FABRICATION OF CNT-REINFORCED ALUMINUM MATRIX COMOSITE ROD BY HYDROSTATIC EXTRUSION METHOD

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Abstract
CNT-reinforced Al matrix composite rod was manufactured by hydrostatic extrusion process to obtain high strength and high elastic modulus aluminum for light weight applications such as robot arms and shaft beams. CNTs used were multi-wall carbon nanotubes (MWCNTs) with average diameter of 10~20nm and length of 10~50μm. As-prepared CNTs were purified by refluxing in 40% nitric acid content solution for 10hr at 293K, and then the CNTs were washed several times with distilled water, and dried in vacuum. The chopped aluminum rod cuts of 8mm in diameter were ball-milled for 24 hours to coat the surface of chopped aluminum cuts with the pretreated MWCNTs. The CNT-coated Al cuts were compacted into the aluminum can with pure aluminum powders, and then the can was welded and pressed by hydrostatic extrusion method. The billet was hydrostatically extruded at 160^oC with an extrusion ratio of 16:1. The composite billet was successfully obtained having clean extrusion surface and shape. Also, the CNT-Al composite inner materials were extruded and well-bonded with outer Al matrix. The distribution of CNTs were analyzed by field emission scanning electron microscopy(FESEM). The suggested hydrostatic extrusion process seems to be a feasible option for producing CNTs-reinforced aluminum composite rods for shaping elongated products.

1 Introduction
Carbon nanotubes(CNTs) are attractive materials for several promising applications in electronic devices, thermal conductors and light-weight high strength metal matrix composites. In recent years, many efforts have led to development of various methods to obtain CNT-metal composites with excellent physical and mechanical properties, [1]. The interest in CNTs as super reinforcements for aluminum(Al) has been growing and studies are largely focused on investigating their contribution to the enhancement of the mechanical performance of structure components. In the manufacture of CNT-reinforced Al composites, powder mixing and sintering processes have been widely selected and studied, [2]. Hydrostatic extrusion(HE) has been considered as one of the most effective processes for the consolidation of powder materials, [3]. The main advantage of this process lies in the significant reduction of the interfacial friction between powder billet and extrusion die, which greatly helps to improve the deformation uniformity of the powder billet during extrusion, to save mechanical work and energy, and to enhance die life. The present paper reports an experimental investigation

on the application of this HE process to the consolidation of CNTs-reinforced Al composites powders. The extruded macrostructures and microstructures of rod were observed by optical microcopy, and the alignment and distribution of CNTs were analyzed by FESEM.

2 Experimental procedures

CNTs used were multi-wall carbon nanotubes(MWCNTs) with average diameter of 10~20nm and length of 10~50μm(Iljin Co. Ltd., purity 99.5%) grown by CVD-catalytic process. Figure 1 shows the SEM images of as-received and purified MWCNTs. As-prepared CNTs products were purified by immersing in 40wt.% nitric acid solution for 10hr at 293K, and then the CNTs were washed several times with distilled water. The chopped aluminum cuts of 8mm in diameter were ball-milled for 24 hours to coat the surface of chopped aluminum cut with the pretreated MWCNTs. The aluminum cut was used as a media for observing the CNT's movement during hydrostatic extrusion. The CNT-coated Al cuts were compacted into the aluminum block container with pure aluminum powders, and then the aluminum container was welded and degassed at 450^{o}C for 2hrs. The hydrostatic extrusion of CNT-Al composite was performed at a temperature of 160^{o}C using a vertical hydrostatic extruder with a load capacity of 20MN. The size of high-pressure container in the extruder was ø150mmxL270mm. High temperature grease for lubricant was used as a hydrostatic pressure medium. The extrusion die angle was 45^{o}.

