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EFFECT OF NANOMATERIALS ON MECHANICAL PROPERTIES OF KEVLAR COMPOSITES

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Fiber reinforced composites find its increasing applications in automotive, marine, aerospace and construction industries. The objective of the present work is to study the effect of titanium oxide, calcium carbonate and graphite powder as nanomaterial and is compared with unfilled or pure Kevlar 49 reinforced composites. The titanium oxide, calcium carbonate and graphite fillers are incorporated in different weight ratios in the fiber reinforced composites. Composites are fabricated by using Vacuum bag molding method. The structural properties like tensile, flexural, delamination and impact strengths are experimented as per ASTM standards. The fracture behavior has been carried out and reported using scanning electron microscope.

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1. Introduction

A composite material consists of two or more distinct materials in macroscopic level with different physical or chemical properties that are combined together in order to get desired enhanced properties. It is widely used for its structural properties and also finds its application in the area of fields such as aircraft, buildings, electrical components, and marine structures.

Zhunge et. al [1] proposed Polymer matrix composites (PMCs) were used in aircraft industries for fuselage and wing structures, since it has excellent mechanical and chemical properties, such as high specific strength and modulus, fatigue, and corrosion resistance. The addition of filler and stronger fibers improves the strength and stiffness of the weak polymer matrix composites (Lei et al, 2007) [2].

The composites with reinforcement material as fibers are generally known as Fiber Reinforced Composite (FRC). It possesses interesting properties like high tensile strength, compressive strength, good fatigue resistance and stiffness. The FRCs are finding its usage as engineering materials in various areas like automobiles and aerospace owing to its light weight and enhanced structural properties. It is also suitable for the production of complex shape components (Varga et al, 2010) [3].

The FRCs has drawn the interest of many researchers in recent times as it exhibits altogether different properties of its constituent elements. Further, the FRCs are fabricated to required shape and size by various manufacturing methods such as hand layup molding, injection molding, extrusion and vacuum forming methods. In FRCs, the commonly used synthetic fibers are glass, carbon, Kevlar and graphite. The commonly used matrix materials are epoxy, polyester, vinyl ester and polyimide resins (Youjiang Wang, et al, 1995) [4].

Kevlar49 is one type of aramid fiber widely used in various engineering applications due to its improved tensile and impact properties. The fibers are used in the woven form for the

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preparation of composite specimen. In order to get better compaction and to eliminate voids between the layers vacuum bag method is employed. Further, other mechanical properties such as tensile, flexural, impact and delamination tests are also performed (M jassal et al, 2002) [5]. Epoxy resin is used in aerospace applications because of its high strength, low viscosity, low shrink rate and low vitality during cure (Yentl Swolfs et al, 2014) [6]. The properties of the kevlar49 and epoxy resin have been summarized in the Table 1.

Table 1. Properties of kevlar 49 fiber and Epoxy matrix material.

Properties	Kevlar49 fiber	Epoxy
Specific gravity (ρ)	1.45	1.20
Young's modulus (E) Gpa	125.00	4.50
Tensile strength (σ_b) Gpa	3.50	0.08
Extension to break percentage	2.20	3.00
Specific Young's modulus (E/ ρ)	86.21	3.75
Specific Tensile strength (σ_b/ ρ)	2.41	0.07

Nanomaterials are ingredients added along with hardener to the epoxy resin to get desired enhanced properties. It helps the matrix to binds the reinforcements also to promote stress transfer.Nowadays nano fillers are used in electrical, electronic, automotive and aerospace applications due to its improved properties (Chiu and Chen, 2015) [7].

Low filler contents gets higher property enhancement compared to high filler content. Low filler content helps in achieving desired mechanical properties. The strength of the composites depends on fiber orientation, matrix composition and interfacial interaction (Khalil et al, 2013) [8]. The nanoparticles of the TiO2 (35 nm) increases the fracture toughness in the hybrid jute/glass reinforced composites (Shukla et al, 2006) [9].

Calcium carbonate (CaCO3) fillers are used in composite industry because of its low cost and it is naturally available in limestone. The graphite powder is used as the filler added to the epoxy resin and manually mixed to get homogeneity of particle distribution. The carbon nano tubes are used instead of graphite powder for better results in electrical and mechanical properties (Hui Q et al, 2010) [10].

