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Review on metal matrix composites for marine applications

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Abstract

This paper reviews the possible Metal Matrix Composites of Grade 5 Titanium alloy (Ti-6Al-4V) with Kevlar® and carbon fiber and their uses. These composites can be implemented in various industries like Marine industry as a hull material for naval warships, in the aerospace industry, in the defense sector and for the fabrication of various structures that require high strength and impact bearing capacity. Effective utilization of these materials in the above industries reduces the cost and size of the materials while increasing the performance in terms of strength, corrosion resistance, weldability and fabricability among other things. Due to the low density of the materials used, the performance of the vessels in terms of speed and maneuverability is also bound to improve.Fabrication of the composites is to be done by sandwich paneling using isophthalic resins. The various material properties of the composite such as hardness, modulus, chemical composition, adhesion and morphology are to be analyzed. The work deals with the comparison of the above mentioned composites with the conventionally used shipbuilding materials. Thevarious results, on analysis, help us to infer the importance and efficacy of such novel composites in this modern age of mechanical engineering. These composites give us the combined advantages of strength and weightlessness coupled with the ability to resist corrosion thereby making it the perfect choice for various impact resistant structures with particular consideration towards marine structures.

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*Keywords:*Titanium; Kevlar®; Carbon fiber;Composite; Sandwich Panelling; Hardness; Weldability; Corrosion resistance; marine structures; Metal Matrix Composites

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1. Introduction

This paper reviews the experimental analysis of various composites of Grade 5 Titanium with fibers like Kevlar® and carbon fiber and their hybrid weave. A composite material can be defined as a material consisting of two or more phases embedded in a continuous phase. The discontinuous phase is reinforcement and continuous phase is the matrix. Materials form an integral part of the way composite structures perform. They are broadly categorized into three types:

- Particulate
- Fiber Reinforcement
- Structural

In general, these composites are made of 3 parts comprising core, resin and reinforcement. Carbon, aramid fibers and other specialty reinforcements are used in the marine field where structures are highly engineered for optimum efficiency. Architecture and fabric finishes are also critical elements of correct reinforcement selection. Resins are the bonding materials which are used to attach the core materials with reinforcements. They are of two types, viz. Orthophthalic and Isophthalic of which the latter exhibits better mechanical resistance, chemical properties and increased resistance to water permittivity. [9]

1.1. Structure

Metals possess much higher modulus than human hard tissues and ceramics are not only stiffer but also more brittle than natural mineralized tissues. Polymers are typically more ductile but not stiff and strong enough to be used to replace hard tissues in load-bearing applications. Emerge of composites allows researchers to design materials that may attain combinations of mechanical properties similar to those of biological hard tissues [1].

Marino AA et al studied the requirements for reinforcement and polymer materials to be used in these applications are multifold. The first requirement for both constitutes is biocompatibility whichincludes that the material and its additives are accepted by the surrounding tissue without toxic, inflammatory or allergic reaction. Other requirements include fatigue resistance, resistance to ageing in biological media, dimensional stability, being sterilizable by standard methods without losses of properties. Carbon fibre is the most widely used reinforcing material and its good biocompatibility has been confirmed [2].Kevlar® is also a widely used fibre for high performance impact resistance applications. They are used in many marine applications like hull materials of small boats and also in the defense sector as impact resistant structures. It is predominantly used in body armor applications and bullet proofing of vehicles used in the defense department and the vehicles of VIPs. *E. Eisenbarth* et al analyzed the effect of the material composition on the cell shape of the Titanium alloys. In order to determine the cell shape, he defined the shape factor which was calculated from the area covered by the cells and from their circumference. To determine the influence of the surface structure, substrate platelets of cp-titanium, TiAl6V4 and TiTa30 were ground. Onto these specimens human gingival fibroblasts of the 5th to 7th passages were cultivated. After a culture time of two days the cells were fixed and stained. The number of orientated cells was determined as a function of the surface roughness of the substrate. The number of orientated cells was shown to increase — independent of the material — with increasing roughness of the ground substrate [3].

