COMAT

The 9th International Conference on Advanced Composite Materials Engineering

Transilvania University of Brasov
FACULTY OF MECHANICAL ENGINEERING

17-18October 2022

ASPECTS REGARDING THE MECHANICAL CHARATERISTICS OF THE CARBON-KEVLAR COMPOSITE MATERIALS

Ursache S.[1], Cerbu C.[*1], Hadăr A.[2], Dumbravă F.[1]

1.Department of Mechanical Engineering, Faculty of Mechanical Engineering, Transilvania University of Brasov, B-dul Eroilor, No. 29, Brasov 500036, Romania, stefania.olareanu@unitbv.ro, florin.dumbrava@unitbv.ro

2.Department of Strength of Materials, Faculty of Industrial Engineering and Robotics, Politehnica University of Bucharest, 313 Splaiul Independentei, 060042 Bucharest, Romania; anton.hadar@upb.ro

[*]Corresponding author: cerbu@unitbv.ro

Abstract: *Carbon-Kevlar hybrid composite material structures are used more and more in applications in the automotive, aerospace and military industries. For this reason, to numerically simulate the distribution of stresses and strains in such structures mechanically loaded, it is necessary to know the mechanical properties of such composite materials. It has also become a necessity to know the effects of the hybridization of the two types of fibers (carbon fibers and Kevlar) on the impact properties. For this reason, the article is a short review of the specialized literature regarding the following properties of carbon-Kevlar composites: tensile stress, tensile modulus, flexural strength, flexural modulus, impact properties in impact tests of low speed. Some applications of the plates made of carbon or hybrid carbon-Kevlar composites are highlighted in the last part of the paper.*

Keywords: *hybrid composite; carbon fibers; Kevlar fibers; mechanical properties.*

1. INTRODUCTION

Composite materials are composed of at least two or more different components that are not soluble in each other. One component is called the reinforcing material and the other is called the matrix. The strength and hardness of the composite materials are mainly provided by the reinforcing materials, while the matrix provides corrosion resistance, ductility and toughness. The mechanical, physical and chemical properties of the composite materials strongly depend on the type, shape, size and volume content of the reinforcing materials and the type of matrix. The most common reinforcing materials, mainly used with polymer matrix, are glass fibers, graphite or carbon fibers, aramid fibers and boron fibers [1].

Among the fibre reinforced polymer matrix composites, epoxy matrix hybrid composites have gained importance in the energy field because the hybrid composites combine low cost with high mechanical properties compared to composite materials reinforced with only one of the reinforcing fibers used in hybridization. Composites reinforced with carbon-Kevlar hybrid fabrics are a good example of high performance properties in terms of high strength-to-weight and stiffness-to-weight ratios, making them more practical towards load-bearing applications in automotive and aerospace industries. These lightweight composite materials may be exposed to low velocity impact loadings during manufacture, normal operation, maintenance and so on [2,3].

Kevlar is a synthetic fibre with a high-modulus, used primarily in fibre optic cable, textile processing, ropes, cables, plastic reinforcement and composite applications for aerospace, automotive, defence, energy, consumer, electronics, medical, and heavy industries. The tensile strength of the Kevlar fibers, are comparable with the one of the carbon fibers. Kevlar fibers are characterized by a modulus of elasticity which is between the ones corresponding to the glass and carbon fibers and a lower density than the both. Kevlar fibers are used for high-performance composite applications where lightweight, high strength and stiffness, resistance to fatigue and stress rupture and especially the impact performance are important. However, Kevlar fibers are sensitive to UV (ultraviolet) rays [4-6]. Due to their high impact strength the Kevlar composite materials are recommended for the ballistic protection applications such as bulletproof vests or protective panels.

Carbon fibre filament is made up of the carbon atoms organized into a crystalline structure. Because of its very high stiffness and strength, it is widely used in the aerospace and automotive industries. It has one of the highest strength-to-weight ratios in existence — higher than both steel and titanium. The main characteristics of the carbon fibre material are: high stiffness, high strength-to-weight ratio, electricity conductor, corrosion resistance, high melting temperature, and high stiffness until fracture. These characteristics of the carbon fibers allow it to be used as a metal replacement in applications where weight saving is very important [7].

