Role of trace elements on tensile behavior of accumulative roll-bonded pure copper

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Previously, the authors reported that small amount of trace phosphorous in deoxidized low-phosphorous copper (DLP) significantly affected the tensile behavior of accumulative roll-bonded (ARB) oxygen-free copper (OFC) [1, 2]. For both alloys, the tensile strength values increased drastically after the first cycle of ARB process. The tensile strength values of OFC tended to saturate after the third ARB process cycle. In DLP, on the other hand, the tensile strength continuously increased with increasing ARB process upto eight cycles. The authors suggested that the continuous increase in tensile strength in ARBed DLP was due to the presence of trace phosphorous, which acted beneficially for tensile properties of pure copper by suppressing the dynamic recovery during severe plastic deformation. The previous study suggested that the presence of trace elements in pure copper could be beneficial for the severe plastic deformation (SPD) [1, 2]. To further confirm this notion, the tensile behavior of ARBed PMC90 alloy, which has approximately five times higher Fe content with similar P content than DLP, was investigated in the present study.

The chemical composition of as-received PMC90 is shown in Table I. For comparison, those of OFC and DLP are also included in the table. Two cold-rolled copper sheets, the thickness, the width and the length of each was 1, 30 and 300 mm, respectively, were continuously accumulative roll-bonded at 200 °C with a rolling ratio of 50%, so that the total thickness of the bonded sheet remained constant. The ARB process was conducted upto eight cycles at a rolling rate of 690 mm/min. The electrical conductivity of each specimen was measured by using a four-probe method. The tensile test was performed with the flat tensile specimen with thickness, width and gauge length of 1, 6 and 25 mm, respectively, at a nominal strain rate of 1×10^{-3}/s on an R&B (Daejun, Korea) model Unitech S series universal testing machine. The microstructures of ARBed specimens were examined with a transmission electron microscope (TEM). TEM specimens were prepared using a jet thinning method in 200 ml CH_3OH + 100 ml HNO_3 solution at −30 °C.

TABLE I Chemical compositions of OFC and DLP used in the present study

Alloys	Cu (wt%)	O (ppm)	Pb (ppm)	Bi (ppm)	Fe	P	S (ppm)
OFC	99.99	2	1	<1	1 ppm	2 ppm	7
DLP	99.9	5	170	<1	0.02%	<0.02%	5
PMC90	99.9	5	170	<1	0.1%	<0.02%	6

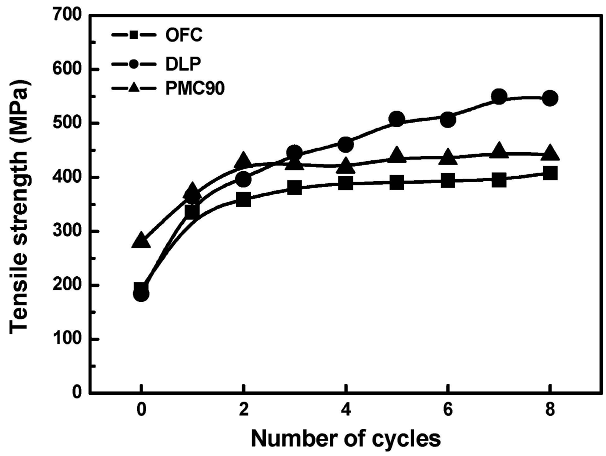

Figure 1 Change in tensile property of pure copper as a function of the number of ARB process cycle.

There have been a considerable number of reports on the extremely high rate of dynamic recovery in the nano grain-sized materials during severe plastic deformation [1, 5–7]. When the grain size is comparable or lower than the mean free path of dislocation movement, the formation of dislocation cells inside the grain would become extremely restricted [6]. The mobile dislocations emitted from the source could then easily glide without an obstruction to the grain boundary area, and disappear as a result of local dynamic recovery. Simultaneously, the number of dislocation sources would be

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Figure 2 TEM micrograph of PMC90 with eight ARB process cycles.

extremely limited due to the lack of dislocation cells inside the grains, which would further promote the dynamic recovery. Previously, it was demonstrated that impurity elements play an important role in determining the tensile behavior of pure copper during severe plastic deformation. The tensile strength values of OFC, for example, tended to saturate after the third ARB process cycle. For DLP, on the other hand, the tensile strength continuously increased with increasing the ARB process upto eight cycles. It was therefore expected that PMC90 would follow the trace of DLP with increasing number of ARB cycle rather than OFC, since PMC90 has higher impurity content than DLP. Fig. 1 shows the change in tensile property of PMC90 as a function of the number of ARB process cycle. For comparison, the previously reported data for OFC and DLP were also included in Fig. 1. Interestingly, the tensile behavior of PMC90 was quite similar to that of OFC rather than DLP, such that the tensile strength values tended to saturate after the third ARB process cycle. In our previous study on the tensile behavior of ARBed DLP, the reason for retardation of dynamic recovery in DLP was reckoned to be due to phosphorous-related precipitates, based on the fractographic examination. If this rationale is true, PMC90, which has higher content of precipitate-formable trace elements, may have greater retarding effect on dynamic recovery than DLP. Fig. 2 shows the TEM micrograph of PMC90 with eight ARB process cycles. Indeed, the precipitates, as marked by arrows, were often observed in PMC90, the density of which was extremely low. In the present study, these precipitates were not identified, since the size of these precipitates was too small to be characterized by selected area diffraction pattern. Most probably, however, these precipitates are Fe_3P according to the Fe–P phase diagram shown in Fig. 3.

