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Tribological performance of UHMWPE reinforced with carbon nanotubes in bovine serum

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Although the factors that cause the failure of orthopedic implants were not clearly determined, it was reported that the shapes of wear debris affect the tribological behavior of artificial implant. Many researches were conducted to examine the wear mechanism by debris but the role of debris shape in inflammatory reaction remains unclear. To observe the debris shape by addition of reinforcement, carbon nanotubes (CNTs) were added to ultra high molecular weight polyethylene (UHMWPE) to investigate the reinforcement effect of CNTs. CNTs which have a diameter of about 10-50 nm, while their length is about 3-5 nm were produced by the catalytic decomposition of the acetylene gas using a tube furnace. Plate on disc type wear test were performed to evaluate the tribological performance of UHMWPE composites reinforced with CNTs in lubricating condition (bovine serum). The wear losses of CNT added UHMWPE in bovine serum were significantly reduced. Worn surface and wear debris of UHMWPE with CNTs and without CNTs were compared to investigate the reinforcement effect of CNT on tribological behavior.

Keywords : CNT, UHMWPE, Wear, Hip joint, Composite, lubricant

1. INTRODUCTION

Ultra high molecular weight polyethylene (UHMWPE) is the adequate material that can be used as an artificial implant because UHMWPE has several excellent properties including wear resistance, biocompatibility, chemical stability and low coefficient of friction. UHMWPE has been used in the field of surgical implant since the early 1960s. But natural wear is inevitable while the patients that are transplanted implants made with UHMWPE make their movements and the implant material fails in the patients' body. The failure of UHMWPE is fatal to the transplanted patients. Especially, wear debris generated by long term wear can cause bone resorption and osteolysis to the patients[1]. This failure promoted the researchs that improve the wear resistance of UHMWPE. Researchers try to add various additives and to irradiate for crosslinking that expect to lower wear loss[2]. And the experiments that inject ions on the surface of UHMWPE is on progress to create the lubricating condition in the joints of the body[3]. In order to decrease the generation of wear debris, carbon nanotube(CNT) was added to UHMWPE as a reinforcement. CNT discovered in 1991 that shows tubelike shape of graphite is the material that has great mechanical strength by strong covalent bonding and superior physical efficiency with high Young's modulus and aspect ratio. thus this abilities make it possible to enhance the mechanical properties when it is used to various composites[4]. Moreover it is expected to display better advantages than any other additives that is conventionally added to reinforce the matrix because CNT is the material that has lower weight compare to it's great mechanical properties. This experiment will show the change of UHMWPE's wear properties and the applicability of advanced biomedicals by adding CNT.

2. EXPERIMENTAL PROCEDURE

CNTs were produced by the catalytic decomposition of the C_2H_2 using a tube furnace which can be operated up to a temperature of 1200°C at atmospheric pressure. The CNTs were grown using a gas mixture of C_2H_2, H_2, $Fe(CO)_5$ with N_2 as a carrier gas. The experimental details were reported elsewhere [5]. After CNT synthesis, the collected CNTs were examined by SEM (Hitachi, S-4300) to measure the length, diameter and uniformity. For TEM observations, samples were dispersed in a carbon tetrachloride (CCl_4) solution, then scooped up onto a holey carbon microgrid. These specimens were examined with a side-entry type HRTEM (Hitachi, H9000-NAR) operating at 300 kV with a point resolution of 0.18 nm. HRTEM was used to determine the wall structure of individual carbon nanotubes. Synthesized CNT was mixed with UHMWPE and the specimens that was added were prepared with 0.1 wt%, 0.2 wt%, 0.5 wt% and 1.0 wt% respectively. Also UHMWPE without CNT addition was fabricated to compare with CNT added UHMWPE. After mixed homogeneously in the ultrasonic bath about 1 hour, it was posited into the hood for 2 days to dessicate toluene. And specimens were produced in size 50×50×5 mm through hot pressing method with 180°C , 25 MPa and 1 hour. For the wear tests, specimens were cut to 5×20 mm-small pieces and cleaned in ethanol through ultrasonic cleaner. Plate-on-disc type wear tests were performed to evaluate the tribological properties of UHMWPE with CNT addition. The normal load and sliding speed (frequency) were fixed at 5 N and 1Hz respectively. The test duration was about 10 days (1 million cycle). After the wear tests, the worn and un-worn surfaces of each sample were examined through scanning electron microscope(SEM).

