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Crashworthiness of carbon fiber hybrid composite tubes molded by filament winding

Jing Xu [a], Yan Ma [b], Qianjin Zhang [a], Toshi Sugahara [b,d], Yuqiu Yang [a,c,*], Hiroyuki Hamada [b]

[a] College of Textiles, Donghua University, Shanghai 201620, PR China
[b] Advanced Fibro-Science, Kyoto Institute of Technology, Kyoto 6068585, Japan
[c] Key Laboratory of Textile Science & Technology, Ministry of Education, Shanghai 201620, PR China
[d] Maruhachi Corporation, Fukui 9100276, Japan

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ABSTRACT

Carbon Fiber Reinforced Composites (CFRPs) with light weights absorbed a large quantity of energy through the progressive crushing modes by a combination of multi micro-crack including fiber fracture and matrix fracture, bending, delamination, splitting, friction and so on. High manufacturing cost of CFRPs was one of the most important reasons for not being used as energy absorption components in wide range. In this study, five types of tubes were manufactured by filament winding method and crashworthiness performance was investigated experimentally. The effects of crushing speed, temperature treatment, raw material and structure including hybrid ratio, fiber orientation and thickness of tube wall on energy absorption capabilities were investigated through quasi-static and dynamic compression tests. Optical microscope observation of cross sections was taken to analyze the mechanism of failure. A hybrid carbon/aramid FRP tube after temperature treatment exhibited the highest *Es* in quasi-static test (98 kJ/kg in average) and dynamic tests (82 kJ/kg in average), which have excellent energy absorption management.

1. Introduction

Lots of research and development have been carried out in the past decades to explore an efficient way to improve the safety especially their crashworthiness and crash compatibility of automobiles. Crashworthiness has attracted significant attention due to its multiple functions, which are to (i) absorb energy, (ii) keep the occupant compartments intact and (iii) ensure tolerable deceleration levels for drivers and passengers during the crash event [1]. To reach the above functions, various designs of materials and structures are carried out in the automobile industry.

CFRPs with light weight did not exhibit the ductile failure mechanism which was related to metals. CFRPs absorb lots of energy through progressive crushing modes by a combination of multi micro-crack, splitting, bending, delamination and friction [1–20]. It is a well-known fact that one can achieve a more excellent energy absorption compared to metal alloys with the proper construction and architecture of composite structures.

According to previous study, the energy absorption capability of composite tubes could be affected by lots of factors such as raw materials (Fibers material [3,4], resin material [5,6] and their combination [5,7]), fiber orientation [8] and lay-up [9], specimen geometry (Inside diameter to wall thickness ratio[10,11], collapse trigger mechanism [1,12], cross-sectional geometry [13]), experimental conditions (Strain rate [4,13], frictional effect [14]) and so on. Most of the static crushing studies had been carried out to investigate the energy absorption capability and crushing characteristics of composite tubes. In this method, slow speed of the crushing process helps to capture the crushing behavior of composite tubes effectively. However, most of the practical conditions are dynamic in nature. Hence, the investigations of crushing process under dynamic condition are necessary.

FRPs with above advantages haven't been used as energy absorption components in wide-range at present, one of the most important reasons is their high manufacturing cost and another is its complicated energy absorption mechanism. Ma et al. [15] investigated the static crushing behavior, energy absorption capability as well as temperature treatment effect of CF/CF-epoxy and CF/AF-epoxy composite tubes manufactured by filament winding method. By optimizing different hybrid method, ratio and reasonable geometry shape of composites, low cost and high energy

* Corresponding author at: College of Textiles, Donghua University, Shanghai 201620, PR China. Tel.: +86 15021982812; fax: +86 021 67792623.

E-mail address: amy_yuqiu_yang@dhu.edu.cn (Y. Yang).

