Process Technology and Mechanical Properties of Polylactic Acid Ply Yarns and 316L Stainless Steel Braids

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Abstract

Biodegradable polymer has been widely used in surgical suture, dressing, artificial bone and other bone-related applications. However, when compared with the human cortical bone, the pure polymer obviously did not have enough strength. The present study aimed to give preliminary insights from a pilot study of designing a scaffold of polylactic acid ply yarns composited with stainless steel (SS) braids. To evaluate the fabrication processes and alkali effects on the individual materials, the different heating temperature and alkali treating time and alkali concentration were applied to clarify the changes in mechanical strength. The experimental results showed that the strength was not significant declined with alkali and heating treatments. The retained mechanical strength was kept at 100-120 MPa and ultimately led to bone-like mechanical properties.

Introduction

Biomaterials applied in clinical applications should have excellent properties such as biocompatibility, non-toxic, non-irritation, carcinogen-free and do not cause any allergy. Bone disease is a serious health condition that directly impacts on the quality of life of sufferers, particularly among the elder [1]. In recent years, bone restorations have been employed extensively in clinical applications, for examples, periodontal defect repair, as scaffolds for bone reconstruction, and in orthopedics. Biomaterials based on metals are well developed that have more completed data of measurements and clinical applications than ceramics and polymers. Due to the properties of fitting workability, biocompatibility and well evaluated clinical trials, the safety of metals have been identification. Metals, such as stainless steel (SS), commercial pure titanium (cp-Ti), the Cobalt/Chromium (Co-Cr) and Ti/Aluminum/Vanadium (Ti-Al-V) series alloys, have been used widely in various medical operations. Ferrous alloy with the Cr additive has the anti-corrosion ability and been developed by Beathier since 1821. In late 1940s, the SS was first recommended to be used in implant surgery [2]. At the same time, the fiber type biomaterial is also one of the most widely used and studied to explore its potential usage in implant surgery [3-19]. Due to the advantages of good biocompatibility, biodegradable to non toxic products during the implantation and easy shaping ability, the polylactic acid (PLA) is widely employed in therapy of skeleton restoration[18]. PLA is also an approved biodegradable biomaterial by FDA which could be metabolized and eliminated from the body. In Ruiyun and Ma study (1999), the highly porous polymer foams (up to 95% porosity) were prepared from polymer solution by solid–liquid phase separation and subsequent sublimation of the solvent. The foams were then immersed in the simulated body fluid (SBF) at 37℃ for 15-30 days to allow the in situ apatite formation. They concluded that after incubation in the SBF, a large number of characteristic micro-particles were formed on the surfaces of pore walls throughout the polymer foams. Those micro-particles were characterized as a bonelike apatite [23]. The main purpose of this study was to composite the metal/polymer materials and braided process to improve their mechanical properties and biocompatibilities.

Experimental

Materials and Methods

The ply yarn of different denier (150, 225 and 300) was prepared by polylactic acid multifilament (75d/36f, UNITIKA Co., Japan) through the doubler. Twisting the ply yarn to form 2, 3, 4 coefficient of twist using a rotor-twister. According to ASTM D2256 standard, the mechanical properties were determined using a mechanical testing machine (HT-9101,Computer Servo Control Materials Testing System, Taiwan). To check the alkali effect, the specimen of measured maximum tensile strength (optimum parameters) was soaking in the solution of 0.5, 1.0, 1.5 and 2.0 M NaOH solution (Osaka Co., Japan) aqueous solutions at 80 ℃ for 10, 15 and 20 min. The specimens were mechanically tested to evaluate the process of alkali treating.

316 L stainless steel braid preparations

The 316L SS fibers 0.17 mm in diameter (YUEN NENG Co., Taiwan) were braided by a 16-spindle braiding machine to construct the braid and then processed using changed the ratio of braid gear and take-up gear from 50/80, 50/70, 50/60, 50/50. To get the optimum parameters, the mechanical tests of braids were measured. Alkali treatment was performed by soaking the braids in solutions of 4 and 5 M NaOH solution at 80 ℃ for 24 h. After the alkali treatment, the braids were washed and dried at 40 ℃ for 24 h. The alkali treated specimens were then heated to the temperatures of 400, 500 and 600 ℃ in a furnace, kept at a given temperature for 1 h, and cooled to room temperature in the furnace. The specimens were tested to measure their mechanical properties.

Results and Discussion

Effects of ply yarn's coefficient of twist on ultimate tensile strength and elongation

The ply yarn of 2, 3, and 4 coefficient of twist showed that the tensile stress was higher than 640 g in Fig. 1. The appropriate inter-fibre cohesion of 2, 3 coefficient of twist had tensile stress that was higher than 4 coefficient of twist. This Phenomenon made the stress lower because over-twisted. According to the result of Fig. 2, the standard deviation of ply yarn of 4 coefficient of twist is the smallest, but the cost of the preparation was higher. On the other hand, the elongation doesn't dramatic changes in Fig. 3. Based on the experimental results, the optimal coefficient of twist was found to be 3.