In applications where structures having reduced thickness, low weight and high strength are required, the use of the carbon-Kevlar hybrid composite material is one of the ideal solutions because it combines the advantages of the individual components. In addition, the simultaneously mitigating of their less desirable qualities is achieved by using these two types of fibers as reinforcement materials [8-10].

2. MECHANICAL CHARACTERISTICS OF THE HYBRID COMPOSITE REINFORCED WITH CARBON AND KEVLAR FIBERS

1.2. Tensile and bending mechanical characteristics

After a review of the specialized literature, in Table 1 it is summarized the mechanical characteristics experimentally obtained in tensile and flexural tests, for the hybrid carbon-Kevlar composite materials in two cases of hybridization: multi-layered hybridization (different reinforcing fibers in each layer); reinforcement with hybrid reinforcement fabric of all layers.

Table 1. Mechanical characteristic of the hybrid composites reinforced with the both carbon and Kevlar fibers

Composite structure*	**Young's modulus *E* (GPa)**	**Tensile strength σ_{max} (GPa)**	**Flexural strength σ_{max} (GPa)**	**Poisson's ratio ν_{12}**	**Transversal modulus G_{12} (GPa)**	**References**
2K/8C/2K	-	1.25	1.15	-	-	[11]
3C/2K/2C/2K/3C	-	-	0.954	-	-	[11]
8CK plain	11.34	-	-	0.09	1.49	[12]
8CK twill	35.25	4.07	4.18	0.141	-	[13]
CKCKC	-	2.0	0.43	-	-	[14]
KCKCK	-	2.4	0.50	-	-	[14]
KKCKK	-	2.6	0.60	-	-	[14]
CCKCC	-	2.7	0.46	-	-	[14]

*CKCKC – hybrid composite material with 5 layers, C-carbon fibers, K-Kevlar fibers; 8CK plain – composite material reinforced with 8 layers of carbon-Kevlar plain hybrid fabric; 8CK twill – composite material reinforced with 8 layers of carbon-Kevlar twill hybrid fabric; 2K/8C/2K – composite hybrid material reinforced with 2 layers Kevlar49 fibers, 8 layers carbon HT fibers and 2 layers Kevlar49 fibers; 3C/2K/2C/2K/3C – composite hybrid material reinforced with 3 layers carbon HT fibers, 2 layers Kevlar49 fibers, 2 layers carbon HT fibers, 2 layers Kevlar49 fibers and 3 layers carbon HT fibers.

Considering Table 1 it can be easily observed that the experimental results obtained for composite materials reinforced with hybrid fabric are approximately with 50% higher than the ones obtained for the hybrid composite materials obtained by multi-layered hybridization, in terms of the tensile strength. The hybrid carbon-Kevlar fabric combines in a single layer, the high stiffness of the carbon fibers with the high tenacity of the Kevlar fibers. The flexural strength is also the highest for the composite material reinforced with hybrid carbon-Kevlar woven fabric.

1.3. Impact properties

Over the years in literature, several advantages and disadvantages of the hybridization of the carbon and Kevlar fibers in the composite structure have been observed, in special regarding the performances of the hybrid composite material subjected to impact tests. Hybrid composite materials reinforced with carbon and Kevlar fibers are characterized by high tensile strength, increased stiffness due to the carbon fibers and high impact resistance due to the Kevlar fibers. Some of the studies focused on the influence of replacing the carbon fibers with Kevlar fibers into the structure of a composite material, taking into account the impact performance of the Kevlar fibers, but also their resistance at high temperatures. In order to analyse the hybridization effect, in Table 2 it is rendered some results obtained in other research published [16], concerning the impact properties for composite materials containing two layers reinforced with carbon and Kevlar fibers [15,16].

