Advanced Materials Research *Online: 2011-12-08*
ISSN: 1662-8985, Vols. 391-392, pp 242-245
doi:10.4028/www.scientific.net/AMR.391-392.242
© 2012 Trans Tech Publications, Switzerland

Applications of Advanced Composite Materials in Bullet-proof Fields and Their Study

Jiang Zhu[1, a] and Yongyou Tian[1, b]

[1]ChongQing University of Arts and Sciences, ChongQing 402160, P.R. China

[a]Jiangzhu415@163.com, [b]Tian9520@139.com

Keywords: UHMWPE fiber; Continuous basalt fiber; Aramid fiber; Bullet-proof composite materials; Enhanced mechanics; Bulletproof products

Abstract. The development of bulletproof materials indicates the military and scientific strength of a country in the fields of modern national defenses and military affairs. With the advancement and development of scientific technologies in the world of human being, the bulletproof materials experienced the changes from the ordinary natural plants or simple metal substances to the synthetic composite materials with high intensity. In this work, we emphasized the applications of some advanced composite materials and their study in bulletproof fields.

Introduction

After World War II, numerous researches have been put into the field of bullet-proof materials for the national defense in many countries because of the exciting protection ability. The historic development of bullet-proof materials experienced from the raw steel and alloy to the high-performance fibers [1]. Currently, materials that widely used in bullet-proof field covered the aramid fibers, ultra-high molecular weight polyethylene fibers (UHMWPE) and liquid crystal polymer matrix fibers (including PBO fiber) and so on.

As one of the high-performance fibers, aramid fibers and products have been widely applied in the different fields for their outstanding physical and chemical properties such as high strength, high modulus, low density and good wear resistance [2]. Aramid is a rigid liquid-crystal polymer composed of the long molecular chains. Because of the high-degree regularity in its molecular structures, excellent performances were endowed to aramid fibers, including the high strength, high modulus, high temperature resistance and light weight. For instance, the strength of aramid fibers is 6 times than the corresponding of the high-quality steel. And the continuous applied temperature for Aramid fibers is in the range from -196°C~204°C. Therefore, the advent of aramid materials (such as Kevlar) was considered an important milestone in the bulletproof fields.

Ultra-high molecular weight polyethylene fibers (UHMWPE), known as the highest strength and high modulus polyethylene fibers in the world, are polyethylene fibers that the molecular weight is from 100 million to 500 million [3]. What is more, the strength of ultra-high molecular weight polyethylene fiber is 1.5 times higher than that of aramid fibers. Ultra-high molecular weight polyethylene fiber has many excellent properties and plays a pivotal role in the modern warfare, aviation, aerospace, marine and other areas, which were made into the all kinds of defense equipment. As one of the excellent bullet-proof fibers, Ultra-high molecular weight polyethylene fibers have the good impact resistance and energy absorption, which are fit for producing military protective clothing, helmets, bullet-proof materials such as helicopters, armor protection plates, body armor and stab-resistant clothing. It was noticeable that the ultra-high molecular weight polyethylene fibers are softer than Kevlar fibers and become an important material in the international fiber market for the bullet-proof products. In addition to the good chemical resistance, electromagnetic transmission, low coefficient of friction, excellent impact resistance and anti-cutting performance, ultra-high molecular weight polyethylene fibers have the good biocompatibility. Therefore, ultra-high molecular weight polyethylene fibers also can be made into the soft bullet-proof vests, radar and missile shield.

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of Trans Tech Publications, www.ttp.net. (#69852440, Pennsylvania State University, University Park, USA-19/09/16,17:34:55)

Additionally, in recent years, basalt fiber has been extensive attention in various fields [4], because of its excellent physical and chemical properties and low price (Table 1 lists the price in the different country), more cost-effective both inside and outside the basalt fiber. Basalt fiber is made of the natural basalt ore, which are melting and drained in platinum or rhodium as catalyst (shown in Fig. 1). Because of its raw materials formed by volcanic magma, basalt fiber does not contain any ingredients that are harmful to human being, and the producing process of fiber does not release any harmful gases and waste. Compared with other fibers such as glass fiber, aramid fiber, ultra-high molecular weight polyethylene fiber, basalt fiber has the comprehensive performances such as acid and alkali-proof, good insulation and noise performance etc. For example, not only the tensile strength of basalt fiber is better than that of the large tow carbon fiber, but the elongation of the fiber is more excellent than the corresponding of the small tow carbon fiber. And the excellent wettability exists in the resin composite because the surface of basalt Fiber is polarity. Furthermore, basalt fiber has a high shearing strength. Therefore, the polymer composite materials reinforced by basalt fiber have wide application prospects in the metallurgical, construction, aerospace, weapons and other fields for its unique performance.

Table 1 Cost comparison of basalt fiber at the different nations.