2. Experimental details

2.1 Materials

The epoxy resin (LY556) with araldite hardener (HY951) is used as matrix material to prepare the Kevlar49 Laminated Composites (KLC). Plain woven (fibers rows are perpendicular) Kevlar49 fiber mats are used as major reinforcement material. The volume percentage of reinforcement is maintained as 60 and the rest is matrix for all categories of composites proposed in the present work. The hybridization of composites is achieved by adding Nano Fillers (NF) such as Titanium oxides (TiO_2), Calcium Carbonate ($CaCO_3$) and Graphite Powder separately. The NFs are added without compromising the volume fraction of reinforcement. The volume percentages of NFs are varied as 2, 4 and 6 percentage. The coding used for various categories of specimens in the present work is presented in the Table 2.

Table 2. Specimen coding with description.

Sl.No.	Specimen Coding	Description
1	KLC	Kevlar49 Laminated Composite without Filler
2	KTO2	Kevlar49 Laminated Composite with 2% Titanium Oxide Powder
3	KTO4	Kevlar49 Laminated Composite with 4% Titanium Oxide Powder
4	KTO6	Kevlar49 Laminated Composite with 6% Titanium Oxide Powder
5	KCC2	Kevlar49 Laminated Composite with 2% Calcium Carbonate Powder
6	KCC4	Kevlar49 Laminated Composite with 4% Calcium Carbonate Powder
7	KCC6	Kevlar49 Laminated Composite with 6% Calcium Carbonate Powder
8	KGR2	Kevlar49 Laminated Composite with 2% Graphite Powder
9	KGR4	Kevlar49 Laminated Composite with 4% Graphite Powder
10	KGR6	Kevlar49 Laminated Composite with 6% Graphite Powder

2.2 Composite fabrication

The KLC is prepared with multiple layers (11 plies) by coating epoxy resin between each layer. The laminated composite of size 350×350×3 mm is fabricated for preparing test specimens. Hand lay-up method is used for applying resin between plies and the total stack up is subjected to vacuum bag moulding to squeeze out the excessive resin and air pockets in order to maintain the desired thickness of 3mm. In this process, the vacuum pressure of 550 mm of Hg is applied through vacuum valve at one corner of the system for 60 minutes. The bagged specimen is then placed in hot air oven for two hours at 100^{o}C and allowed to cool at room temperature. The hot air oven used for curing process has two separate heating zones of each 1.5 KW and has the size of 700×610×700 mm. The photographic views of kevlar49 plies before fabrication and the vacuum bag mould setup are shown in Fig. 1(a) and 1(b) respectively. In order to characterize the prepared composites, the static mechanical tests such as tensile, flexural, impact and de-lamination are performed as per ASTM standards. The specimens for tensile and flexural tests are cut from the sheet such that one row of fibers parallel to the outer edge in length wise direction. The computerized water jet machine is used for cutting the specimen. The various test standards followed in the present characterization are listed below.

Tensile	-	ASTM D695
Flexural	-	ASTM D790
Impact	-	ASTM D256
De-lamination	-	ASTM D2344M

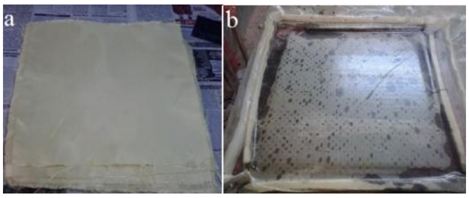

Fig. 1 (a & b). Images of kevlar49 fiber & vacuum bag method preparation.

The tensile and flexural tests were conducted in the Department of Aerospace Engineering, Indian institute of Technology Madras (IITM), Chennai, India. The digital universal testing machine is used for performing tensile test of composite specimens. The computerized flexural testing machine with 5 tons capacity was used for conducting flexural test. Exclusively designed fixtures were used for holding and loading the specimen and are shown in the Fig. 2. The impact strength of the composite specimens is determined using Izod Impact tester with un-notched specimen. In all tests, the average of four specimens is considered as result.

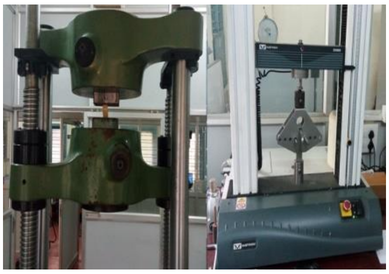

Fig. 2. Photographic image of tensile and flexural testing machine.