2. Mechanical properties of Kevlar

Ming Cheng and Weinong Chen studied the mechanical properties of Kevlar and found that tensile stress-strain response in the axial direction is linear and elastic until failure [4]. For a linear elastic, transversely isotropic and homogeneous material, which is the case of the Kevlar KM2 fibers, the longitudinal shear modulus is given by,

$$G = \frac{\pi M\,[8(D_o^2 - D_i^2) + 32/3\, h^2]\, lf^2}{d^4}$$

Where, 'M' – Mass of the Washer

'D_o' and 'D_i' – Outer and Inner diameters of the washer

'h' – Thickness of the washer
'l' – Length of the fiber
'f' – Oscillation Frequency of the Torsional Pendulum
'd' – Diameter of the fiber

2.1 Bismaleimide Composites

*T.K. Lin*et all examined the Thermal properties of Bismaleimide composites/Kevlar – Fiber composites by using differential scanning calorimetry, thermo-gravimetry and thermo-mechanical analysis.Kelvlar 49 ®bers were cleaned successively with 1,2- dichloroethane, methanol and deionized water and then vacuum-dried. Some of the fibers served as `experimental'16 mm x 11 mm x 2 mm, with a span to thickness ratio of 5. The condition of the test specimen and the test in an enclosed space was maintained at 23°C and 50% relative humidity. The specimen was tested at a rate of cross-head movement 0.5 mm/min [5]. The interlaminar shear strength, , for the short-beam test is calculated by the expression ,

$$\tau = \frac{3p}{4Bh}$$

Where, 'p' – Maximum Load
'B' – Width of the specimen
'h' – Thickness of the specimen

Gang Li et all studied the Interface correlation and toughness matching of phosphoric acid functionalized Kevlar fiber and epoxy matrix for filament winding composites. In this analysis, Kevlar fiber was functionalized with phosphoric acid (PA) of different concentrations. The monofilament tensile strength was constant with less than 40 wt % PA functionalization. The amount of surface oxygen functional groups was maximal at 20 wt % PA-functionalized Kevlar fiber, in which the surface roughness of functionalized fiber approached to that of as-received fiber.The interfacial shear strength (IFSS) and inter-laminar shear strength (ILSS) were 76 and 79 MPa, respectively and the Microstructure analysis revealed that better interfacial adhesion resulted in higher improvement of composite mechanical properties [6].

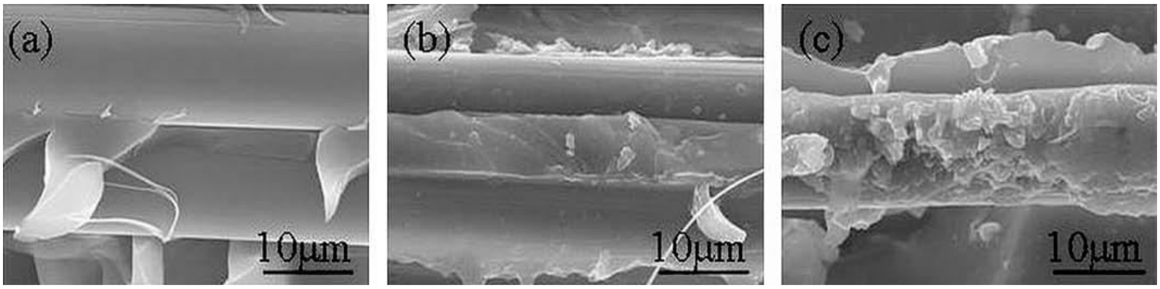

Fig. 1. SEM images of split surface of Kevlar fiber composites of (a) DGEBA/MeHHPA/as-received fiber, (b) DGEBA/MeHHPA/PA-functionalized fiber, (c) DGEAC/DGEBF/DDM/ DETDA/PA-functionalized fiber.[6]

