Carbon Fibre Reinforced Nano-HA/PA46 Ternary Biocomposite: Mechanical Properties and Cytocompatibility

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ABSTRACT

A novel ternary composite of carbon fiber, nano-hydroxyapatite and polyamide46 (CF/HA/PA46) was prepared by extrusion method. The mechanical properties were characterized and preliminary cell responses were investigated to explore the feasibility of load-bearing bone repair. The results showed that the bending strength and tensile strength were 159-222 MPa and 117-199 MPa, respectively, when the CF content was in the range of 5%-20%. The tensile modulus was 7.7-10.8 GPa. The MG-63 cells with an osteogenic phenotype were well adhered and spread on the CF/HA/PA46 surface. Compared to the HA/PA46 control, the addition of CF into HA/PA46 manifest improved the toughness and had little negative effects on MG-63 cells. The obtained ternary composite has potential as load-bearing bone repair.

INTRODUCTION

Ideal bone repair material should be of good biocompatibility and high bioactivity. Besides, their mechanical properties should be equivalent to or better than those of natural bone. Nowadays, metals are mainly used of clinical application for load-bearing bone repair. However, due to the mismatch between the mechanical properties of the implant material and that of the bone, metal stress shielding on bone will result in twice trauma [1]. In the past few years, polymers and their composites have been widely used for bone replacement due to excellent properties, such as poly ether ether ketone, ultrahigh molecular weight polyethylene, nano-hydroxyapatite/polyamide66 composite, etc. [2] But the mechanical properties of this material are much lower than metal, so their application in load-bearing bone repair and fixation devices were limited.

Polyamide (PA) is one of the widely used engineering polymers with perfect balance of various mechanical properties and many complementary attributes. Compared to PA66, polyamide46 (PA46) shows better mechanical properties and dimensional stability for its higher crystallinity and higher degree of molecular
regularity. The success of the HA/PA66 composite and the good properties of the PA46 encouraged us to study PA46 as biomaterial. Many studies indicate that carbon fibers exhibit biocompatibility, and have already been used as biomaterial [3]. Due to its favorable osteoconductive and osteoinductive properties, implants containing it as an ingredient can fasten together directly with the bone (biological binding) [4].

MATERIALS AND METHODS

Preparation of the CF/HA/PA46 Composite

CF/HA/PA46 composites containing 5, 10, 15 and 20 wt% carbon fibre were prepared with a twin screw extruder by extrusion compounding method, the extrusion temperature was ranged from 250℃ to 290℃, main engine speed: 50 Hz, feed rate: 40 Hz. The prepared CF/HA/PA46 composites with different CF contents of mass fractions of 5, 10, 15, and 20 wt% were named as 5CF/HA/PA46, 10CF/HA/PA46, 15CF/HA/PA46, and 20CF/HA/PA46, respectively.

The HA/PA46 was prepared by following procedure: HA/PA46 (30:70, mass fraction) composites were prepared in N,N-dimethyl acetamide (DMAC) solution by co-deposition method. PA46 and DMAC were added into the three-neck flask, then the temperature increased to 140℃, and keeping the temperature at 140℃ for 4h till PA46 was dissolved completely, thus the co-solution of PA46 and DMAC was obtained, HA powder was added into the co-solution, stirring 2h. When the reaction ended, the co-precipitation mixture was cooled down to room temperature. CF/HA/PA46 and HA/PA46 composite samples were made with an injection moulding machine.

SEM Analysis and Mechanical Properties

The morphology of the fracture surface of the composite was observed using scanning electron microscopy. The tensile strength, bending strength and elastic modulus of the composites sample were conducted by mechanical testing machine with 50 kN load cells.

Cytocompatibility

In this study, MG-63 cells were used to evaluate the cytocompatibility of 20CF/HA/PA46 composites, which have previously been widely employed as in vitro test for assessing the cytocompatibility of many types of biomaterial. In all of the cell culture experiments, 20CF/HA/PA46 samples with a size of Ф 8 mm × 2 mm were used, and a tissue culture plate were used as the control.