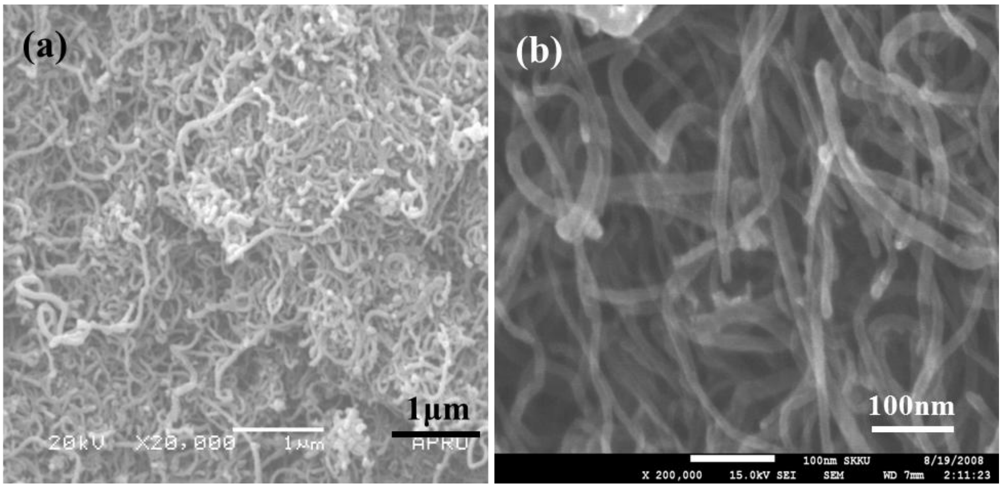
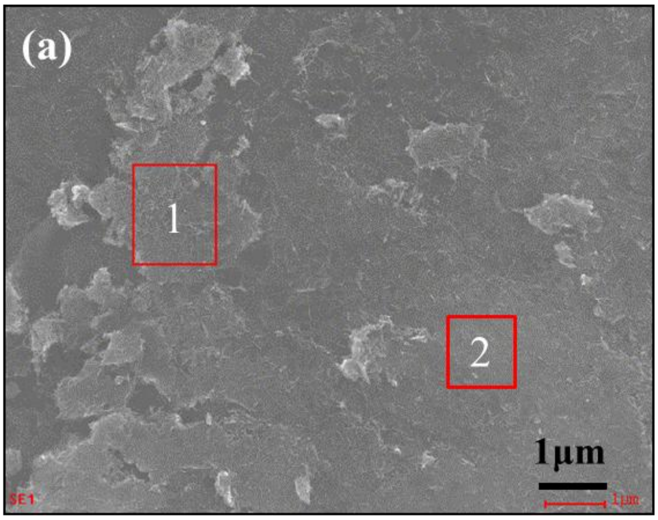


Figure 1. SEM images of MWCNT; (a) as-received and (b) purified with acid treatment.

3 Results and discussion

The surface of chopped aluminum cuts were fully coated with CNTs by dry ball milling process. The surface of CNT-coated aluminum cuts were analyzed by FESEM. The SEM images and EDXs results were shown in Figure 2. CNTs were homogeneously deposited on the surface of Al cuts, but some agglomerates of CNTs were also found due to entanglement of CNTs during ball milling process as shown in Figure 2(a). It can be clearly noticed that coated CNTs are identified by carbon element in the EDS analysis shown in Figure 2(b). In this experiment, the magnesium powders were also included in the dry ball milling process for enhancing the sintering of Al powders. These Mg powders were used to increase the strength of extruded bar by minimizing the oxidation inclusions from Al powders.



(b)

Element (1)	Wt%	At%
CK	25.63	41.17
OK	11.14	13.44
MgK	02.45	01.95
AlK	60.77	43.45

Element (2)	Wt%	At%
OK	07.62	12.21
AlK	92.38	87.79

Figure 2. SEM images and EDX results on the CNT-coated Al cuts; (a) images and (b) EDS results

Figure 3 shows a bar shape product of CNT-Al composite and extrusion block before and after hydrostatic extrusion. The billet was hydrostatically extruded at 160°C with an extrusion ratio of 16:1, and extrusion was carried out at press ram speed of about 15mm/s. The extrusion load was measured by a load cell installed between the hydraulic press and punch. An extrusion pressure of 420MPa was recorded and kept constantly during extrusion process. The surface of the extruded billet was very smooth without any peeling. Figure 3(b) shows the schematic diagram of aluminum 1050 extrusion block before extrusion. The diameters of Al can block and inner composite part were 118mm and 35mm, respectively.

