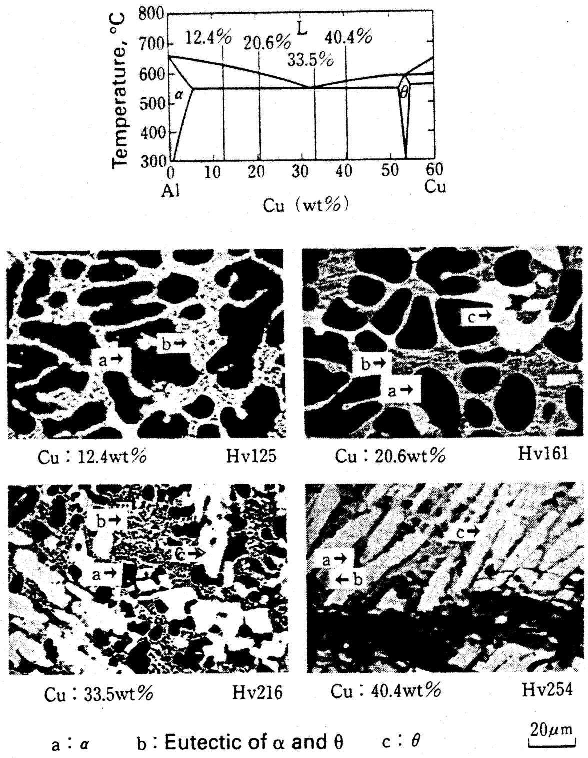
Figure 7 shows the relationship between Ni and Cu content, hardness and cracking for Ni and Cu build-up metals. The hardness of the build-up metal increased with increasing Ni and Cu. When the Ni or Cu content was at the same level the Ni build-up metal had a higher hardness compared with the Cu build-up. In addition, the hardness became greater with increasing content in both cases. Cracking developed at HV 375 for Ni and at HV 245 for Cu.

The SEM structure of the Ni build-up metal was related to the Al-Ni equilibrium diagram. Figure 8 shows the results. For the case where Ni content was 17.5 wt%, primary crystals of Al_3Ni and eutectic of Al with Al_3Ni were identified. For the case where Ni 27.7 wt%, Al_3Ni, eutectic of Al with Al_3Ni and also Al3Ni2 were identified. For the case where Ni was 36.2 wt%, Al_3Ni, eutectic of Al with Al_3Ni and also Al_3Ni_2 were identified and cracking developed at the area where Al_3Ni_2 segregated. Furthermore, Al_3Ni_2 identified for the cases where Ni was 27.7 wt% and 36.2 wt% is a phase which should not have been present according to the equilibrium diagram. For the case of Ni 55.1 wt%, Al_3Ni_2, Al_3Ni and, although in a very small quantity, the eutectic of Al with Al_3Ni_2 which again should not have existed according to the equilibrium diagram, were identified. Cracking developed in the zones where Al_3Ni_2 segregated and propagated after penetrating Al_3Ni_2. The reason why the build-up metal structure is not consistent with the equilibrium diagram is thought to be an incomplete peritectic reaction due to rapid heating and cooling during welding, and Ni segregation within the weld metal. Furthermore, from the comparison between these structures and Fig.7 it is inferred that an increase in the hardness of the build-up metal with increasing Ni content is caused by an increase in Al_3Ni and Al_3Ni_2.

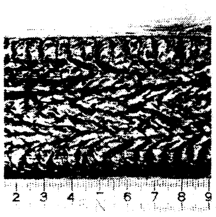
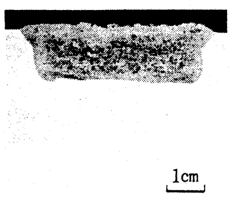
The SEM structure of the Cu build-up metal was compared with the Al-Cu equilibrium diagram. The results are shown in Fig. 9. For the case where Cu content was content was 12.4 wt%, primary α crystals and a eutectic of α with θ were identified. For the case where Cu was 20.6 wt%, α, eutectic of α with θ and also θ were observed. For the case where Cu was 33.5 wt%, θ, eutectic of α with θ and a small quantity of α were identified. For the case of 40.4 wt%, θ, eutectic of α with θ and a small quantity of α were identified. In this case θ showed a large columnar structure and cracking propagated penetrating the θ. In the case where Cu was 20.6 wt%, θ was observed; in the cases where Cu was 33.5 wt% and 40.4 wt% α was observed. These θ and α phases should not have existed according to the equilibrium diagram. It is inferred that this effect was caused by Cu segregation within the weld metal due to rapid heating and cooling during welding.

In addition, from comparison of these structures with Fig.7, it is considered that the increase in hardness of the build-up metal due to an increased Cu content is caused by an increase of θ.

The abrasion resistant properties of Ni and Cu build-up metals were compared with the Al alloy base metal and the NbC build-up metal. Figure 4 shows the results. The Cu build-up metal showed slightly superior abrasion resistant properties compared with the Ni build-up metal. The abrasion resistant properties of the Ni and Cu build-up metals, although only a little superior to the Al alloy base metal at low friction rates, were considerably improved at increased friction rates; furthermore, at high friction rates the Ni and Cu build-up metals were shown to have an abrasion resistance approximately three times greater than the NbC build-up metal. It is thought that this is due to the existence of hard Al-Ni intermetallic compound in dispersed form in the Ni build-up metal and of hard θ in the Cu build-up metal, also in dispersed form.