3. RESULTS AND DISCUSSING

Soot-like deposits were formed on the entire inner-wall of the quartz tube after the catalytic pyrosis of hydrocarbon at 750°C for 60 min. Fig. 1(a) shows the SEM image of the collected soot-like deposits without any purification process. The tubes have a diameter of about 10 – 50 nm, while their length is about 3 – 5 μm. HRTEM was used to observe the interior and wall structures of the CNTs. Fig. 1(b) shows a typical TEM micrograph of the CNTs. It clearly shows that the nanotube is a multi-walled hollow tube, not solid fiber. Also, most of the closed tips are filled with iron particles. Fig. 1(c) is a HRTEM image of a single CNT and tip structure. It shows the inside hollow with a diameter of 3 – 5 nm. The fringes on each side of the tube represent individual cylindrical graphitic layers. The CNT has approximately 12 – 15 walls of graphitized carbon. An iron nanoparticle is encapsulated at the end of the nanotube. This indicates that the iron catalyst particles promote tip growth process and play an essential role in the formation of the nanotube. After the wear test, the worn surfaces of UHMWPE are observed as shows in the Fig. 2(a) and 2(b). It shows different morphologies of worn surfaces as to each specimen. UHMWPE without CNT shows lines on the worn surface that may be caused by counterface. But UHMWPE with CNT does not show the same morphology of worn surface appeared in UHMWPE without CNT. It is thought that CNT makes counterface possible to slide down on the interface that the wear is occured and thus, to decrease the wear loss of UHMWPE. Fig. 2(c) shows the CNTs on the surface of UHMWPE. These CNTs lead the wear-resistant property of UHMWPE when they are exposed onto the surface of matrix during the wear test. Because of CNT's helpful effect to tribological property on UHMWPE, wear loss is decreased while contents of CNT that is added into the matrix is increased as shown in the Fig. 3. It is noted that the fabrication of composite by adding CNT is widely applicable as an artificial implant in that CNT contributes to decrease the weight loss of matrix and it shows excellent mechanical properties compared to other additives. It is thought that CNT as an additive has a lot of merits through the friction. In general, it is necessary that continuous experiments and researches have to be conducted to adapt fittably in the field of surgical implant that hope the long span of life.

4. CONCLUSIONS

Multi-walled CNTs were fabricated by thermal CVD method and were effectively added to the UHMWPE. Wear of UHMWPE in bovine serum was significantly reduced when CNTs were added. Different morphology of abraded specimens by addition of CNTs shows reinforcement effect on tribological behavior. This study shows that CNT can be potential additive for artificial implant materials and high quality device that needs good wear resistance.

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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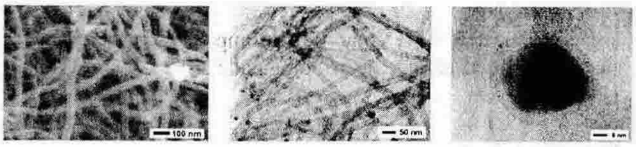
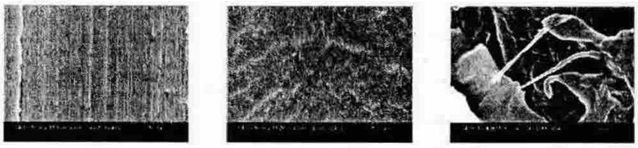


(a) (b) (c)

Fig. 1 (a) SEM image of the CNT. (b) TEM image of carbon nanotubes, showing multi-walled hollow nanotube. (c) HRTEM image of multi-walled carbon nanotube.



(a) (b) (c)

Fig. 2 Worn surfaces of UHMWPE (a) without CNT, (b) with 0.5wt% CNT. (c) Higher magnification of worn surfaces of UHMWPE with 0.5 wt% CNT.

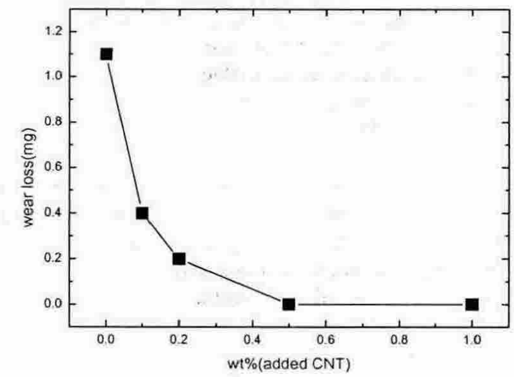


Fig. 3 Variations of weight loss as a function of CNT addition after wear test.