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Fabrication of CNF Reinforced Aluminum Composites by Compressive Torsion Processing

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The compressive torsion process (CTP) is applied for fabrication of carbon nano fiber (CNF) reinforced aluminum composites. Pure aluminum and CNFs were mixed by ball milling and the mixed powder was compacted at R.T. The consolidation of mixed powder compaction was carried out by the CTP under different processing temperatures (473-573K) and torsional rotation (20-30times). The microstructure was investigated and cleared the effects of the CTP conditions. The CNF-aluminum mixed powder was successfully consolidated all over the cylindrical specimen by the CTP and relative density of the processed specimen reached to 100%. The agglomerated CNFs with initial tens of micrometer were refined under 5μm except around rotation axis of a cylindrical specimen, while it was not refined but only elongated around the axis. The refinement of agglomerated CNF was promoted even around the rotation axis subjected to relatively low shear deformation by decreasing processing temperature and increasing rotation number.

Keywords: *carbon nano fiber, aluminum, severe plastic deformation process*

1. Introduction

Carbon nano fiber (CNF) which was developed in 1991 has many attractive mechanical and physical properties because of elastic modulus of up to 1TPa, tensile strength as high as 60GPa [1]. So it is very useful as reinforcements of metal matrix composites. But, it is difficult to achieve homogeneous dispersion of the CNFs because CNF tends to form bundles due to its high aspect ratio and its van der Waals bondings [2]. This agglomeration prevents improvement of the mechanical and physical properties of the composite. Chemical reaction with metal matrix also hinders these properties. Some methods of composite fabrication such as mechanical alloying and spark plasma sintering have been attempted to solve such problems.

We applied a compressive torsion process (CTP) which is a unique severe plastic deformation process to CNF and aluminum mixed powder to realize direct powder consolidation and homogeneous dispersion of CNF. The CTP can easily apply severe shear deformation under low pressure to cylindrical processed material. As the shear deformation is applied to the work piece under hydrostatic pressure, this process is very effective in direct powder consolidation at low temperature [3][4]. The CTP is especially effective in dense consolidation of metal powder with hard oxide film like aluminum. Furthermore, in applying to metallic and ceramic powder mixture, this process is also effective in homogeneous dispersion of fine ceramic particles as well as dense consolidation.

In the present work, the CTP was applied to mixed powder of CNFs and aluminum to investigate the possibility of direct powder consolidation and dispersibility of CNFs. Effects of processing temperature and rotation number on the consolidation behavior of the mixed powder and microstructure were examined.

2. Experimental procedure

The compressive torsion process (CTP) is a very useful for introducing large shear deformation to a cylindrical specimen without change in shape. The equipment for the process constructs of upper and lower dies and container as shown in Fig.1. The specimen inserted in the container is subjected to simultaneous compressive and torsional loading with both dies which move vertically and rotate in the opposite direction. Top of the both dies has a rugged face with 1mm depth so that the torsional loading can be sufficiently imposed on the specimen. Because the specimen is enclosed by the container, it is possible to give large strain to the specimen under hydrostatic pressure. Therefore, it is very effective in homogeneous dispersion of fine particles as well as direct powder consolidation.

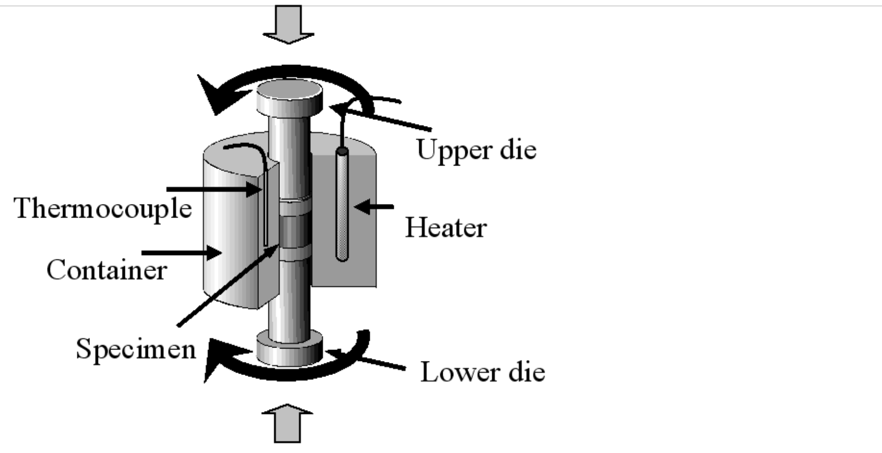

Fig.1: Schematic illustration of experimental apparatus for compressive torsion processing.