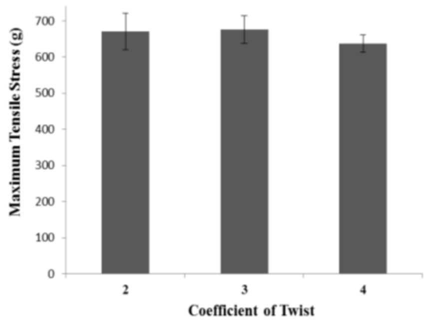

Fig. 1. The maximum tensile stress of 225D ply yarn with different coefficient of twist.

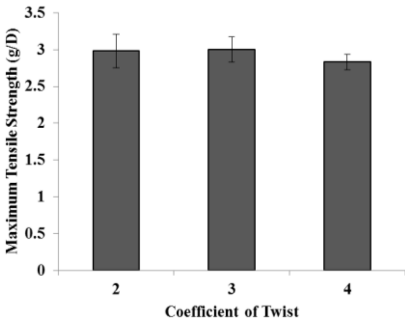

Fig. 2. The maximum tensile strength of 225D ply yarn with different coefficient of twist.

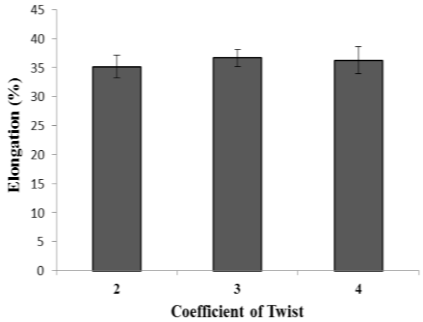

Fig. 3. The elongation rate of 225D ply yarn at the ultimate tensile strength.

Effects of alkali treating on ultimate tensile strength and elongation of ply yarn

The alkali treating process had no significant impact on ply yarn's tensile strength, but the strength was raised in some immersion times (Fig. 4). This strength increasing phenomenon was due to the shrinkage of ply yarn through alkali treating and decreased by corrosion. Fig. 5 showed that different coefficient of twist through the alkali treating did not significantly affect the yarn's strength (between 2.9 g/d to 3.2 g/d). However, when ply yarn immersed at different alkali treating time were compared, the values of elongation were slightly decreased as shown in Fig. 6. The phenomenon is a ply yarn that can be decomposed the structure in NaOH solution.

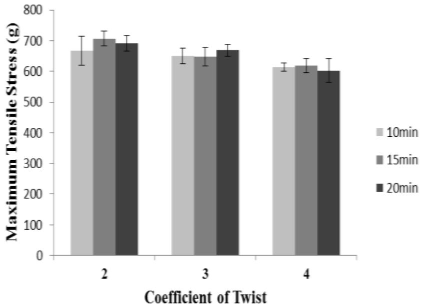

Fig. 4. Maximum tensile stress of ply yarns at different immersion time (10, 15 and 20 min).

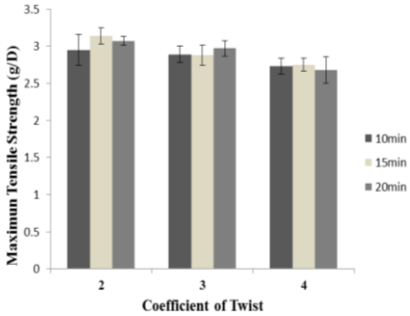

Fig. 5. The maximum tensile strength of ply yarn in per unit denier at different immersion time.

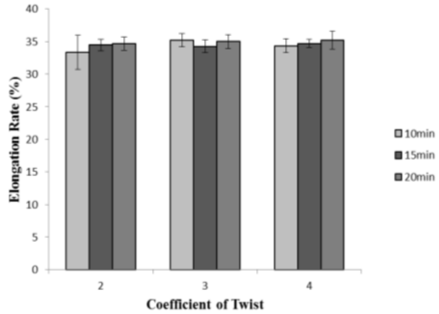

Fig. 6. The elongation rate of ply yarn at the ultimate tensile strength after different immersion time.

Effects of take-up gears on mechanical properties and pore area of SS braids

Comparisons of tensile strengths in SS braids with different take-up gears had demonstrated that the strength of 50/50 group was significantly higher than the other groups (Fig. 7). This was likely due to the fact that higher speed mechanism resulted in a small braid angle and the fiber filament axis tended to the diametral axis in the take-up gears 50/50 groups. Therefore, they had greater tensile strength values. The extension rate of take-up gear from 50/80 to 50/50 with given break elongation was increased in Fig. 8. Experimentally, our work showed that the pore area of take-up gear group (50/50) increased in Fig. 9. It was shown that when the Take-up gear increased the angle of the braid was also increased in Fig. 10. To conclude the results, the optimal take-up gear was found to be 50/50.