Property / Production	Density (g/m^3)	Diameter (μm)	Tensile strength (MPa)	Elasticity modulus (/GPa)	Elongation at break (%)	Price (/ton)
Russia	2600	11.0	2300	92.8	2.0	7.5~8.1
Ukraine	2800	14.6	2500	100.0	2.2	7.2~8.0
China	2560~3050	9.0~17.0	3000~4840	79.3~93.1	3.15	3.0~4.0

In order to meet the needs of modern warfare, bullet-proof composite materials could be widely developed for their excellent physical and mechanical properties such as the acoustic shocking resistance in addition to the specific strength and specific modulus, compared with metallic materials. More importantly, composite materials have lighter weight and can be easily designed into all types of weapon systems. Thus, the more and more attentions will be put into the bullet-proof composite material based on the high-performance fibers in the future.

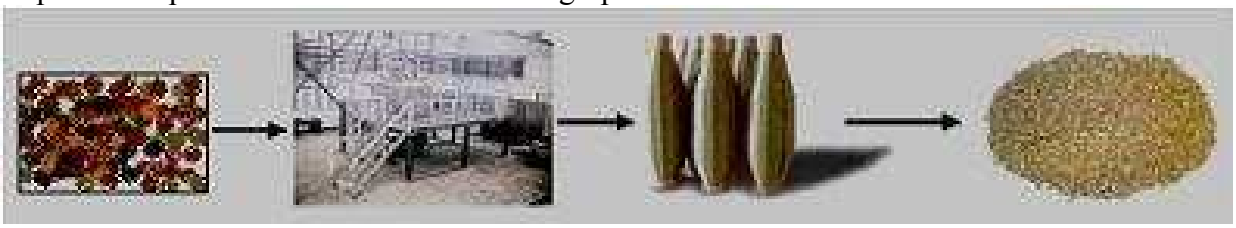

Fig. 1 Preparing process of short basalt fiber.

The Development of the High-performance Composite Materials in Bulletproof Fields

Bullet-proof composite material is a special class of composite materials that design and manufacture to prevent the penetration from all kinds of warheads, shrapnel and other ballistic. So, bullet-proof composite materials must have two functions including the bearing and shellproof ability. In general, the bullet-proof composite materials are the mixture made of the resin matrix and the high-performance fibers.

Composites Based on the Aramid Fiber. Kevlar bullet-proof composite materials are a class of ballistic composite materials that made from polymer system reinforced by aramid fiber. Because of good impact resistance, high protection performance, aramid fiber composites can be functionally designed and used with other ballistic materials or composites. Therefore, aramid fiber composites

have the versatile applications in the vehicle protection, engineering protection, armor protection, body protection and other fields. The United States firstly made Kevlar and resin composite materials into individual helmet with the excellent shellproof performance, and then turned aramid laminate and ceramic or steel plate into the composite used for tank armor protection. To install Kevlar fiber composite onto the armor steel plate, can improve anti-knock performance of vehicles. It is well known that the structure of materials will affect the shocking attenuation. So the material with the multi-layer structure can have the better shocking attenuation performance than that of the material with the double-layer structure, the material with the multi-layer structure is the good protective material with the excellent anti-knock performance.

Composites Based on the Ultra-high Molecular Weight Polyethylene Fiber. Compared with aramid fibers, ultra-high molecular weight polyethylene fibers have a slightly lower modulus and higher failure strain, and thus have higher shock resistance than aramid fibers [5]. In particular, the density of ultra-high molecular weight polyethylene fibers is much smaller than aramid fibers, so its surface density is lower than the corresponding of Kevlar in the same bullet-proof level. In addition, ultra-high molecular weight polyethylene fiber has the excellent absorbing low-impact energy property for its highly oriented molecular structure. Therefore, when the projectile hits onto the surface of composites, its surface can produce a large number of fragments, which have the lower speed than the speed of the original projectile. Among the high-performance fibers, ultra-high molecular weight polyethylene fiber is the best commercial fiber for the bullet-proof composites. In recent years, bullet-proof helmets made of the resin composite reinforced by the fiber, has become the alternative to the composite reinforced by Kevlar. The ultra-high molecular weight polyethylene can be used with a lot of resin substrates, such as polyurethane, rubber, unsaturated polyester (thermoset vinyl ester). In general, the chosen resin can not only improve the interface adhesion between fiber and matrix, but has good infiltration for the fiber. On the other hand, the curing temperature of the chosen resin is not higher than 120°C. It can be explained that ultra-high molecular weight polyethylene fibers will show the rubbery state above the melting point (150°C), and melts have the poor scalability and the larger contraction after heating, which have a great influence on properties of the fiber. However, due to the producing cost of ultra-high molecular weight polyethylene as the commercial product, the application of ultra-high molecular weight polyethylene is not rich than Kevlar, but it will become a promising light and high-efficient bulletproof material.