3. Results and discussion

The various types of composites are fabricated as sheets and the specimens are characterized. The test results are presented with discussion separately with respect to each test in the Table 3.

Table 3. Mechanical properties of KLC, KTO, KCC and KGR with different filler percentage.

Specimen code	Filler %	Tensile			Flexural			Delamination		I.S (KJ/m^2)
		UTL (KN)	TS (MPa)	E (GPa)	UFL (KN)	FS (MPa)	E_{bend} (GPa)	UDL (KN)	DS (MPa)	
KRC	0	72.97	973	57.23	1.036	28.85	24.04	0.87	58.20	288
KRCTO2	2	73.20	976	57.41	1.060	29.70	24.75	0.90	60.00	289
KRCTO4	4	73.50	980	57.64	1.130	31.60	26.33	0.93	62.40	291
KRCTO6	6	75.52	1007	59.23	1.210	33.80	28.16	0.97	65.00	292
KRCCC2	2	73.65	982	57.76	1.050	29.30	24.41	0.88	59.30	289
KRCCC4	4	76.05	1014	59.64	1.120	31.20	26.00	0.93	62.00	288
KRCCC6	6	77.55	1034	60.82	1.150	32.00	26.66	0.96	64.40	288
KRCG2	2	75.97	1013	59.58	1.040	28.90	24.08	0.89	59.50	290
KRCG4	4	77.02	1027	60.41	1.050	29.30	24.41	0.91	61.00	291
KRCG6	6	78.07	1041	61.23	1.100	30.60	25.50	0.93	62.30	293

Where UTL – Ultimate tensile load, TS – Tensile strength, E – Young's Modulus
UFL – Ultimate Flexural load, FS – Flexural strength, E – Bending Modulus
UDL – Ultimate Delamination load, DS – Delamination strength & I.S – Impact strength

3.1 Tensile test

In view of predicting tensile strength of the specimen of KLC, KTO, KCC and KGR with different percentage is carried out. The ASTM D 695 standard is employed for the test. The tensile test is performed in Digital Universal testing machine with appropriate testing fixtures. The machine is capable of giving Ultimate load in KN, Ultimate stress in KN/mm^2, yield stress in KN/mm^2, Elongation at the maximum load in mm and maximum elongation in mm for each specimen. In the present work, the specimen of size 250mm×25mm×3mm is used for the tensile test for KLC,KTO, KCC and KGR with different percentage.

Each specimen is gripped at both ends and slowly pulls lengthwise on the specimen till it gets failure. In each category four specimens are considered and the corresponding results are presented in Table 3. The specimen that yields higher values of Ultimate load gives maximum tensile strength and correspondingly the composite specimen with ultimate tensile strength is presented in the Fig. 3.1.

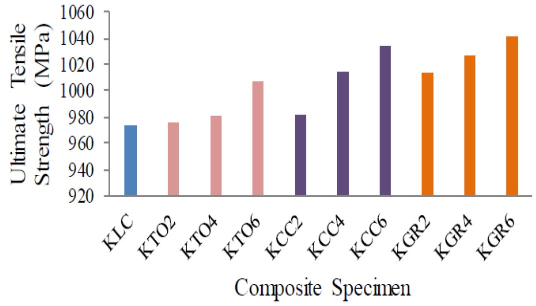

Fig. 3.1. Composite specimen with ultimate Tensile strength

In this test, the KGR has the good resistance in withstand load, higher rigidity and stiffness compared to remaining three categories. Also the KCC and KTO shows higher values compared to KLC. The filler percentage of 2, 4 and 6 gives higher values of tensile strength gradually for all the four different variations of the composites.

3.2 Flexural test

Flexural test indicates the load required to deflect a beam when it is subjected to three points loading. It is often used to design and select the materials that support loads without deflection. Flexural modulus is the indication of a material's stiffness when deflection occurs. The flexural test is carried out on a specimen that is supported between two supports and the load is applied at the center of the span at a specified rate. The parameters for the test are span length, rate of loading and maximum deflection. As per the standard, the variety of shapes of the specimen can be used.

In the present work, the specimen of size 120mm×12mm×3mm is used for the flexural test of KLC. The load is applied till the rupture of the specimen and the load versus displacement curve is obtained for each specimen. The ultimate load, ultimate stress, maximum displacement and displacement at maximum load are obtained as output from the machine. The KLC specimen is tested and the test results are compared with the test result specimens of KTO, KCC and KGR. In each case four specimens are tested to get the accurate results also to eliminate the experimental error. The ultimate load and the flexural strength for all the specimens are presented in the Table 3 and the corresponding composite specimen with ultimate flexural strength is presented in the Fig. 3.2.