Table 2. Absorbed energy in impact tests for composite materials reinforced with carbon fibers and/or Kevlar fibers [16]

Composite structure*	**Dimensions l x L (mm x mm)**	**Absorbed energy at impact (J)**
K-K	100 x 100	2.8
C-C	100 x 100	2.4
C-K	100 x 100	3.1
K-C	100 x 100	3.1

**#-# – two layered composite material; C-carbon fabric; K-Kevlar fabric.*

The experimental results have shown, that the hybridization of the carbon fibers and Kevlar fibers in the composite structure, has significantly improved the mechanical properties of the composite material.

3. STRUCTURAL APPLICATIONS OF THE COMPOSITE REINFORCED WITH CARBON AND KEVLAR FIBERS

In civil engineering for the consolidation of structural elements made of concrete, wood, brick and steel, the usage of composite materials has gain interest over the years, due to their several advantages. Pultruded fibre reinforced polymer (FRP) composites have become the attractive alternative for steel in civil engineering owing to high strength-to-weight, stiffness-to-weight and superior fatigue and corrosion resistances.


(a)

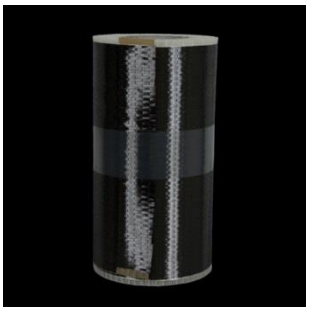
(b)

Figure 1: Materials used to strengthen the concrete beams: (a) CFRP pultruded plates used for beam reinforcement [17], and (b) woven sheets used for manufacturing of CFRP [21]

The plates made of carbon fibre reinforced polymer (CFRP) (Figure 1) [17] is a flat, hardened sheet that is manufactured by pulling carbon fibers through epoxy and thermally treated in factory conditions. CFRP plates are suitable for strengthening structures with flat surfaces. For strengthening curved sections, woven CFRP sheets (Figure 1) may be applied via a wet lay-up process. The CFRP are mainly used for consolidating and reinforcing concrete and wood structural elements [18-20].

Nowadays, the Kevlar fibers also became very popular among the civil engineers, due to their impact performance. Sheets made of Kevlar woven fabric impregnated with epoxy resin are widely used to improve the impact response of the structural elements [14].

More and more often, civil engineers prefer FRP for strengthening the structural elements and also for improving their mechanical parameters. The FRP materials can be used on the surface of the structural element or directly inserted into the element structure. For structural elements made of concrete, CFRP bars has become a promising option for replacing steel reinforcement bars. As a result of drawback of steel, the idea of using Kevlar fabric as a strengthening material appeared by using an epoxy bonding agent.

Mostly, concrete beams fail in two ways: flexural failure and shear failure. Bonding of the carbon or Kevlar fabrics with epoxy resin to the beam surface subjected to tensile stresses can improve the mechanical performance.

Table 3. Results obtained for concrete beams strengthen with composites in bending [22,23]

Beam structure	Beam size l x b (mm x mm)	Failure load (kN)
Concrete Beam	230 x 380	190
Concrete beam with laminated bottom with 2 CFRP sheets	230 x 380	263
Concrete beam with laminated bottom with 3 CFRP sheets	230 x 380	287
Concrete beam	150 x 200	70.5
Concrete beam with laminated bottom (1 Kevlar layer)	150 x 200	84.06
Concrete beam with laminated bottom(2 Kevlar layers)	150 x 200	97.07

In Table 3 are presented some comparative experimental results for typical rectangular concrete beams subjected to flexural tests.

Considering the data from Table 3, it can be easily observed, that the flexural strength is increased up to 51 % for the concrete beams strengthened with three laminated CFRP sheets located at the bottom of the beam and up to 37 % for the concrete beams strengthened with laminated composite reinforced with two layers of Kevlar fabric. As a conclusion of the comparison of the experimental results obtained in flexural tests, it can be noted that greatest flexural strength can be obtained and crack growth can be controlled by the addition layers at the surface of the concrete beams, subjected to tensile stresses.