The used powders are pure aluminum and CNFs shown in Fig.2. The average size of the aluminum powder is around tens of micrometer. The CNFs form bundles over 100μm with agglomeration of hundreds of micrometer. These powders were mixed by ball milling and the mixed powder was compacted into a cylindrical billet at room temperature with 800MPa. After filling the billet into the container, the billet was heated to given temperature by cartridge heaters embedded in the container. The consolidation of mixed powder by the CTP was examined under different processing temperatures, 473K, 573K and different rotation number, 20, 30 times. The other processing conditions were constant as follows; compressive pressure: 100MPa, rotation speed: 5rpm. The microstructure on longitudinal cross sections of the specimens processed by CTP was examined by a scanning electron microscope.

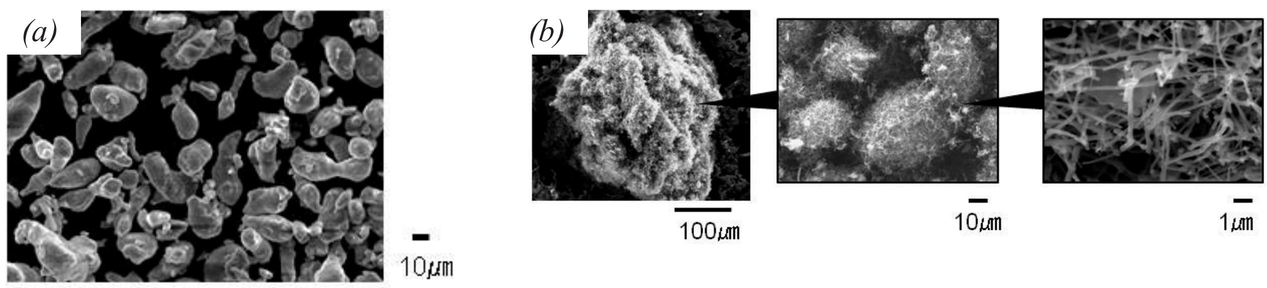

Fig.2 The used powder in this study (a)aluminum powder (b) agglomeration of CNFs

3. Result and discussion

3.1 Possibility of direct consolidation and dispersion of CNFs

Fig.3 shows an appearance of mixed powder by ball milling. The agglomeration of CNFs was remained in tens of micrometer, though bundles of hundreds of micrometer were released.

Fig.4 shows microstructure of the specimen processed at 523K and with 20 rotations. Microstructure was observed at 9 points on a half vertical section of cylindrical specimen. No cracks and cavities and no powder boundaries were observed and relative density of the processed specimens reached to 100%. Therefore, the direct consolidation of CNF-aluminum mixed powder was successfully performed by the CTP. The CNFs were finely dispersed except for the region around the axial center of a cylindrical specimen. In the most of section, the agglomerations of CNFs were refined into around 5μm. However, around the axial region in which the shear deformation would be relatively small, the agglomeration of CNF was not refined but only elongated.

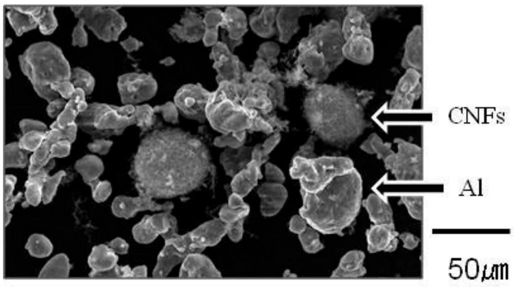

Fig.3 Mixed powder by ball milling

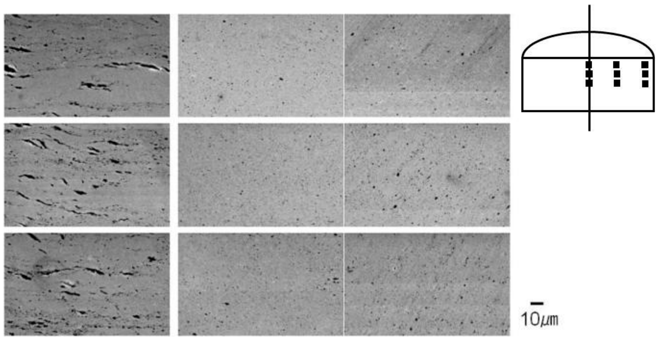

Fig.4 Microstructure of specimens processed at 523K and with 20 rotations

3.2 Effect of rotation number and processing temperature

Microstructures of specimens processed with difference rotation numbers at 573K are compared in Fig.5. At the peripheral region subjected to severe shear deformation, most agglomerations of CNF were refined under 5μm at 20rotations, though much finer was possible by increasing rotation number. At the center region subjected to relatively low shear deformation, elongated agglomeration of CNF began to be broken in small agglomeration by increasing rotation number. This is because metal flow of consolidated aluminum matrix becomes stronger at even axial region by strain gradient enlarged by increasing rotation numbers.