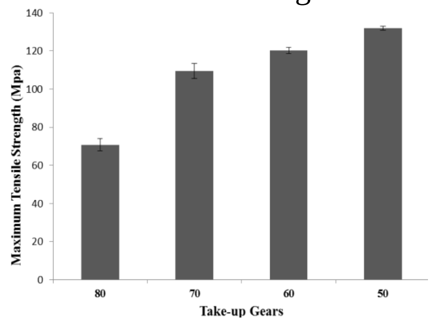

Fig. 7. The tensile strength of 316L SS braids.

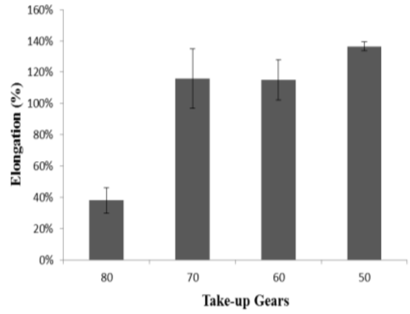

Fig. 8. The elongation rate at break of 316L SS braids.

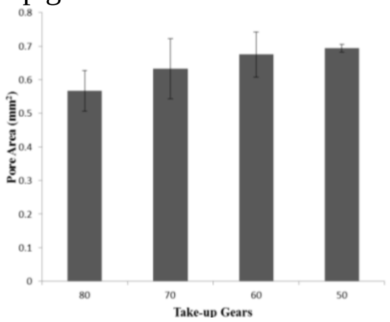

Fig. 9. Pore areas of 316LSS braids

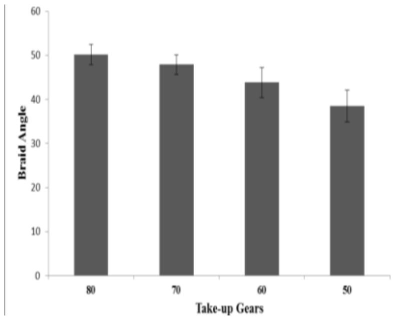

Fig. 10. Braid angle of 316L SS braids

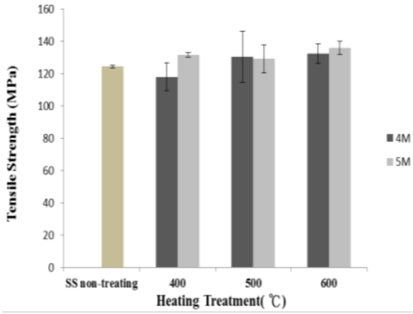

Fig. 11. Maximum tensile strength of 316L SS braids through different concentration alkali treating.

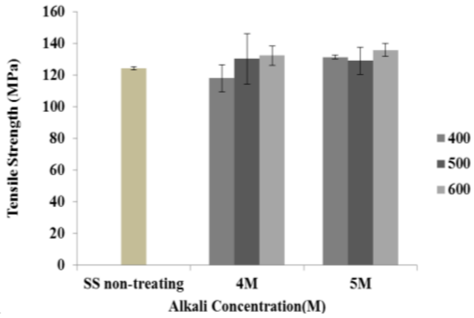

Fig. 12. Maximum tensile strength of 316L SS braids through different heat treating temperature ℃.

Effects of alkali treating processes and heat by different temperate on ultimate tensile strength of SS braids

Our results suggested that alkali treating processes made no significant contribution to the mechanical properties. Furthermore, the strength did not depend on heating temperatures. Based on the result in Fig. 11, the strength was measured between 118 to 132 MPa after 4 and 5 M alkali treating for 24 h and showed no differences when compared to pure SS braid 122 MPa. Because SS had the obvious anti-corrosion and excellent heat resistance abilities which also were revealed in our results. The strength of specimen was all tested larger than 118 MPa[19].

Conclusion

The proper composite of polylactic acid ply yarn and 316L stainless steel fiber in the scaffold processes is important in the production of tissue or organ regeneration materials in load-bearing defects. Accordingly to the results, 1M alkali treating process in polylactic acid ply yards is most suitable for removing the oiling agent on the surfaces and has no significant effect on the dropping of mechanical strength. The ration of braid gears and take-up gears process (50/50) is especially applicable to 316L SS braids that can produce excellent tensile strengths, higher pore areas and is suitable for preparing a scaffold. This study is a preliminary study to fabricate a scaffold that possesses excellent mechanical properties and pores adequate to apply Hydroxyl Apatite to despite on the 316L braid.

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