UNIVERSITI SAINS MALAYSIA

First Semester Examination
2008/2009 Academic Session
Peperiksaan Semester Pertama
Sidang Akademik 2008/2009

November 2008
November 2008

ESA 423/3 – Aerospace Material & Composite
Bahan Aeroangkasa & Komposit

Duration : 3 hours
[Masa : 3 jam]

INSTRUCTION TO CANDIDATES
ARAHAN KEPADA CALON

Please ensure that this paper contains **THIRTEEN (13)** printed pages and **FIVE (5)** questions before you begin examination.
*Sila pastikan bahawa kertas soalan ini mengandungi **TIGABELAS (13)** mukasurat bercetak dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.*

Answer **ALL** questions.
*Jawab **SEMUA** soalan.*

Student may answer the questions either in English or Bahasa Malaysia.
Pelajar boleh menjawab soalan dalam Bahasa Inggeris atau Bahasa Malaysia.

Appendix/Lampiran

1. Table 1.1 Tensile Properties of Some Metallic and Structural Composite Materials [2 pages/mukasurat]

2. Table 2.1 Properties of Selected Commercial Reinforcing Fibers [1 page/mukasurat]

Each questions must begin from a new page.
Setiap soalan mestilah dimulakan pada mukasurat yang baru.

1. (a) In fabrication of polymer matrix composite (PMC), the selection of matrix between thermosets and thermoplastic proved to be a key element in determining the performance of the material. Discuss comprehensively the design requirements for fabrication of the high performance composites. The discussion may include the mechanical requirements, advantages and disadvantages, thermal and dimensional stabilities.

Dalam pembikinan komposit polimer matriks (KPM), pemilihan matriks di antara set-terma dan plastik-terma telah terbukti sebagai satu elemen penting dalam menentukan prestasi bahan tersebut. Bincangkan secara menyeluruh keperluan rekabentuk untuk pembikinan komposit prestasi tinggi. Perbincangan tersebut merangkumi keperluan mekanikal, kebaikan dan keburukan, terma dan stabiliti dimensi.

(40 marks/*markah*)

(b) In a certain application, a steel beam (AISI 4340 steel) of round cross section (diameter = 10 mm) is to be replaced by a unidirectional fiber-reinforced epoxy beam of equal length. The composite beam is designed to have a natural frequency of vibration 50% higher than that of the steel beam. Among the fibers to be considered are high-strength carbon fiber, high-modulus carbon fiber and Kevlar 49. By using the given table, select one of these fibers on the basis of minimum weight for the beam and the design requirement.

Satu rasuk besi (AISI 4340 besi) yang mempunyai keratan rentas bulatan (diameter = 10 mm) bakal diganti boleh satu rasuk epoksi bertetulang fiber eka-arah yang mempunyai panjang yang sama. Rasuk komposit direkabentuk untuk mempunyai frekuensi asli getaran 50 % lebih tinggi daripada rasuk besi. Antara fiber yang sesuai adalah fiber karbon kekuatan tinggi, fiber karbon modulus tinggi dan Kevlar 49. Dengan menggunakan jadual yang diberi, pilih salah satu fiber yang dinamakan di atas dan tentukan berat minimum rasuk dan keperluan rekabentuk.

Note: The natural frequency of vibration of a beam is given by the following equation:

Nota: Frekuensi asli getaran rasuk adalah seperti persamaan di bawah:

2. (a) The amount of fibers in a composite sample can be determined by a burn-out test; the burn-out eliminates all the resin and only the fibers remain. A composite sample plus its container weighs 50.182 grams before burn-out and 49.448 grams after burn-out. The container weighs 47.650 grams. Compute the fiber weighs fraction W_f and matrix weight fraction W_m.