*Sirui Fu*et all examined the combined effect of interfacial strength and fiber orientation on mechanical performance of short Kevlar fiber reinforced olefin block copolymer [7]. They showed that, pristine Kevlar fiber can be used to reinforce OBC, significantly improved tensile yield strength and modulus can only be obtained by introducing hydrolyzed or polydopamine-coated Kevlar® fiber using a small amount (3 wt.%) of MA-g-PP as the reactive compatibilizer. It clearly indicates the key role of interfacial interaction between Kevlar fiber and OBC matrix in improving mechanical properties of the composites. It clearly demonstrated that, the mechanical performance of the short Kevlar fiber reinforced OBC can be greatly improved by enhancing interfacial strength and fiber orientation using green surface modification strategy and conventional melt-processing technology.

C.Y. Yue et all studied the Effects of heat treatment on the mechanical properties ofKevlar-29 ® Fibre. In this analysis, The single-Kevlar® Fibre tensile test was used to evaluate the mechanical properties of Kevlar-29® subjected to heat treatment at 100, 200 and 300°C fordurations between 2 to 8 h. The dimension of Kevlar-29®Fibres was thermally stable and did not vary with heat treatment. The Kevlar® Fibre tensile strengths and failure strains decreased as the treatment temperature was increased [8].

3. Mechanical Properties of Ti-6Al-4V

Table.1: Mechanical Properties of Grade 5 Titanium Alloy [10-13]

Density	4.43 g/cc
Hardness, Brinell	334
Hardness, Knoop	363
Hardness, Rockwell C	36
Hardness, Vickers	349
Tensile Strength, Ultimate	950 MPa
Tensile Strength, Yield	880 MPa
Elongation at Break	14 %
Reduction of Area	36 %
Modulus of Elasticity	113.8 GPa
Compressive Yield Strength	970 MPa
Notched Tensile Strength	1450 MPa
Ultimate Bearing Strength	1860 MPa
Bearing Yield Strength	1480 MPa
Poisson's Ratio	0.342
Charpy Impact	17 J
Fatigue Strength	240 MPa
Fatigue Strength	510 MPa
Fracture Toughness	75 MPa-m½
Shear Modulus	44 GPa
Shear Strength	550 MPa

A.S.Oryshchenko et al tested the influence of Titanium alloys in the ship building. In this Titanium ingots containing 5% Aluminum were used. These Titanium ingots were melted using spongy Titanium with an ultimate Tensile Strength of 480 MPa. Also, Aluminum and Molybdenum equivalents were used for determining the permissible content of alloying elements to predict the various properties. The governing equation was given as,

$$[Mo]_{eq} = [\%Mo] + [\%v]/1.4 + [\%Nb]/3.3 + [\%W]/2.0 + [\%Cr]/0.6 + [\%Fe]/0.6$$

$$[Al]_{eq} = [\&Al] + [\%Sn]/3 + [\%Zr]/6 + [\%O]/0.1 + [\%C]/0.085$$

The above equation shows that Aluminum equivalents is the sum of equivalent concentrations of α-stabilizers and Molybdenum equivalents is the sum of equivalent concentrations of β-stabilizers[14].This analysis yielded a good result for the implementation of Titanium alloys in marine applications.

J.G.Bakuckas et al monitored the damage growth in Titanium Matrix composites using Acoustic Emission. In this, the damage growth in TMC was studied using various optical techniques like long focal length, high magnification microscope. The Acoustic Emission technique was used to locate the damage growth in between the matrices [15].

The damage growth arrival times was given by the following mathematical equation [15],

$$X = \ell \left(\frac{t_2 - t_1}{\Delta t_{gage}} \right)$$

Where, ‘X’ – Damage Growth

‘t_1’ – Time of arrival at sensor 1

‘t_2’– Time of arrival at sensor 2

‘Δt_{gage}’ - Difference in the arrival time

‘l’- Distance between the AE sensors

Jiaxu Wang c et all investigated the Rolling contact fatigue (RCF) behaviors of titanium matrix composites (TiB + TiC)/Ti–6Al–4Vincluding the micro-structural variables, the stress distribution and the RCF life.The influence of reinforcements onstress distribution is studied using the analyses of subsurface stress distributions based on an approximatenumerical method, in which the reinforcement distributions are considered.The results reveal that the existence of reinforcements causes RCF life reduction due to the stress concentration in andaround the reinforcements. [16]

Table.2: Elastic parameters of Ti–6Al–4V and reinforcements [17-20].