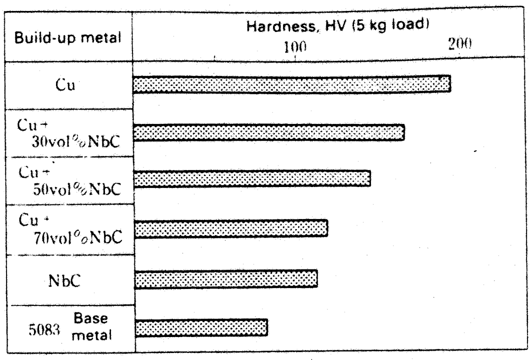
9 *SEM structure of Cu build-up metal (base metal: 5083).*

Build-up metal	Bead appearance	Cross section of macrostructure
Cu + 50vol%NbC		

10 *Bead appearance and macrostructure of Cu + 50 vol% NbC build-up metal (base metal: 5083).*

Alloying of carbide (NbC) and metal (Cu)

A mixture of NbC powder (100 - 250 mesh) and Cu powder was used with 5083 Al alloy plate and build-up metal was produced using the PTA method (direct current, straight polarity). A description of the various properties of this build-up metal is given below.



12 *Hardness of Cu + NbC build-up metal.*

It was decided that, for the mixed powder, the ratios of NbC powder to Cu powder would be 30 vol%, 50 vol% and 70 vol%. The resulting build-up metals are designated Cu + 30 vol% NbC, Cu + 50 vol% NbC and Cu + 70 vol% NbC respectively. The chemical composition of Cu powder is shown in Table 2.

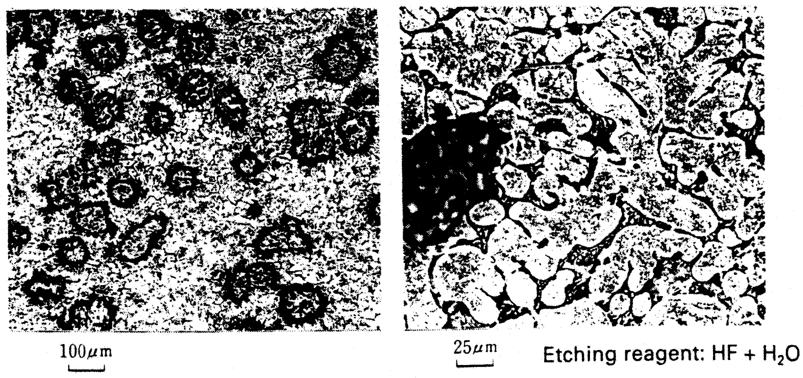
No flaws could be identified on the bead surface but porositiy was observed in the cross section and the bead surface was covered by a thick Al alloy layer. Figure 10 shows the external bead appearance and cross section of the macrostructure of the Cu + 50 vol% NbC build-up metal.

The microstructure of the Cu + 50 vol% NbC build up metal is shown in Fig. 11. NbC, in an undissolved condition, was dispersed within the Al - Cu alloy matrix. α (rounded white-coloured area), eutectic of α and θ (black-coloured area) and, although in small quantities, θ (angular white-coloured area) were observed in the matrix alloy.

With increasing NbC within the build-up metal, α increased and the eutectic and θ decreased.

Figure 12 shows the hardness of Cu, Cu + 30 vol% NbC, Cu + 50 vol% NbC, Cu + 70 vol% NbC and NbC build-up metals made under identical welding conditions. The hardness of the Cu + NbC build-up metal indicated values between the Cu build-up metal hardness and the NbC build-up metal hardness and declined with increasing NbC content. The contribution of NbC to the hardening of the build-up metal is small compared with that of Cu.

The abrasion resistant properties of Cu + 50 vol% NbC build-up metal is shown in Fig.4. This indicates satisfactory



11 *Microstructure of Cu + 50 vol% NbC build-up metal.*

abrasion resistant properties compared with the Al alloy base metal. By comparison with the build-up metals described above, Cu has the best abrasion resistant properties, followed by Ni, Cu + 50 vol% NbC and then NbC. This corresponds to the hardness of the build-up metal.

Tasks for the future

1. During Ni and Cu build-up welding a large amount of porosity developed within the deposit. Investigation is required into causes of this and to find preventative measures.
2. The maximum hardness obtained in the NbC build-up metal is HV 140 (carbide area ratio approximately 45 %). The maximum values are about HV 200 for Ni and Cu build-up metals, and if this value is exceeded there is a high possibility of cracking. It is thought to be difficult to achieve a hardness of more than HV 200, which is the maximum for the Cu build-up metal, and even for Cu + NbC build-up metal. Varieties of metal and carbide and effects of carbide grain size should be studied as there is a requirement to increase the hardness of build-up metal even more.
3. It is necessary to investigate how the abrasion resistant properties of carbide and the metal materials employed for build-up are influenced by the mechanical properties of the partner material and by the abrasion conditions; in addition it is necessary to study the effects of carbide grain size upon carbide build-up metal.
4. The results described in this paper were achieved using the PTA method with direct current, straight polarity. However, PTA methods with direct current, reverse polarity and with alternating current should be investigated.

Conclusions

The PTA method is thought to be most practical when alloying on Al alloy surface using carbide and metal because it is easy to select a suitable type of build-up material and to add a quantity to the Al alloy surface. Also it is possible to obtain a thick film with superior adhesion to the base metal. However, as described in this paper, there are several tasks required to improve the method such as countermeasures to prevent porosity and the development of cracking in the build-up metal and to improve the hardness and abrasion resistant properties of the build-up metal to expand the applications. In the future a wide range of research will be required to solve these problems.

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