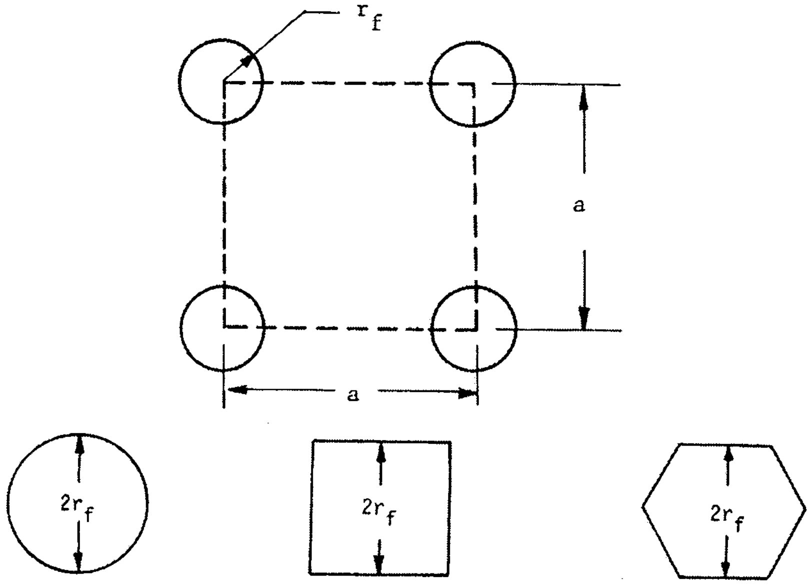
Kuantiti gentian dalam sampel komposit boleh ditentukan dengan ujian pembakaran; ujian pembakaran membuang semua damar dan yang tinggal hanya gentian. Satu sampel komposit yang jisimnya 50.182 gram termasuk jisim bekas, manakala selepas pembakaran, jisimnya ialah 49.448 grams. Jisim bekas adalah 47.650 grams. Tentukan pecahan jisim gentian W_f *dan pecahan jisim matriks,* W_m.

(20 marks/*markah*)

(b) Using the simple square arrangement in **Figure Q2 (b)**, show that fibers with square or hexagonal cross section can be packed to higher fiber volume fractions than fibers with round cross sections. Compare the fiber surface area per unit volume fraction for each cross section. Explain the significance of the surface area calculations.

Dengan menggunakan susunan segi empat sama yang mudah seperti dalam ***Rajah Q2 (b)****, tentukan bahawa gentian dengan keratan rentas segi empat sama atau keratan heksagonal boleh dibungkus untuk menjadi pecahan isipadu gentian yang lebih besar daripada gentian yang mempunyai keratan rentas bulatan. Bandingkan luas permukaan gentian per pecahan unit isipadu untuk setiap keratan rentas. Jelaskan keperincian pengiraan luas permukaan.*

(30 marks/*markah*)



(a) Round/*bulatan* (b) Square/*segiempat sama* (c) Hexagonal/*heksagonal*

<u>Figure Q2 (b)/*Rajah Q2 (b)*</u>

(c) Consider a unidirectional continuous fiber lamina containing 60 vol % of brittle, elastic S-glass fibers in an elastic, perfectly plastic epoxy matrix. The stress-strain diagrams for the fibers and the matrix are shown in **Figure Q2 (c)**. Using the fiber properties in **Table 2.1 (Appendix)** and matrix properties as E_m = 3.45 GPa and σ_{my} = 138 MPa, determine:

*Andaikan satu gentian lamina eka-arah yang berterusan mengandungi 60% isipadu gentian rapuh dan elastik kaca-S dalam matrik epoksi yang elastik dan plastik sempurna. Rajah ketegasan-terikan untuk gentian dan matrik ditunjukkan dalam **Rajah S2 (c)**. Dengan menggunakan ciri-ciri gentian dalam **Jadual 2.1 (Lampiran)** dan ciri-ciri matrik seperti E_m = 3.45 GPa dan σ_{my} = 138 MPa, tentukan:*

(i) Calculate the longitudinal modulus of the composite lamina before and after matrix yielding.

Kirakan modulus longitud komposit lamina sebelum dan selepas matriks alah.

(20 marks/*markah*)

3. (a) Name <u>TWO (2)</u> manufacturing processes of composite materials. For each process, discuss its main advantages and disadvantages.

Namakan <u>DUA (2)</u> proses pembuatan dalam bahan komposit. Untuk setiap proses, bincangkan kebaikan dan keburukan.

(20 marks/*markah*)

(b) What manufacturing process would you recommend to produce a cylindrical tube for **EACH** of the following configurations of the reinforcement? Elaborate your answer on the criteria you applied for the decision of the processes.

*Proses pembuatan manakah yang anda memperakukan dalam menghasilkan tiub silinder untuk **SETIAP** konfigurasi yang berikut untuk tetulang? Terangkan dengan terperinci jawapan anda untuk kriteria yang anda telah pilih untuk proses-proses tersebut.*

(i) Only unidirectional fibers along the length of the tube.
Hanya gentian eka-arah sepanjang panjang tiub.