Materials	**Elastic modulus E (GPa)**	**Poisson’s ratio m**
Ti–6Al–4V	113.8	0.342
TiC	400–460	0.18–0.2
TiB	371–485	0.14–0.15

Yu-Chi Lin analyzed the effect of different methods to add nitrogen to titanium alloyson the properties of titanium nitride clad layers. In his thesis, titanium nitride (TiN) reinforcements were synthesized in situ on the surface of Ti–6Al–4V substrates with gas tungsten arc welding (GTAW) process by different methods to add nitrogen,nitrogen gas or TiN powder, to titanium alloys. The results showed that if nitrogen gas was added to titanium alloys, the TiN phase would be formed. Also Dry Sliding Wear test was conducted which showed that, the wear performance of the Ti–6Al–4V alloy specimen coated with TiN or TiN + TiNx clad layers were much better thanthat of the pure Ti–6Al–4V alloy specimen [21].

Table.3: Experimental elastic modulus and hardness values from the load–displacement curve of the Nano indenter for four kinds of phases [21]

Phase	**Elastic modulus at max load (GPa)**	**Hardness at max load (GPa)**
TiN (Single phase)	227	18.16
TiN (In dual phases)	225	17.43
TiNx (Out dual phases)	194	12.42
Inter-dendritic areas (α′-Ti martensitic structure)	159	8.18

4. Mechanical Properties of Carbon Fiber

Isidor M. Djordjevi et al studied the Non-linear elastic behaviour of carbon fibres of different structural and mechanical characteristics of it. In their thesis, 5 types of poly-acrylonitrile, PAN, based carbon fibres, differing in modulus, breaking strain and in crystallite orientation, have been studied. It was revealed that, It was found that the value of the coefficient of non-linear elasticity of the fibre crystallite structures.It was also found that the value of the coefficient of non-linear elasticity is lowerin fibres of higher modulus and that it decreases with decreasing interlayer spacingof the fibre crystallite structure and the width at maximum intensity of the 002 reflection on X-ray diffractograms. Simultaneously, the apparent lateral dimension of the crystallites increases [22].

Zhishuang Daia et al investigated about the effect of heat treatment on carbon fiber surface properties and fibers/epoxy interfacial adhesion since, Carbon fiber surface properties are likely to change during the moulding process of carbon fiber reinforced matrix composite, and these changes could affect the infiltration and adhesion between carbon fiber and resin. In this experiment, X-ray photoelectron spectroscopy (XPS) was used to detect the activatedcarbon atoms, which are defined as the carbon atoms conjunction with oxygen and nitrogen. Surface chemistry analysis showed that the content of activated carbon atoms on treated carbon fiber surface, especially those connect with the hydroxyl decreased with the increasing heat treatment temperature. So, the solution provided by *Zhishuang Daia* et all is that, in order to improve the performance of carbon fiber reinforced resin matrix composite, thesurface energy should be raised, the polar surface energy of carbon fiber and resin should be modified to be closed. [23] Vijaya Ramnath et al [24, 25, 27] reviewed and investigated mechanical behavior of aluminium metal matrix composites and concluded that addition of reinforcement increases mechanical behavior of composites. Subramaniya Reddy et al [26] investigated of Mechanical Properties of Aluminium6061-Silicon Carbide, Boron Carbide Metal Matrix Composite and found that if boron content increases the hardness of composite also increases.

