Consolidation of Cr-Cu/Cu powder laminated material by compressive torsion processing

Wataru Kimura*, Yuji Kume, Makoto Kobashi, Naoyuki Kanetake

Department of Materials Science and Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8601, Japan

Abstract

The Cu-Cr composite material is widely used as an electrode material in a vacuum circuit breakers used in electric power systems. It is generally produced by sintering processes, and then Cr particles were refined in the surface part. Using the Compressive Torsion Process (CTP) which is one of the severe plastic deformation processes, the Cu-Cr composite powder can be fully dense consolidated without sinter, and the Cr particles are refined in surface layer portion at the same time. In this study, the CTP was applied to the laminated material of Cu-Cr composite and Cu powders and the possibility of consolidation and Cr particle refinement of the laminated material was investigated. The consolidation of Cr-Cu/Cu laminated powder was possible by the CTP, and Cr particles near a drive end were extremely refined. Hardness and tensile strength of the laminated material were medium between both single Cu-Cr and Cu specimens. It means they were largest and the same level as Cu-Cr single composite near the end of a cylindrical specimen, and decreased gradually toward the middle part of Cu layer until the same level as Cu single material.

* Corresponding author. Tel.: +81-52-789-3358; fax: +81-789-5348
E-mail address: kimura.wataru@d.mbox.nagoya-u.ac.jp
1. Introduction

The Cu-Cr composite material is widely used as an electrode material in a vacuum circuit breaker used for an electric power system. The Cu-Cr composite electrode is generally produced by the sintering process, and then Cr particles were refined in the surface part to improve blocking performance. We have developed a new process to produce the Cu-Cr electrode without sintering by our original severe plastic deformation process, Compressive Torsion Process (CTP) [1-3]. In the CTP, compressive and torsional load are applied simultaneously to the materials and it enables to apply huge strain even to powder metals as well as bulk metals. The Cu-Cr composite powder can be easily consolidated without sintering by the CTP, and Cr particles in surface part can be refined during the CTP.

As an ideal electrode material, refined Cr grains are needed only in the surface part of the Cu single phase electrode body to achieve both high conductivity and high strength. In this study, the CTP was applied to laminated material of Cu-Cr composite powder and Cu powder. The possibility of consolidation of laminated powders and Cr particle refinement and mechanical properties of the consolidated materials were investigated.

2. Experimental procedure

Fig. 1 shows the schematic illustration of the CTP equipment. Due to the compressive and torsional combined loadings, the CTP provides severe plastic deformation under hydrostatic pressure without a change in cylindrical specimen shape. Therefore it is easy to produce the fully consolidated specimen without sintering from metal powder. In this study, Cu powder (particle diameter is 100 μm), Cr powder (particle diameter is 50~100 μm) and Cu-30 wt%Cr composite powder were prepared. Before CTP a compact with three-layer structure shown in Fig.2 were prepared (it is referred by 30-0-30 in below). The Cu-30 wt%Cr composite powder and Cu powder were layered in a die and together compressed under 300 MPa at room temperature into a cylindrical specimen of 25 mm diameter and 30 mm height. Besides the 30-0-30 compacts, Cu single phase compact (referred by Cu) and Cu-30 wt%Cr single phase composite compact (referred by 30Cr) were also prepared with the same conditions. The parameters of the CTP processing condition are working temperature, compression pressure, rotation speed, and rotation numbers. To examine the effect of rotation number to consolidation and refinement of Cr particles, the CTP was performed with different rotation numbers 10, 20, 30 times at 673 K. Compression pressure was 200 MPa and rotation speed was 5 rpm.

The microstructure on longitudinal cross sections of CTPed specimens was examined by a scanning electron microscopy. The observation was carried out at 45 points in the cross section, at 2.5 mm intervals from an end face in height and at 3 mm from the center in radius.

Using the same specimens for microstructure observations, hardness and tensile strength were also examined. The hardness was measured using the micro-Vickers hardness tester under the conditions of indenter load 1000 g and retention time for 15 seconds. Machining fourteen small tensile test specimens from consolidated cylinder, the tensile strength was measured at room temperature and strain rate of $8.3 \times 10^{-3}$ s$^{-1}$. 

![Fig. 1. Schematic illustration of apparatus for CTP.](image)

![Fig. 2. Compact three layer structure (reference to 30-0-30).](image)
3. Result and Discussion

Fig. 3 shows microstructures of the laminated 30-0-30 and single 30Cr specimens processed by the CTP. In all specimens including the single Cu specimen, no cracks or residual cavities were seen, and their relative density were over 98%. In the single 30Cr specimen with 30 rotations, a good composite structure with uniformly dispersed Cr particles can be seen and the Cr particles near a drive end were extremely refined. In the laminated 30-0-30 specimen with 30 rotations, the extreme refinement of Cr particle was equally observed near the end. Furthermore the Cu-Cr composite phase and Cu phase were mixed together around the border of both phases with the increase of rotation times.

Fig. 4 shows the hardness distribution in height at 3 mm radius of five kinds of specimens processed by CTP. The hardness of single Cu specimen was substantially uniform around 70 HV, while the hardness of 30Cr single specimen was not uniform. It was around 100 to 120 HV in the middle part in height and it was increased to around 150 HV near upper and lower ends of the cylindrical specimens because of refinement and work hardening of Cr particles. The hardness of the laminated 30-0-30 specimen was medium between both single Cu and 30Cr specimens. Although the hardness distribution of the 30-0-30 specimen was not symmetrical in upper and lower parts, the hardness in the 30%Cr layer with refined Cr particles was approached the same level as 30Cr single specimen with the increase of rotation times and that in the middle part of Cu layer was also the same level as single Cu specimen. In the border part in which the 30Cr composite and Cu phases were mixed together, hardness was varied between the levels of two single phases. The hardness variation in the border part would depend on the Cr content between 0 to 30 wt% of the mixed part.

Fig. 5 shows the tensile strength distribution in height at 3 mm radius of five kinds of specimens. The distribution curve was quite similar to the hardness one, and the tensile strength of the laminated 30-0-30 specimen was medium between both single Cu and 30Cr specimens. The tensile strength of the 30-0-30 was the largest near the drive end as well as the single 30Cr specimen, and decreased toward the middle part in height until the same level as single Cu specimen.

From the results of microstructure, hardness and tensile strength evaluation it has concluded that the Cu-Cr/Cu laminated powder could be successfully consolidated as well as Cu and Cu-Cr single phase powders.
Fig. 3. Microstructure of specimens at 673 K (a) 30-0-30 with 10 rotations (b) 30-0-30 with 20 rotations (c) 30-0-30 with 30 rotations (d) single 30Cr with 30 rotations.
4. Conclusion

The compressive torsin process (CTP) was applied to laminated powder of Cu-Cr composite and Cu powder, and the possibility of consolidation and Cr particle refinement were investigated. The results conclude as follows:

1. Consolidation of Cr-Cu/Cu powder laminated material was possible by the CTP, and Cr particles near a drive end were extremely refined to 1 \( \mu \)m or less simultaneously with consolidation.

2. Hardness and tensile strength of the laminated material (30-0-30) were medium between both single Cu-Cr and Cu specimens. It means they were largest and the same level as Cu-Cr single composite near the drive end, and decreased gradually toward the middle part of Cu layer until the same level as Cu single material.
References