Recent studies have also focused on understanding of the effects of the hybrid composites materials on the structural behaviour of the concrete beams, subjected to flexural tests. In the experimental flexural tests

conducted on concrete beams strengthened with hybrid carbon-Kevlar laminate, it has been shown, that the ultimate load capacity increased with approximately 4 % compared to reference concrete beam [24].
Also, some studies focused on the test results of concrete beams strengthened at the top, but also at the bottom faces, with carbon and Kevlar composite laminates and subjected to impact loading. In regular reinforced concrete beams without shear reinforcement, the beam would fail immediately after the formation of diagonal cracks. In case of concrete beams strengthened with composite materials, it has been remarked that the laminate is preventing the cracks from opening and the beam could still resist to further impact loading [25].

4. CONCLUSIONS

This paper is a short review which summarizes and compares the mechanical properties of the carbon-Kevlar composite materials considering the results reported by other researchers in literature in order to highlight the effects of the hybridization of the carbon and Kevlar fibers.
It can also be concluded from literature that the composite materials could play an important role in the structural behaviour of the concrete beams. Furthermore, the type of the fibers used to reinforce the composite materials and the number of layers applied to strengthen the beam, influences the types of failure modes as well.

References

[1] Sismanoglu S., Gungor A., Aslan B., Sen D., The synthesis and mechanical characterisation of laminated hybrid-epoxy matrix composites. International Journal of Mining Reclamation and Environment 2017, 31, 382-388, doi:10.1080/17480930.2017.1326076.

[2] Ravishankar B., Nayak S.K., Kader M.A., Hybrid composites for automotive applications - A review. Journal of Reinforced Plastics and Composites 2019, 38, 835-845, doi:10.1177/0731684419849708.

[3] Priyanka P., Dixit A., Mali H.S., High-Strength Hybrid Textile Composites with Carbon, Kevlar, and E-Glass Fibers for Impact-Resistant Structures. A Review. Mechanics of Composite Materials 2017, 53, 685-704, doi:10.1007/s11029-017-9696-2.

[4] Singh T.J., Samanta S., Characterization of Kevlar Fiber and Its Composites: A Review. Materials Today-Proceedings 2015, 2, 1381-1387, doi:10.1016/j.matpr.2015.07.057.

[5] Priyanka P., Dixit A., Mali H.S., High strength Kevlar fiber reinforced advanced textile composites. Iranian Polymer Journal 2019, 28, 621-638, doi:10.1007/s13726-019-00721-7.

[6] Kumar S., Gupta D.S., Singh I., Sharma A., Behavior of Kevlar/Epoxy Composite Plates Under Ballistic Impact. Journal of Reinforced Plastics and Composites 2010, 29, 2048-2064, doi:10.1177/0731684409343727.

[7] Simil T.S., Midhun A.J., James V.J., Lakshmidasan S.K., Usha K.M., Rakesh S., Study on Mechanical Properties of Carbon-Carbon Composites Developed for Aerospace Applications. In Proceedings of the National Conference on Carbon Materials (CCM) - Carbon Materials for Energy Harvesting, Environment, Nanoscience and Technology (Carbon Materials), Mumbai, INDIA, Nov 01-03, 2012; pp. 163-167.

[8] Sanjay M.R., Arpitha G.R., Yogesha B., Study on Mechanical Properties of Natural - Glass Fibre Reinforced Polymer Hybrid Composites: A Review. Materials Today-Proceedings 2015, 2, 2959-2967, doi:10.1016/j.matpr.2015.07.264.

[9] Xu D., Cerbu C., Wang H., Rosca I.C., Analysis of the hybrid composite materials reinforced with natural fibers considering digital image correlation (DIC) measurements. Mechanics of Materials 2019, 135, 46-56, doi:10.1016/j.mechmat.2019.05.001.