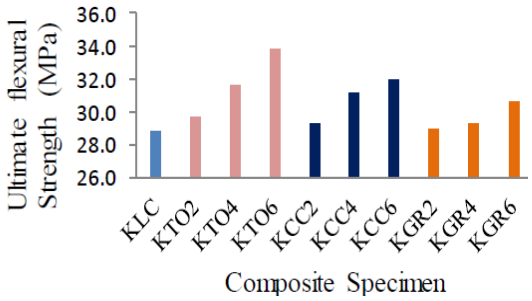

Fig. 3.2. Composite specimen with ultimate flexural strength

In this test, the KTO6 has the maximum flexural strength values for the all three different percentages compared to remaining three categories. Also the KCC and KGR shows higher values compared to KRC. The filler percentage of 2, 4 and 6 gives higher values of flexural strength gradually for all the four different variations of the composites.

3.3 Impact test

The impact test is used to measure directly the total energy absorbed by the specimen for complete failure under impact loading condition. The ASTM D 256 standard is employed for the test. The impact strength (I.S) of the KLC specimens has been predicted using IZOD test. Three specimens are prepared for every KLC, KTO, KCC and KGR categories.

The specimen is supported at both of its ends and the load is applied at the middle using a hammer that falls with velocity of 3.5m/sec. The energy absorbed by the specimen is recorded from the dial provided in the machine directly. The I.S is calculated for a particular specimen by dividing the total energy absorbed by the cross sectional area of the fracture location. The specimen of size 64mm×12.7mm×3mm is used for the impact test.

In this test, the KGR has the maximum impact strength values for the all three different percentages compared to remaining three categories. Also the KTO and KCC shows higher values compared to KLC. The filler percentage of 2, 4 and 6 gives higher values of impact strength gradually for all the four different variations of the composites and is presented in the Fig. 3.3.

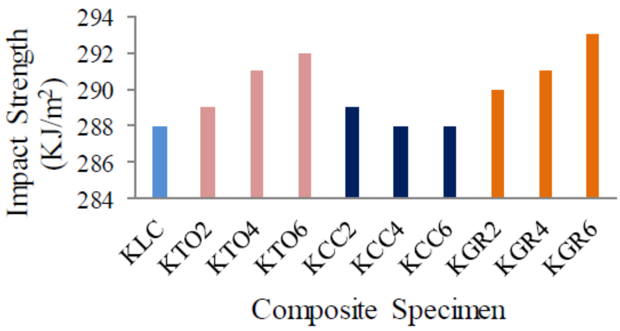

Fig. 3.3. Composite specimen with impact strength.

The surface topology is observed in a scanning electron microscope (SEM) and is employed to investigate the fractured surfaces, defects and matrix cracks of the specimen samples. The fractured surface of the KLC specimen after impact test is shown in the Fig. 3.3(a & b).The interfacial adhesion between reinforcing fiber and polymer matrix plays an important role on the mechanical properties of the composites and its defects. The poor interfacial adhesion takes place between the Kevlar 49 fiber and the matrix of KGR4 is shown in the Fig. 3.3(c). The separation of fibers in the KGR6 specimen can be seen clearly in the Fig. 3.3(d).