(ii) Only hoop fibers.
Hanya gegelang gentian

(iii) A combination of unidirectional and $\pm 45^0$ (angle measured with respect to the axis of the tube).
Satu kombinasi eka-arah dan $\pm 45^0$ (sudut diukur daripada paksi tiub tersebut)

(iv) Only chopped or CSM reinforcement.
Hanya tetulang potong atau CSM

(v) A short length of tube fabricated as a prototype with arbitrary fiber orientations.
Satu tiub terbikin sebagai prototaip dengan orientasi gentian sembarangan yang mempunyai panjang yang singkat.

(50 marks/*markah*)

(c) What manufacturing process would you recommend to produce a large quantity of the following parts while minimizing cost? Discuss your decision in term of the suitability of the process, productivity and the cost.

Proses pembuatan manakah yang anda akan memperakukan dalam penghasilan satu kuantiti besar untuk yang berikut sambil meminimumkan kos? Terangkan dengan terperinci dalam bentuk kesesuaian proses, produktiviti dan kos.

(i) Automotive door panel where structural performance is not critical but surface finish must be excellent.
Pintu panel automotif di mana prestasi struktur adalah tidak kritikal tetapi kemasan permukaan mestilah bagus.

(ii) Aircraft door panel where structural performance is critical but surface finish is not important.
Panel pintu pesawat di mana prestasi struktur adalah kritikal tetapi kemasan permukaan adalah tidak penting

(iii) A few prototypes samples of both (i) and (ii).
Beberapa contoh untuk kedua-duanya di (i) dan (ii).

(30 marks/*markah*)

4. (a) **Figure Q4 (a)** shows two types of stress-strain behaviors of a CFRP composite consisting of unidirectional carbon fibers and epoxy matrix. Discuss the behaviors of the material regarding the relative magnitudes of the ultimate tensile strains of the constituents and effects to the overall load distribution and energy absorbing capabilities of the composites.

Rajah Q4 (a) *menunjukkan dua jenis sifat bagi tegasan-terikan komposit CFRP yang mengandungi gentian karbon eka-arah dan matrik epoksi. Bincangkan sifat-sifat bahan tersebut berdasarkan nilai-nilai relatif tegangan terikan akhir bahan-bahan komponen dan kesan-kesan kepada keseluruhan daya agihan dan keupayaan tenaga penyerapan bagi komposit.*

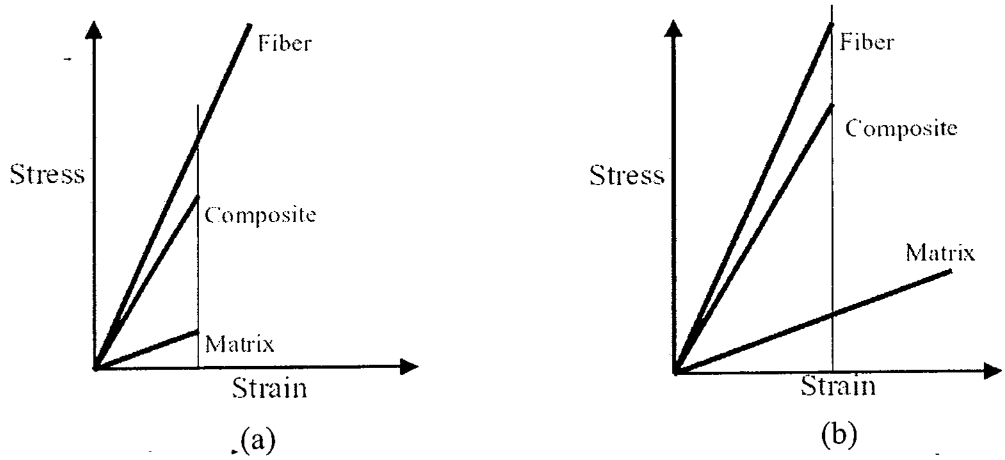


Figure Q4 (a)/*Rajah Q4 (a)*

[30 marks/*markah*]

(b) Unidirectional 0^0 Kevlar 49 composites exhibit a linear stress-strain curve in a longitudinal tension test; however, their longitudinal compressive stress-strain curve is similar to that of an elastic, perfectly plastic metal as shown in **Figure Q4 (b)**. Furthermore, the compressive proportional limit for a Kevlar 49 composite is lower than its tensile strength. Explain how these two behaviors may affect the stress distribution across the thickness of a unidirectional Kevlar 49 composite beam as the transversely applied load on the beam is increased. Estimate the transverse load at which the flexural load deflection diagram of a Kevlar 49 beam becomes nonlinear. Assume that the strain distribution through the thickness of the beam remains linear at all load levels.