[10] Pincheira G., Canales C., Medina C., Fernandez E., Flores P., Influence of aramid fibers on the mechanical behavior of a hybrid carbon-aramid-reinforced epoxy composite. Proceedings of the Institution of

Mechanical Engineers Part L-Journal of Materials-Design and Applications 2018, 232, 58-66, doi:10.1177/1464420715612827.

[11] Dorey G., Sidey G.R., Hutchings J., Impact properties of carbon fibre/Kevlar 49 fibre hydrid composites

[12] Haidzir H., Majid D.L., Rafie A.S.M., Harmin M.Y., Modal Properties of Hybrid Carbon/Kevlar Composite Thin Plate and Hollow Wing Model Applied Mechanics and Materials Vols. 446-447 (2014) pp 597-601 2013.

[13] Cerbu C., Ursache S., Botis M.F., Hadăr A., Simulation of the Hybrid Carbon-Aramid Composite Materials Based on Mechanical Characterization by Digital Image Correlation Method. Polymers 2021, 13, doi:10.3390/polym13234184.

[14] Karthik K., Rajamani D., Raja T., Subramani K., Experimental investigation on the mechanical properties of Carbon/Kevlar fibre reinforced epoxy LY556 composites. Materials today: Proceedings 2021.

[15] Gustin J., Joneson A., Mahinfalah M., Stone J., Low velocity impact of combination Kevlar/carbon fiber sandwich composites. Composite Structures 2005, 69, 396-406, doi:10.1016/j.compstruct.2004.07.020.

[16] Jang B.Z., Chen L.C., Wang C.Z., Lin H.T., Zee R.H., Impact resistance and energy-absorption mechanisms in hybrid composites. Composites Science and Technology 1989, 34, 305-335, doi:10.1016/0266-3538(89)90002-x.

[17] SIKA. Lamele Sika® CarboDur®. Fisa tehnica de produs, Editia 21/01/2008, Nr. identificare:02 04 01 01, Lamele Sika® CarboDur®.

[18] Han Y., Liu H.B., Guo T., Analysis of Bending Stiffness of Reinforced Concrete Beams Strengthened with Carbon Fiber Sheet. In Proceedings of the International Conference on Civil, Architectural and Hydraulic Engineering (ICCAHE 2012), Zhangjiajie, Aug 10-12, 2012; pp. 2887-2890.

[19] Takeda K., Mitsui Y., Murakami K., Sakai H., Nakamura M., Flexural behaviour of reinforced concrete beams strengthened with carbon fibre sheets. Composites Part a-Applied Science and Manufacturing 1996, 27, 981-987, doi:10.1016/1359-835x(96)00059-0.

[20] Wang W.W., Li G., Experimental study and analysis of RC beams strengthened with CFRP laminates under sustaining load. International Journal of Solids and Structures 2006, 43, 1372-1387, doi:10.1016/j.ijsolstr.2005.03.076.

[21] SIKA. Available online: https://aus.sika.com/en/construction/structural-strengthening/shear-strengthening/sikawrap-230-c.html (accessed on

[22] Pandulu G., Jayaseelan R., Jeganathan S., Performance of RCC Beams Laminated with Kevlar Fabric. Jordan Journal of Civil Engineering 2020, 14, 225-237.

[23] Alagusundaramoorthy P., Harik I.E., Choo C.C., Flexural behavior of R/C beams strengthened with carbon fiber reinforced polymer sheets or fabric. Journal of Composites for Construction 2003, 7, 292-301, doi:10.1061/(asce)1090-0268(2003)7:4(292).

[24] Cakir F., Acar V., Aydin M.R., Aksar B., Yildirim P., Strengthening of reinforced concrete beams without transverse reinforcement by using intraply hybrid composites. Case Studies in Construction Materials 2021, 15, doi:10.1016/j.cscm.2021.e00700.

[25] Tang T.P., Saadatmanesh H., Behavior of concrete beams strengthened with fiber-reinforced polymer laminates under impact loading. Journal of Composites for Construction 2003, 7, 209-218, doi:10.1061/(asce)1090-0268(2003)7:3(209).