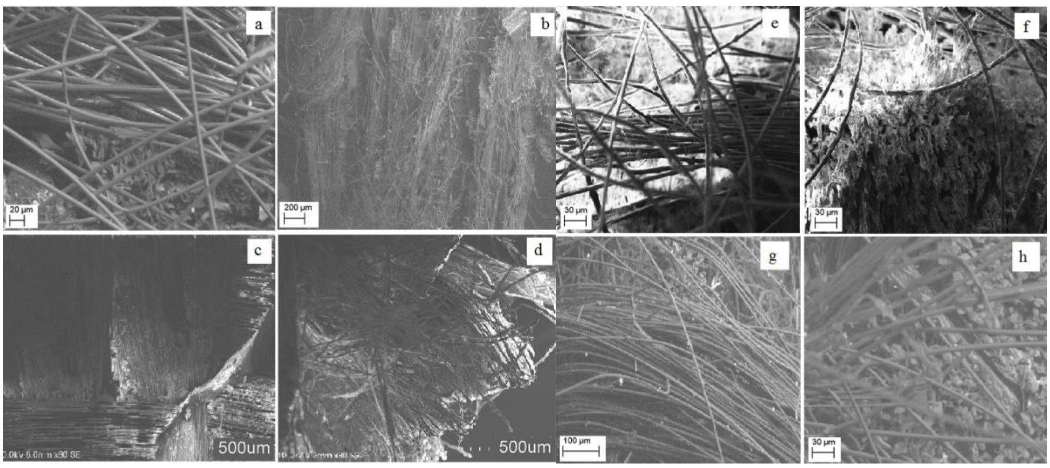

Fig. 3.3(a, b, c, d, e, f, g & h). SEM images of fractured surface of (a & b)-KLC specimen, (c)-KGR4, (d) - KGR6, (e) - KCC4, (f) – KCC6, (g) – KTO4, (h) – KTO6.

More cavities, delamination, and voids on the worn surface are seen in the KCC4 specimen also the fiber pull out occurred results in failure of the material is shown in the Fig. 3.3(e). The matrix failure and fiber pull out for the specimen KCC6 is shown in the Fig. 3.3(f). The specimen KTO2 shows significantly peel in large number and deep cracks can be seen on the damaged surface in the Fig. 3.3 (g). When the contents of the Nano materials like titanium oxide is increased to 6 percentage results in good matrix bonding. Even though matrix failure happens due to small cracks in large numbers are shown in the Fig. 3.3 (h).

3.4 De-lamination test

Experimental results are presented from an investigation into cracks emanating from delamination tips in KLC. The ASTM D 2344M standard is employed for the test. Delamination is the separation of two adjacent plies in composite laminates. It represents one of the most critical failure modes in composite laminates. In fact**,** it is used to measure the interlaminar strength of the specimen and it is an essential issue in the evaluation of composite laminates for durability and damage tolerance. A study of the results indicates different behavior for the crack formation depending on the KLC configuration and the position of the delamination through the thickness of the specimen. This test leads to better design methodologies and better damage detection. The crack tip deformation is determined to be most important energy dissipation mechanism involved in composite delamination. The photographic view of the fracture surfaces and side view of the fatigue crack propagation for the sample specimens KLC, KCC6, KTO6 and KGR6 are shown in the Fig. 3.4(A, B, C & D).

Fig. 3.4. Delamination images of KLC (A), KCC6 (B),KTO6 (C) & KGR6 (D).

In the present work, the specimen of size 50mm×5mm×3mm is used for the delamination test for the entire specimen.In this test, the KTO6 has the highest delamination strength values compared to the remaining three categories. Also the KCC and KGR shows higher values compared to KLC.

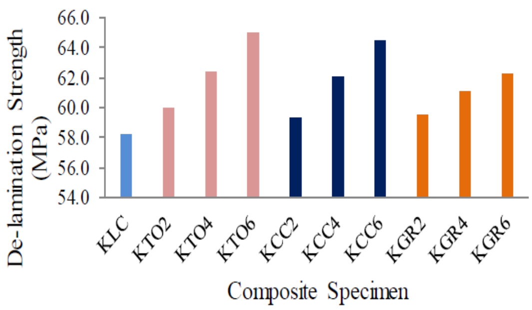

Fig. 3.4 Composite specimen with De-lamination strength.

The filler percentage of 2, 4 and 6 gives higher values of delamination strength gradually for all the four different variations of the composites and is presented in the figure-3.4.

4. Conclusions

The four types of composites by adding zero, two, four and six percentage fillers are prepared and tested for its characterization. Based on the experimental results, the following conclusions are arrived and presented below.

The Tensile test results indicated that the cracked specimens are tougher along the fiber orientations as compared with across the fiber orientations. The tensile strength and yield strength values of the KGR6 are higher than that of remaining specimen. The KGR6 specimens have the capability to withstand higher load. It reflects the high stiffness and rigidity of KGR6 compared to remaining categories. The percentage elongation indicates that the KCC6 and KTO6 specimen has ductility and toughness. In this present work, it is clearly stated that KGR6 is recommended for tensile application.

Flexural test reveals that the flexural strength of the KTO6 is higher than that of remaining specimen. The KTO specimens have the capability to withstand higher load compared to KCC and KGR specimens. The filler addition resulted in increased flexural strength. Minimum displacement takes place only in KTO’s specimen compared to all specimens. Kevlar49 in combination with the titanium oxide as filler has the good flexural strength and hence KTO6 is highly recommended for flexural application. Delamination test clearly indicated that the KTO6 has good delamination strength than the remaining specimen also this test shows the separation of fibers from the matrix at weak locations in both KCC and KGR specimens.