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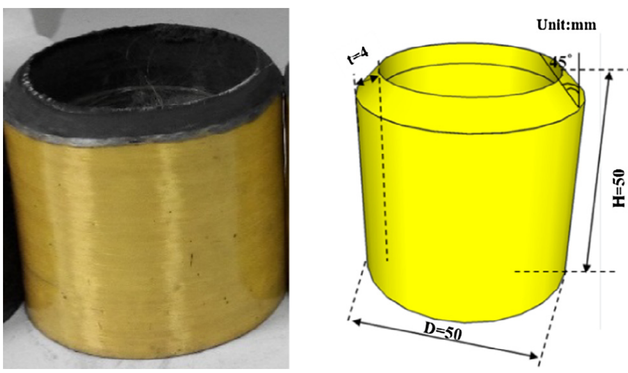
Table 1
Specification of raw material.

Raw materials	Manufacturers	Type	Tensile modulus /GPa	Tensile strength /MPa	Density /g cm^{-3}	Elongation /%
Carbon fiber	Toray	T700SC-12 k	230	4900	1.8	2.1
Aramid fiber	Dupount-Toray	Kevlar 29	70.4	2920	1.44	3.6
Glass fiber	Nittbo	T-glass	84.3	4650	2.49	2.49
Epoxy	Mitsubishi chemical	308A3801	4	64	–	1.9



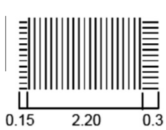
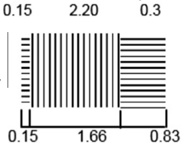
(a) Realistic appearance (b) Schematic diagram

Fig. 1. Realistic appearance (a) and schematic diagram (b) of typical A/C2 specimen.

absorption components whose specific energy absorption (*Es*) were near 96 kJ/kg could be manufactured to put to use on vehicles. However, investigated aspects were relative limited and more practical dynamic tests methods are not carried out. In addition, temperature effect is commonly investigated of energy absorption components in automobile industry because quantity heat giving off will result in rise of temperature when engine runs. Ma et al. [15] also investigated temperature treatment effect. However, further investigation is needed to be conducted and more detailed mechanism of temperature treatment effect is needed to be introduced.

In order to investigate the energy absorption capability of CF hybrid FRP tubes further, carbon fiber (CF), aramid fiber (AF) and also glass fiber (GF) were chosen as reinforcements and same epoxy resin was chosen as matrix to manufacture five new types of different structures and raw materials of FRPs composite tubes through high productive and low cost winding method in this study. Except of static tests, the effects of material, temperature treatment and hybrid ratio on the energy absorption capability

Table 2
Parameters of designed CFRPs and volume fraction measured.

Type	Structure				V_f (%)
A/C2 	Distribution	Aramid fiber	Carbon fiber	Aramid fiber	39.6
	Ratio	1.0	13.3	3.3	
	Thickness/mm	0.15	2.00	0.50	
	Orientation	88°	17.6°	88°	
A/C2.2 	Distribution	Aramid fiber	Carbon fiber	Aramid fiber	41.1
	Ratio	1.0	14.7	2.00	
	Thickness/mm	0.15	2.20	0.30	
	Orientation	88°	17.6°	88°	
A/C1.6′ 	Distribution	Aramid fiber	Carbon fiber	Aramid fiber	38.3
	Ratio	1.0	11.0	5.5	
	Thickness/mm	0.15	1.66	0.83	
	Orientation	88°	10°	88°	
C/C2 	Distribution	Carbon fiber	Carbon fiber	Carbon fiber	43.9
	Ratio	1.0	13.3	3.3	
	Thickness/mm	0.15	2.00	0.50	
	Orientation	88°	17.6°	88°	
G/C2 	Distribution	Glass fiber	Carbon fiber	Glass fiber	42.9
	Ratio	1.0	13.3	3.3	
	Thickness/mm	0.15	2.00	0.50	
	Orientation	88°	17.6°	88°	
A/C1.6 [15] 	Distribution	Aramid fiber	Carbon fiber	Aramid fiber	/
	Ratio	1.0	11.0	5.5	
	Thickness/mm	0.15	1.66	0.83	
	Orientation	88°	17.6°	88°	
A/C1.5 [15] 	Distribution	Aramid fiber	Carbon fiber	Aramid fiber	/
	Ratio	1.0	10	2.5	
	Thickness/mm	0.15	1.5	0.39	
	Orientation	88°	17.6°	88°	