Sample for cell attachment assay were taken after 4h incubation. The unattached cells were removed by washing with PBS three times. Then the left over cells on the samples were digested by trypsin and the cells were counted with a hemacyctometer. The cell viability was investigated following culture periods of 1, 3, 5, and 7 days using MTT assay. The morphology of MG-63 cells cultured on the composite samples was observed by SEM.
RESULTS

SEM Observation and Mechanical Properties

It is obvious that irregular and basin-shaped surface of fracture formed in ternary composite while relatively regular surface of fracture for binary composite, indicating the ternary composite has good toughness. The CF fibre was uniformly distributed with random orientations in the HA/PA46 matrix. There were some cavities formed because CF was pulled out. It was also confirmed that CF/HA/PA46 exhibited a roughness fracture surface compared to that of HA/PA46.

The mechanical properties of the CF/HA/PA46 composite with different CF contents are listed in Table 1. It can be seen that the bending strength and tensile strength were 159-222MPa and 117-199MPa, respectively, manifestly influenced by the addition of CF.

Cytocompatibility

After 4 h of culture, cell adhesion on the 20CF/HA/PA46 composite was investigated using MG-63 cells, using HA/PA46 as the control. Over 4 h, the cell adhesion rate on the ternary composite was 101%, while the rate on HA/PA46 was 104%. There was no significant difference in optical density values between the composite and HA/PA46 at days 1, 3, 5, and 7 (Fig. 1). The results indicated that the ternary composite facilitated cell proliferation.

The morphology of MG-63 cells cultured on the CF/HA/PA46 and HA/PA46(control) composite for 3 days are shown in Fig. 2. At 3 days, both the CF/HA/PA46 and HA/PA4 composite surfaces presented a confluent layer with intimate attachment to the composite surfaces. And there no significantly differences on cell population and morphology between CF/HA/PA46 and HA/PA46, indicating that CF incorporation in HA/PA46 showed no negative effects on cell morphology and viability.

| Samples   | Bending strength (MPa) | Tensile strength (MPa) | Tensile modulus (GPa) |
|-----------|------------------------|------------------------|-----------------------|
| HA/PA46   | 116±3                  | 95±7                   | 4.6±0.4               |
| 5 CF/HA/PA46 | 159±7                  | 117±8                  | 7.7±0.6               |
| 10 CF/HA/PA46 | 181±4                  | 163±6                  | 8.5±0.6               |
| 15 CF/HA/PA46 | 213±9                  | 199±5                  | 9.0±0.4               |
| 20 CF/HA/PA46 | 222±6                  | 185±5                  | 10.8±0.5              |
DISCUSSION

In this study, we developed a novel biocomposite CF/HA/PA46. It was found that the CF distributed evenly into the HA/PA46 matrix with no preferred orientation. The CF bonded tightly with the HA/PA46, and no cracks were observed between the CF and the HA/PA46 matrix. The results indicated that CF had good compatibility with the HA/PA46 matrix, which was considered to be evidence of a reinforced material with improved mechanical properties compared to that of the matrix [5]. It is obvious that the addition of CF significantly improved the mechanical properties of the HA/PA46 composite. Furthermore, the bending and tensile strength of 15CF/HA/PA46 were higher than those of bone, while its modulus was close to that of natural bone[6]. Hence, the ternary composite has potential for use in orthopaedic clinical fixation applications.
Biocompatibility and safety are very important for implants. In this study, after 4 h of culturing, cell adhesion onto the CF/HA/PA46 composite was 101% and that onto HA/PA46 was 104%, indicating that incorporation of CFs into HA/PA46 resulted in negligible negative effects on the cell adhesion.

CONCLUSION

A novel composite of CF-reinforced HA/PA46 was prepared by the extrusion method in this study. In summary, the CF/HA/PA46 exhibited good mechanical strength and modulus as well as cytocompatibility and has promise for use in orthopaedic clinical fixation applications.

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