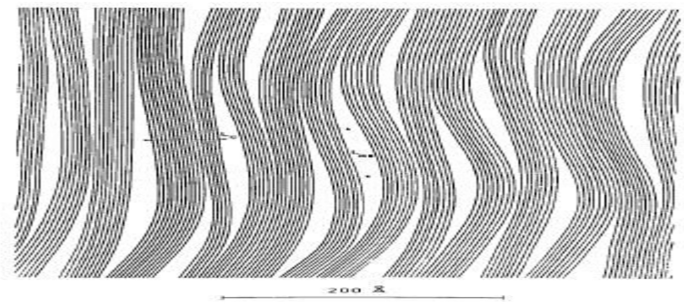

Fig 2: Microstructure of PAN carbon fibers (Reproduced with permission from International Union of Crystallography (http://journals.iucr.org/), © 1970

He also showed that, optimizing the carbon fiber microstructure can improve carbon fiber strength through decreasing its flaw sensitivity. The carbon fiber microstructure is dependent on the precursor morphology andprocessing conditions. So, the research in these two areas will aid in the development of carbon fibers with improved performance. Many polymers, such as PE and lignin, have been evaluated as low cost carbon fiber precursor materials. By doing this, it will pave way for low cost carbon fibers.

References

[1]. Y.Z. Wan a, Y.L. Wang a, F. He a, Y. Huang a,*, H.J. Jiang b, “Mechanical performance of hybrid bismaleimide composites reinforced with three-dimensional braided carbon and Kevlar fabrics”, Composites Part A – 38, (2007), pp 495-504

[2]. Marino AA, Fronczak S, Boudreaux C, Liles DN, Keating EM, Albright JA. “Orthopaedic applications of carbon fibres”, IEEE Eng Med Biol Mag 1986;5:31–4.

[3]. E. Eisenbarth *, J. Meyle **, W. Nachtigall ***, J. Breme, “Influence of the surface structure of titanium materials on the adhesion of fibroblasts”

[4]. Ming Cheng and Weinong Chen, “Mechanical Properties of Kevlar® KM2 Single Fiber”, Journal of Engineering Materials and Technology, APRIL 2005, Vol. 127 pp 203

[5]. T.K. Lin, S.J. Wu, J.G. Lai, S.S. Shyu, “The Effect of chemical treatment on reinforcement/matrix interaction in Kevlar-fiber/bismaleimide composites”, Composites Science and Technology 60 (2000) pp 1873-1878

[6]. Gang Li a, Chen Zhang a, Yang Wang a, Peng Li a, Yunhua Yu a, XiaolongJia a, Haiyang Liu a, Xiaoping Yang a,*, Zhongmin Xue b, Seungkon Ryu c, “Interface correlation and toughness matching of phosphoric acid functionalized Kevlar fiber and epoxy matrix for filament winding composites”, Composites Science and Technology 68 (2008) 3208–3214

[7]. Sirui Fu, Bowen Yu, Lingyan Duan, HongweiBai, Feng Chen , Ke Wang, Hua Deng, Qin Zhang, Qiang Fu, “Combined effect of interfacial strength and fiber orientation on mechanical performance of short Kevlar fiber reinforced olefin block copolymer”, Composites Science and Technology 108 (2015) 23–31

[8]. C.Y. Yue*, G.X. Sui, H.C. Looi, “Effects of heat treatment on the mechanical properties of Kevlar-29 ®fibre”, Composites Science and Technology 60 (2000) 421 –427

[9]. C.Elanchezhian, B.Vijaya Ramnath, Mithun Muralidharan, K.N.Sripada Raghavendra, J.Sujay Dhamodar, C.Kartikeyan, “Review on uses of composites in shipbuilding”, Indian Journal of Science and Technology, 2016.

[10]. R. Boyer, G. Welsch, and E. W. Collings Materials Properties Handbook: Titanium Alloys,eds. ASM International, Materials Park, OH, 1994.

[11]. Metals Handbook, Vol.2 - Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International 10th Ed. 1990.

