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A study on the energy absorption properties of carbon/aramid fiber filament winding composite tube

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ABSTRACT

Fiber reinforced composites (FRPs) with light weight did not exhibit the ductile failure mechanism which was related to metals. FRPs absorb lots of energy through progressive crushing modes by a combination of multi micro-crack, bending, delamination and friction. FRPs with half weight of traditional metals while absorb more than doubled energy. But FRPs were not used as energy absorption components in wide range; one of the most important reasons is their high manufacturing cost.

In this study, carbon fiber and aramid fiber were chosen as reinforcements and common epoxy resin was chosen as matrix to manufacture five types of different structures and raw materials of carbon/aramid and carbon/carbon fiber reinforced composite tubes through high productive and low cost winding method. Then specimens were dealt under 100 °C condition for 100 h, 200 h and 400 h treatment respectively. After that, energy absorption ability was tested by quasi static compression tests and microscope observation of cross section was taken to analyze the mechanism of failure. By optimizing different hybrid method, ratio and reasonable geometry shape of composites, low cost and high energy absorption components whose specific energy absorption (*Es*) were near 100 kJ/kg could be manufactured to put to use on vehicles.

1. Introduction

Till now, the global automotive industry is almost one of the biggest and most complicated fields in industrial history. While with the sharp increasing quantity of automobiles, the traffic accidents old as cars themselves increased accordingly. At present, the injuries of traffic accidents account for about a quarter of worldwide injuries and deaths [1]. On the one hand, worldwide governments as policymakers are doing their best efforts to specify the safety standard of vehicles. On the other side, car manufacturers are also focusing their efforts on the quality of safety especially their crashworthiness and crash compatibility. Lots of products including bumper, seat belt, airbag, anti-locked braking system (ABS) improve the safety of drivers when suddenly stopping and crashing happen. Except safety, pollution is one big serious problem. The vehicles bring lots of poisonous gas such as NO_x and CO_2 which was one major cause of global warm. With the urgent needs for saving energy and protecting environment, economic cooperation (ECO) vehicles are becoming more and more desirable. It is a good way to improve the fuel efficiency through reducing the weight of cars. However, for traditional mental materials, it is hard to achieve high energy absorption properties with light weight. Therefore, new material system was considered to substitute traditional metal materials to manufacture next generation vehicles. In this field, fiber reinforced composites (CFRPs) attracted attentions specially.

CFRPs with light weight did not exhibit the ductile failure mechanism which was related to metals. FRPs with half weight of traditional metals while absorb more than doubled energy. But FRPs were not used as energy absorption components in wide-range, one of the most important reasons is their high manufacturing cost and another is its complicated energy absorption mechanism. FRPs absorb lots of energy through progressive crushing mode by a combination of multi micro-crack, bending, delamination and friction [2–7]. For FRPs composite tube which was compressed through progressive crushing mode, the energy absorption mechanism could be observed from the axial cross sections of the crush zone. Based on previous work, the tube wall was

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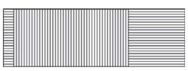
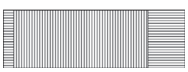
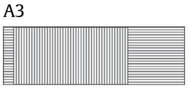
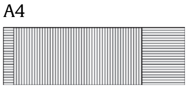
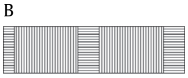
Table 1
Specification of raw materials.

Raw material	Manufacturer	Type	Tensile strength/MPa	Tensile modulus/GPa	Density/(g · cm^{-3})	Elongation/%
Carbon fiber	Toray	T700SC-12000	4900	230	1.8	2.1
Aramid fiber	Dupont–Toray	Kevlar 29	2920	70.5	1.44	3.6
Epoxy	Mitsubishi chemical	308A3801	64	4	–	1.9

Table 2
Structure design of CFRPs.

Type	Parameters	Structure				
		Inner side		Middle side		Outer side
A1	Fiber distribution	Aramid fiber		Carbon fiber		Aramid fiber
	Ratio	1.0		11.0		5.5
	Thickness/ mm	0.15		1.66		0.830
A/C/A:1/11/5.5	Fiber orientation	88°		17.6°		88°
A2	Fiber distribution	Aramid fiber		Carbon fiber		Aramid fiber
	Ratio	1.0		13.3		3.3
	Thickness/mm	0.15		2.00		0.50
A/C/A:1/13.3/3.3	Fiber orientation	88°		17.6°		88°
A3	Fiber distribution	Carbon fiber		Carbon fiber		Carbon fiber
	Ratio	1.0		11.0		5.5
	Thickness/mm	0.15		1.66		0.83
C/C/C:1/11/5.5	Fiber orientation	88°		17.6°		88°
A4	Fiber distribution	Aramid fiber		Carbon fiber		Aramid fiber
	Ratio	1.0		10.0		2.5
	Thickness/mm	0.15		1.50		0.39
A/C/A:1/10/2.5	Fiber orientation	88°		17.6°		88°
B	Fiber distribution	Aramid fiber	Carbon fiber	Aramid fiber	Carbon fiber	Aramid fiber
	Ratio	1.00	5.00	1.25	5.00	1.25
	Thickness/mm	0.150	0.750	0.188	0.750	0.188
A/C/A/C/A:1/5/1.25/5/1.25	Fiber orientation	88°	17.6°	88°	17.6°	88°

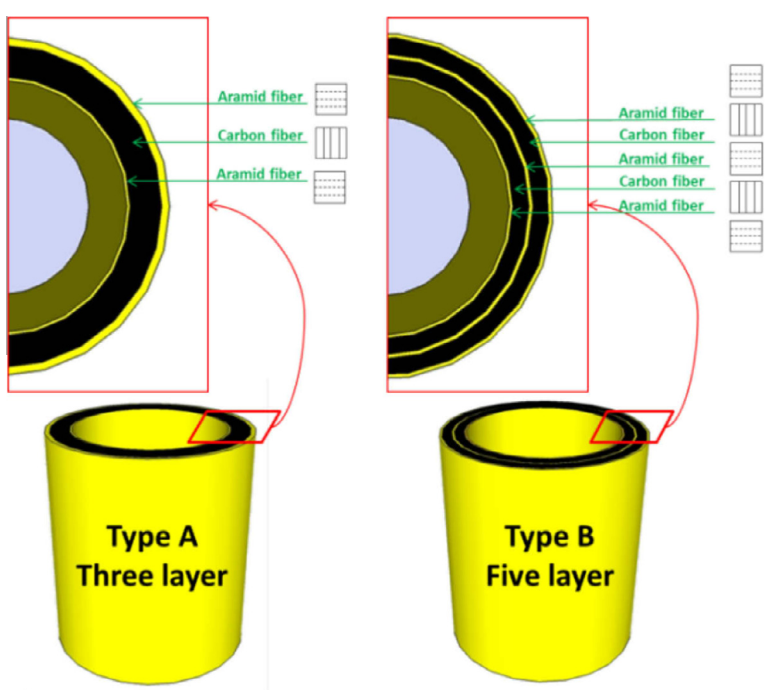


Fig. 1. Schematic diagram of two types of carbon/aramid CFRPs.