氏名（本籍・生年月日）	徐　安長	（　中国　・　1984 年 2 月 11 日）
学位の種類	博士（　工学　）	
学位記番号	甲　第　597　号	
学位授与の日付	平成 26 年 3 月 20 日	
学位授与の要件	信州大学学位規程第 5 条第 1 項該当	

学位論文題目　On the molding method and the mechanical properties of advanced composite materials
（先進複合材料の成形とその力学特性）

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論　文　内　容　の　要　旨

On the molding method and the mechanical properties of advanced composite materials

For nowadays there are demands of light-weight materials in transportation area. The advanced polymer matrix materials are made of a fibrous reinforcement embedded in a polymer matrix resin. The reinforcement fibers are generally with unusually high strength and modulus comparing to other materials. When bound together by the matrix, the reinforcement materials transfer their superior properties to the final composite materials, and endow them with desirable physical and chemical properties including light weight coupled with high stiffness (elasticity), and strength along the direction of the reinforcing fiber, dimensional stability, temperature and chemical resistance and so on. The advanced polymer matrix composites are promising materials for light-weight of transportation devices by replacing metal components.

The advantages of FRTP composite over FRP composite include superior toughness and greater recyclability, as well as the possibility of a rapid processing cycle that does not involve a chemical reaction. However, the main problem of using thermoplastic matrices for composites is the difficulty in impregnating the fibrous reinforcement with resins that have higher viscosity (500 to 5000Pa s) than thermosets (typically less than 100Pa s). In the purpose of improving the fiber volume fraction in FRTP composites, vacuum-assisted solution impregnation prepreg thermoplastic composite molding was proposed. After the poly(p-phenylenebenzobisoxazole) (PBO) fabric was pre-impregnated with thermoplastic resin solution, vacuum was employed for further impregnation and solvent volatilization in the prepreg manufacturing process. On the basis bonding test, the treating time of the fabric and solution condition can be determined (10s/20cm and 25wt% respectively). Under the determined manufacture condition, the fiber volume fraction in the thermoplastic composite material was up to 60%, which is similar to that of fiber-reinforced thermosetting composite at the lab level. The tensile strength and tensile modulus were improved similar to those of PFRP after the fiber volume fraction of PFRTP was improved. Tensile testing and comparison confirmed the effectiveness of vacuum-assisted solution impregnation. The feasibility of the proposed method was confirmed, and its application is promising in the manufacture of carbon or glass fabric-reinforced thermoplastic.

Composites reinforced by organic fibers such as aramid or poly(p-phenylenebenzobisoxazole) (PBO) are with different bending properties comparing to that of carbon or glass fiber reinforced composites. Those composites can undergo large curvature bending without fiber failure on the tension side, but buckling occurs on the compression side. A custom-built pure bending apparatus is employed to determine the influence of fiber on the response of fiber reinforced polymer matrix composite under bending moment. It is found that the failure mode of PFRP is different from those of CFRP and GFRP during pure bending. For hybrid-fiber–reinforced composites, the choice of fiber on the compression side affects the failure mode of the composite. Load-unload cycled bending tests revealed that PFRP and PCFRP retained more irreversible plastic strain than CFRP, CPFRP, and GFRP did. Investigating the instantaneous modulus of each material revealed two disparate phenomena, one analogous to CFRP (little change) and the other to PFRP (significant decrease, but the residual modulus is still larger than that of GFRP). In further investigation the influence of other properties rather than the low compressive strength of PBO fiber, for example, the bonding behavior of between fiber and matrix, will be put into investigation to clarify the deformation behavior observed in this paper.

The spread tow fabric (STF) technique increases the mechanical properties of the material and is also used to reduce weight on composite. Spread tow fabric offers the advantage of relatively lower crimp, increased smoothness and less-pronounced crossover defects. As a greater number of filaments are exposed in STF they also present correspondingly improved wetting ability. The aramid spread tow fabric is used to reinforce epoxy matrix composite. The bending property of AFRP is different from that of carbon fiber reinforced epoxy composite, because of the differences between tension and compression properties of AFRP. Subsequently, the bending results in bending properties of hybrid fiber reinforced composite suggest that it is promising to employ the thin aramid STF to produce advanced materials with small amount of fiber. Also the compression after impact (CAI) test result indicated that using small amount of thin aramid STF can manufacture a composite with good impact resistance and high residual compression strength.

From the result of our existing research, there is a problem that fiber-reinforced plastic (FRP) composites always break down because of cracks between the laminae for their particular laminated structure. To decrease the probability of cracking between laminae, carbon nanotubes (CNTs), were used to enhance the interlaminar strength and to obtain an FRP product with a higher longevity. Adding CNTs improved the bending strength flexural modulus and ILSS. Within the test range, the sample with 2 wt% CNTs exhibited the highest degree of strengthening, owing to the stitching effect of CNTs between the laminae. In samples with CNTs exceeding 2 wt%, the CNTs bunched together, reducing the degree of enhancement. New dispersion methods that can fill more CNTs into a matrix are essential for the further improvement of the materials. In the creep test with an imposed 40% load, only the sample without CNTs broke; samples with 1 and 2 wt% CNTs did not break, even after a long time. With an imposed 60% load, the samples failed in the order of 0, 1, and 2 wt%. These findings were due to the stitching effect and improved thermal properties of CNTs. The longevity of the FRP can be predicted by comparing the flexural rigidities of samples with and without CNTs.