In the Impact Test, the total impact energy required to fracture the specimen is measured and can be used as a basis for comparison of KLC, KTO, KCC and KGR specimen tested under the same conditions. The results indicate that the impact strength is higher for KGR6 compared to remaining specimen. The KGR6 has the good toughness and impact resistance and it is highly recommended for impact application.

References

[1] J. Zhuge, J. Gou, R. Chen, A. Gordon, J. Kapat, D. Hart, C. Ibeh, Composites: Part **B**(43), 3293 (2012).
[2] Y. Lei, Q. Wu, C. M. Clemons, F. Yao, Y. J. Xu Appl. Polym. Sci. **106**, 3958 (2007).
[3] C. S. Varga, N. Miskolczi, L. Bartha, G. Lipoczi, Mater. Des. **31**, 185 (2010).
[4] YoujiangWang, Jian Le, Dongming Zhao, Composites Engineering (5), 1159 (1995).
[5] M. Jassal, S. Ghosh, Indian Journal of Fibre and Textile Research (27), 290 (2002).
[6] Yentl Swolfs, Larissa Gorbatikh, Ignaas Verpoest, Composites: Part **A**, (67), 181 (2014).
[7] F. Chiu, Y. Chen, Composites: Part **A** (68), 62 (2015).
[8] H. P. S. A. Khalil, H. M. Fizree, A. H. Bhat, A. M. Jawaid, C. K. Abdullah, Composites: Part **B** (53), 324 (2013).
[9] A. Shukla, V. Parameswaran, Y. Du, V. Evora Adv. Mater. Sci. (13), 47 (2006).
[10] Q. Hui, E. S. Greenhalgh, M. S. P. Shaffer, A. Bismarck, J. Mater Chem. (23), 4751 (2010).
[11] Thingujam Singh, Sutanusamantan, Science Direct, Materials today (2), 1381 (2015).
[12] Praveen Kumar A. International Journal of Advanced Materials Science (3), 173 (2012).
[13] Abbas A. Al-Jeebory, Ali I. Al-Mosawi, Al-Qadisiya. Journal for Engineering Sciences (3), 44 (2010).
[14] B. Wang, L. Tabil, S. Panigrahi, Sci. Eng. Compos. Mater. (15), 43 (2011).
[15] M. S. Hunt, Materials Design (8), 113 (1987).
[16] E. L. Kostoryz, P. Y. Tong, C. C. Chappelow, J. D. Eick, A. G. Glaros, D. M. Yourtee, Dental Materials (15), 363 (1999).
[17] Abhijit Majumdar, Bhupendra Singh, Ankita Srivastava, Materials and Design (51), 148

(2013).
[18] P. S. Shivakumar Gouda, Kudari, S. K. Prabhuswamy, S. Dayananda Jawali, Journal of Minerals & Materials Characterization & Engineering (10), 671 (2011).
[19] Hulin Li, Zhong Wei Yin, Dan Jiang, Ya Jun Huo, Yu Qing Cui, Elsevier, Tribology International (80), 172 (2014).
[20] Mahmood Ansari, Wang Xinwei, Zhou Chouwei, Composite Structures (93), 1947 (2011).
[21] P. N. B. Reis, J. A. M. Ferreira, P. Santos, M. O. W. Richardson, J. B. Santos, Composite Structures (94), 3520 (2012).
[22] M. Jawaid, Abdul Khalil, Carbohydrate Polymers (86), 1 (2011).
[23] N. Mortas, P. N. B. Reis, J. A. M. Ferreira, Composite Structures (108), 205 (2014).
[24] A. Karthikeyan, K. Balamurugan, Kalpana, Sci. Eng. Composite Materials (21), 315(2011).
[25] Ronald F. Gibson, Composite Structures (92), 2793 (2010).
[26] J. P. Duncan, M. A. Freilich, S. J. Latvis, J. Prosthet. Dent (84), 200 (2000).
[27] Tapas Kuillaa, Sambhu Bhadra, Dahu Yao, Nam Hoon Kim, Saswata Bose, Joong Hee Lee, Progress in Polymer Science (35), 1350 (2010).