In the present study, it was demonstrated that the presence of trace elements in pure copper affected the tensile property during severe plastic deformation. Compared to DLP, PMC90 has greater Fe content. Most of Fe and P in PMC90 were reckoned to be present in the precipitates instead of solute elements in the copper matrix, while the trace P in DLP would remain in the matrix as solute element. It was hypothesized that

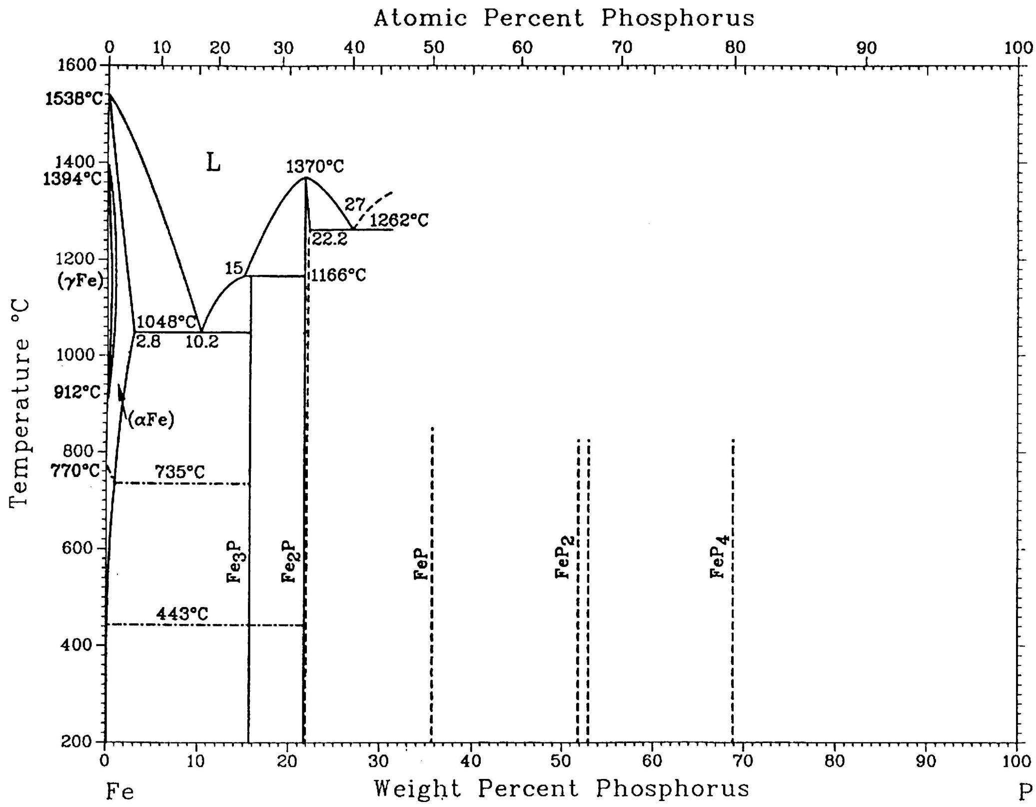

Figure 3 Fe–P phase diagram.

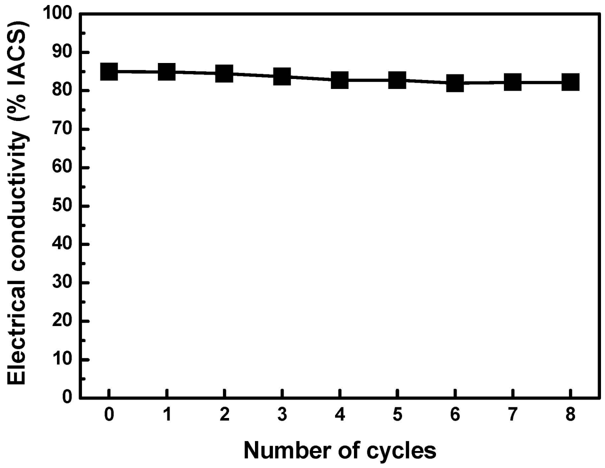

Figure 4 Change in electrical conductivity of PMC90 as a function of the number of ARB process cycle.

the density of precipitates in PMC90 was not enough to retard the dynamic recovery process during severe plastic deformation. Eventually, tensile behavior of PMC90 was similar to that of OFC, rather than DLP, despite the considerably higher impurity contents. The present observation has a certain implication for the future application of ARBed copper for the connector materials with high conductivity and high strength. At present, PMC90 is the most widely used commercial material for high conductivity connector. As shown in Fig. 4, the electrical conductivity, as represented by % (international annealed copper standard IACS) value, was almost unaffected by ARB process. It was, however, demonstrated that the ARB process of over three cycles was not effective for PMC90, considering the high processing cost.

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References
1. Y. H. JANG, S. S. KIM, S. Z. HAN, C. Y. LIM, C. J. KIM and M. GOTO, *Scripta Mater*. **52** (2004) 21.
2. Y. H. JANG, S. S. KIM, S. Z. HAN, C. Y. LIM and C. J. KIM, *J. Kor. Inst. Met. Mater*. **42** (2004) in press.
3. J. C. KIM, Y. NISHIDA, H. ARIMA and T. ANDO, *Mater. Lett*. **57** (2003) 1689.
4. V. V. STOLYAROV, Y. T. ZHU, T. C. LOWE and R. Z. VALIEV, *Mater. Sci. Eng.* **A303** (2001) 82.
5. Y. T. ZHU, H. JIZNG, J. JUANG and T. C. LOWE, *Metall. Mater. Trans*. A **32A** (2001) 1559.
6. S. S. KIM, M. J. HAYNES and R. P. GANGLOFF, *Mater. Sci. Eng*. **A203** (1995) 256.
7. S. Z. HAN, C. Y. LIM, C. J. KIM and S. S. KIM, *Metall. Mater. Trans.* A (2004) accepted.

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