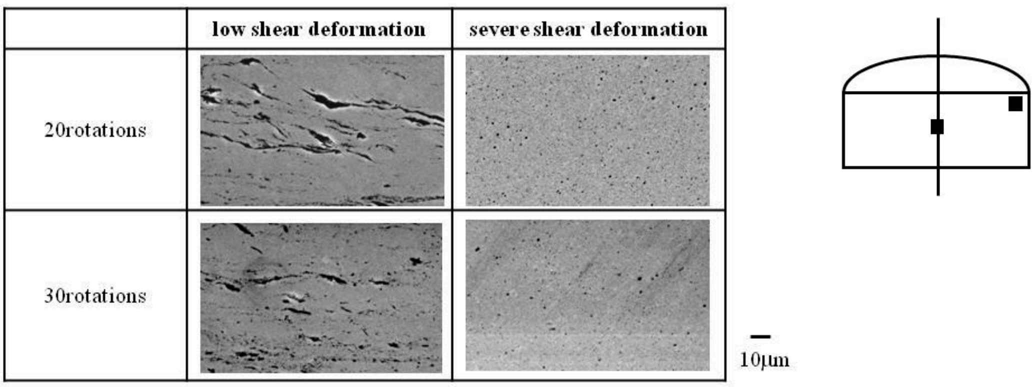

Fig.5 Effect of rotation number on the refining of CNFs

Microstructures at the periphery and the rotation axis of a cylindrical specimen processed at different processing temperature are compared in Fig.6. The processing temperature were 573K and 473K, and rotation number was 30 rotations. At the peripheral region, fine and homogenious dispersion of agglomerations of CNF was cleary promoted and all of them were finer than 1μm by decreasing processing temperature. Even around rotation axis, agglomerations of CNF were considerably broken into finer dispersion at 473K. As flow stress and strain hardening of consolidated aluminum matrix become higher by reducing processing temperature, metal flow by torsional loading is extended near the rotation axis and enlarged all over the specimen. Therefore, agglomerations of CNF were effectively broken and refined even at relatively lower shear defomation region.

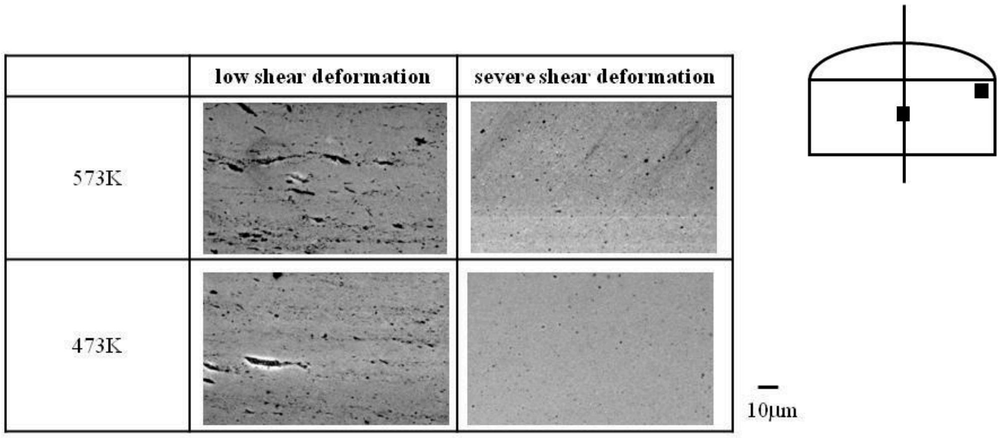

Fig.6 Effect of processing temperature on the refining of CNFs

4. Conclusion

The compressive torsion process (CTP) was applied to consolidate mixed powder of aluminum and CNFs and effects of processing temperature and rotation number on the consolidation behavior of the mixed powder were examined. The results can be concluded as follows:

1) The direct consolidation of CNF-aluminum mixed powder and fine dispersion of CNF were successfully realized by the CTP.
2) The agglomerated CNF with initial tens of micrometer was refined under 5μm except around rotation axis of a cylindrical specimen, while it was not refined but only elongated around the axis.
3) With increasing rotation number and reducing processing temperature, CNF became much finer at the peripheral region subjected to severe shear deformation, and the elongated agglomeration of CNF was broken into fine dispersion around rotation axis subjected to relatively low shear deformation.

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