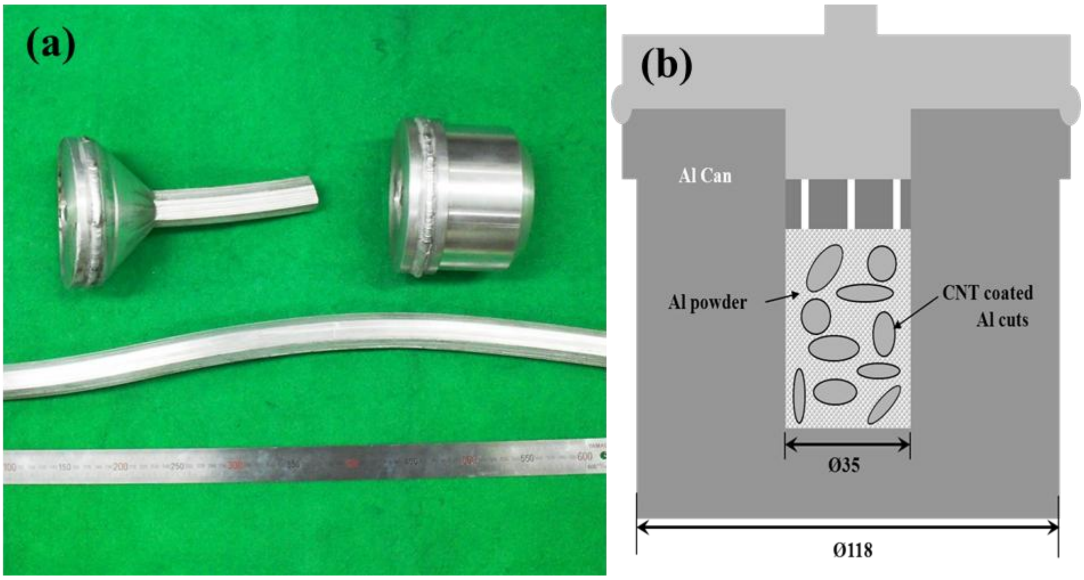


Figure 3. Appearance of extruded rod(a) and aluminum block before extrusion(b)

Figure 4(a) shows cross-sectional view of the CNT-Al composite extruded rod. The cross-section of the extruded rod was hexagonal shape and inner CNT-Al composite part was well bonded with outer 1050 Al block. But, the core parts were located slightly off-center in the extruded rod. The hydrostatic extrusion was a non-friction process between the extrusion block and die. So, it was considered that the off-center position of core part was caused by the unsymmetrical position of guide plate supporting the extrusion block. Figure 4(b) shows the optical microstructure of CNT-coated Al cuts in the core area. The CNT-coated Al cuts were also extruded, and reduced in diameter due to the same extrusion ratio of 16:1. The size of Al cuts were decreased to 2mm in size. It was reported that the composite hard particles were dispersed finely during the hydrostatic extrusion process, [4]. But, in this study, the extrusion ratio was somewhat not enough to severely deform the Al cuts for dispersing the CNTs in the matrix.

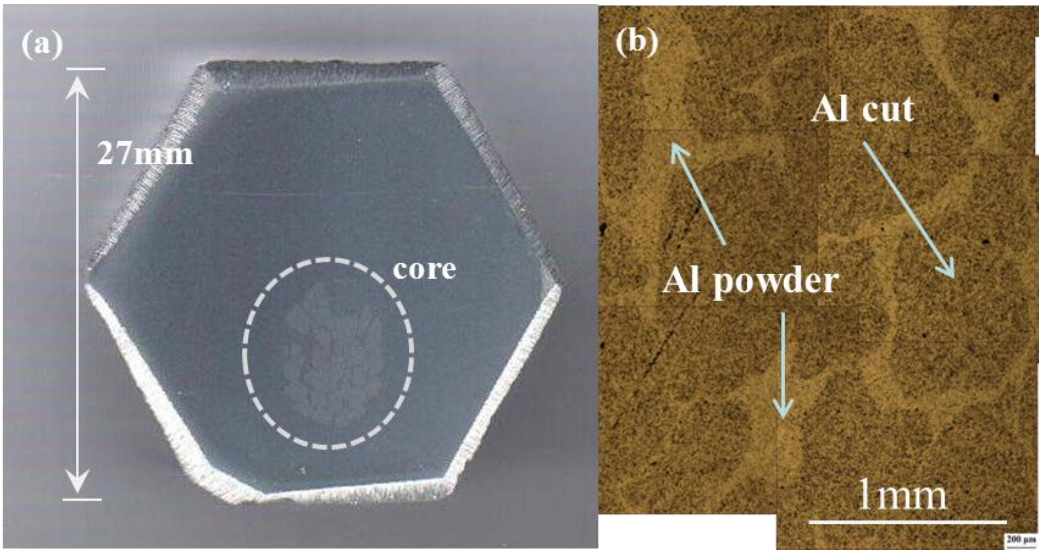


Figure 4. Appearance of extruded rod(a) and optical microstructure of extruded composite core(b)

4 Conclusions

In this study, we applied a hydrostatic extrusion process to fabricate a CNT-Al metal matrix composite billet. The effect of hydrostatic extrusion on the alignment of CNTs in the extruded microstructure was studied by OM and SEM analyses. The followings are the summaries obtained in the present work. The hexagonal shape of extruded composite rod was successfully obtained having clean surface without any peeling. Also, the CNT-Al composite core structures were extruded and well-bonded with outer Al matrix. It was considered that the severe deformation with high extrusion ratio should be applied to disperse the CNTs in the Al matrix. But, it is suggested that the hydrostatic extrusion is a useful process to obtain new CNT-reinforced Al matrix composites.

References

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