Composites based on Continuous Basalt Fiber. Continuous basalt fiber have excellent performances, and is the fourth high-tech fibers after following carbon fiber, aramid, ultrahigh molecular weight polyethylene fiber. Both basalt fibers and the corresponding composites have be widely used in the field of national defense including the aerospace, rockets, missiles, fighter planes, nuclear submarines and warships, tanks and other equipment. It can promote the upgrading of military weapons and equipment. In some areas, carbon fiber also can be substituted for continuous basalt fiber, which is lower cost. Currently, numerous researches for composites based on the basalt fiber have been put into all kinds of fields including the fire environment, petrochemical and electronics.

Impact Mechanism for the Composites Reinforced by the Fiber. About the main impact mechanism of composite material reinforced by the fiber [6], it could be said that the impact onto the surface of plastic sheet produces the stress wave, which can transmit along the axis and vertical direction of fibers. And at the crossing of the fibers, the stress wave will transfer to the adjacent fiber. By the mechanism, composite material reinforced by the fiber can transfer and absorb the energy of the impact. For instance, in terms of the plastic sheet, this process can be inhibited by the resin matrix.

Advanced Composite Materials in the Bulletproof Field

Preparation of High-performance Bulletproof Helmet by Molding Method. The materials (aramid fiber, basalt fiber, ultrahigh molecular weight polyethylene) and the coupling agent were put into supersonic flow solid-phase reactor (Fig.2 shows the principle for the supersonic flow solid phase reactor) [7], and then the high-performance helmet were be produced by the molding method.

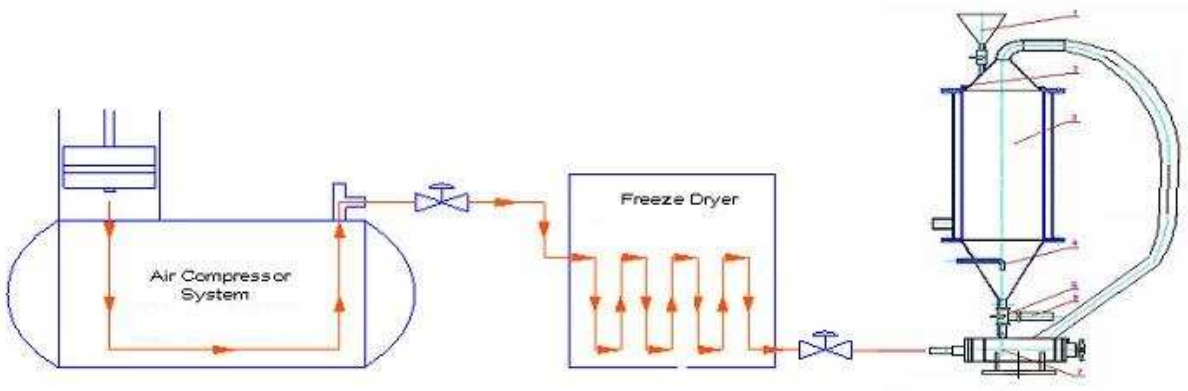

Fig. 2 Scheme of solid-phase reactor with supersonic airflow
1) Charging port; 2) Outlet; 3) Cycle collector; 4) Jet port; 5) Ball valve;
6) Discharging port; 7) Reactor

Preparation of High-performance Bulletproof Glass by Injection Molding. After the surface treatment, the fibers (aramid fiber, basalt fiber, ultrahigh molecular weight polyethylene) according to a certain proportion were weaved the reinforced network. And then poly acrylic acid was injected into the above reinforced network. Finally, high-performance bulletproof glass was obtained. The shot test for the bulletproof glass will be reported in no distant future in our next works.

Conclusion

Because composite materials can make up for the shortcoming of the single material which was be used widely, composite materials will play an increasingly important role in the national defense and the development of the society. Researches about composite materials based on the fiber and resin can speed product innovation in the course of social development. Due to its special physical and chemical properties, composite materials reinforced by the fiber will become popular in all kinds fields. Particularly, composite materials are indispensable in the special industries such as bullet-proof and explosion-proof products, which can be used for aircraft and automobile cockpit wall and door, the troops, the armed police, public security, the bank's security guards and other special equipment. Thus, composite materials have the latent economic benefits and the good prospects in the future.

Acknowledgements

This work was supported financially by the Local Fund for ChongQing University of Arts and Sciences (Y2010CL44).

References

[1] X. Xie: Industrial Textiles Vol. 185 (2006), p. 31

[2] X. Wang and X. Wei: China Xian Jian Vol. 5 (2007), p. 72

[3] Y. Zhang: Functional Textiles and Nanotechnology Applications Vol. 4 (2009), p. 16

[4] L. Wang: FRP/Composites Vol. 6 (2000), p. 22

[5] C.J. Guo: Engineering Plastics Applications Vol. 37 (2009), p. 75

[6] H.E. Yang: New Chemical Materials Research Vol. 30 (2002), p. 28

[7] Y.H. Cai, R.F. Peng, J. Zuo and S.J. Chu: China Surfactant Detergent & Cosmetics Vol. 37 (2007), p. 102