[12]. Metals Handbook, Vol. 3, Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals, Ninth Edition, ASM Handbook Committee, American Society for Metals, Materials Park, OH, 1980.

[13]. John M. (Tim) Holt, Structural Alloys Handbook, 1996 edition, Technical Ed; C. Y. Ho, Ed., CINDAS/Purdue University, West Lafayette, IN, 1996.

[14] A.S.Oryshchenko ,A.S.Kudryavtsev, V.I.Mikhailov, V.P.Leonov, “Titanium Alloys for shipbuilding and nuclear power engineering” , 2011

[15] J.G.Bakuckas, Jr., W.H.Prosser, W.S.Johnson, “Monitoring Damage Growth in Titanium Matrix Composites using Acoustic Emission”, march 1993, p.6

[16]. Lechun Xiea, b.Jiaxu Wang c, Qinghua Zhou a, Q. Jane Wang a,c, Xiaoqing Jin a, Zhanjiang Wang a,c, Chuanhai Jiang b, Weijie Lu b, “Effect of reinforcements on rolling contact fatigue behaviors of titanium matrix composite (TiB + TiC)/Ti–6Al–4V [17] Hannink R, Murray M. Elastic moduli measurements of some cubic transition metal carbides and alloyed carbides”. J Mater Sci 1974;9:223–8.

[17] Török E, Perry A, Chollet L, Sproul W. “Young’s modulus of TiN, TiC, ZrN and HfN. Thin Solid Films” 1987;153:37–43.

[18] Gorsse S, Miracle D, “Mechanical properties of Ti–6Al–4V/TiB composites with randomly oriented and aligned TiB reinforcements”. Acta Mater 2003;51:2427–42.

[19] Panda K, Chandran K, “First principles determination of elastic constants and chemical bonding of titanium boride (TiB) on the basis of density functional theory”, Acta Mater 2006;54:1641–57.

[20]. Yu-Chi Lin, Han-Ming Chen, Yong-Chwang Chen, “The effect of different methods to add nitrogen to titanium alloys on the properties of titanium nitride clad layers” Materials and Design 54:222-229 · February 2014.

[21]. isidor m. djordjevi*, daniela r. sekuli and mom^ilo m. stevanovi,”Non-linear elastic behaviour of carbon fibres of different structural and mechanical characteristic”, J. Serb. Chem. Soc. 72 (5) 513–521 (2007).

[22]. Zhishuang Daia,b, Baoyan Zhangb, Fenghui Shib, Min Li a, Zuoguang Zhanga, Yizhuo Gua, “Effect of heat treatment on carbon fiber surface properties and fibers/epoxy interfacial adhesion”, Applied Surface Science 257 (2011) 8457–8461.

[23]. Xiaosong Huang, “Fabrication and Properties of Carbon Fibers”. Materials 2009, 2, 2369-2403; doi:10.3390/ma2042369.

[24] B.Vijaya Ramnath, C. Elanchezhian, RM. Annamalai, S.Aravind, T. Sri Ananda Atreya, V. Vignesh, C.Subramanian, “Aluminium metal matrix composites – a review”, Reviews on advanced material science, Volume 38, Pages 55-60.

[25] B.Vijaya Ramnath, C. Elanchezhian, M.Jaivignesh, S. Rajesh, C. Parswajinan, A. Siddique Ahmed Ghias, "Evaluation of Mechanical Properties of Aluminium Alloy-Alumina-Boron Carbide Metal Matrix Composites", Materials and design, Volume 58, June 2014, Pages 332-338.

[26] P.Subramaniya Reddy, R.Kesavan, and B.Vijaya Ramnath, "Investigation of Mechanical Properties of Aluminium6061-Silicon Carbide, Boron Carbide Metal Matrix Composite ", Accepted for publication, Silicon, 2016.

[27] Siddique Ahmed Ghias B.Vijaya Ramnath, 'Investigation of Tensile Property of Aluminium SiC Metal Matrix ', International Journal Applied Mechanics and Materials, Volume 766-767, 2015, Pages 252-256.