*Komposit eka-arah 0^0 Kevlar 49 menunjukkan satu garis lengkung tegasan-terikan yang linear dalam ujian tegangan longitud. Bagaimanapun, garis lengkung untuk mampatan longitud bagi tegasan-terikan adalah hampir serupa dengan garis lengkung elastik, plastik sempurna bagi logam seperti dalam **Rajah Q4 (b)**. Selanjutnya, had berkadaran bagi mampatan untuk sesebuah komposit Kevlar 49 adalah lebih rendah daripada kekuatan tegangan. Terangkan bagaimana kedua-dua sifat ini mampu memberi kesan ke atas agihan tegasan sesebuah rasuk eka-arah komposit Kevlar 49 sekiranya satu beban melintang ke atas rasuk ditingkatkan. Anggarkan pada Rajah Kevlar 49 di mana pemesongan beban lenturan menjadi tidak linear. Andaikan agihan terikan sepanjang ketebalan rasuk adalah linear di sepanjang tahap beban.*

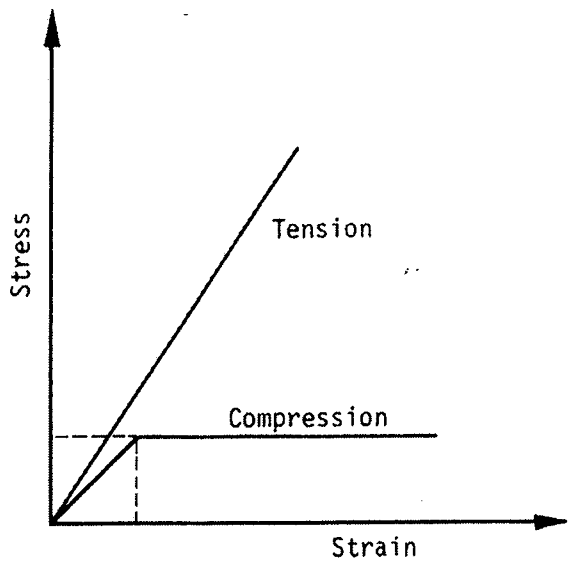


Figure Q4 (b)/*Rajah Q4 (b)*

[30 marks/*markah*]

(c) A glass matrix is reinforced with unidirectional silicon carbide fibers and loaded in longitudinal tension until matrix failure. Determine the minimum fiber volume ratio, so that the composite does not fail catastrophically (i.e., the unbroken fibers can support the load) immediately after matrix failure. The material properties for constituents are provided as follows:

Satu matriks kaca dikuatkan dengan satu gentian karbaid silikon eka-arah dan diletakkan beban untuk tegasan longitud sehingga matriks itu gagal. Tentukan nisbah minimum isipadu gentian supaya komposit itu tidak akan mengalami kegagalan bencana (i.e., gentian yang tidak pecah boleh menyokong beban) sejurus kegagalan matriks. Sifat-sifat bahan untuk juzuk adalah seperti berikut:

$E_f = 400$ GPa
$E_m = 69$ GPa
$F_{ft} = 3175$ MPa
$F_{mt} = 125$ MPa

(40 marks/*markah*)

5. (a) Assume that the area under the stress-strain diagram of a material is a measure of its toughness. Using the stress-strain diagram shown in **Figure Q5 (a)**, compare the toughnesses of three matrix resins considered. Explain how the toughness values contribute to the performance of the materials.

*Andaikan luas di bawah rajah tegasan-terikan sesuatu bahan adalah ukuran kekuatan. Dengan menggunakan rajah tegasan-terikan seperti ditunjukkan dalam **Rajah Q5 (a)**, bandingkan kekuatan ketiga-tiga damar matriks yang ditunjukkan. Terangkan bagaimana nilai kekuatan menyumbang kepada prestasi bahan.*

(40 marks/*markah*)

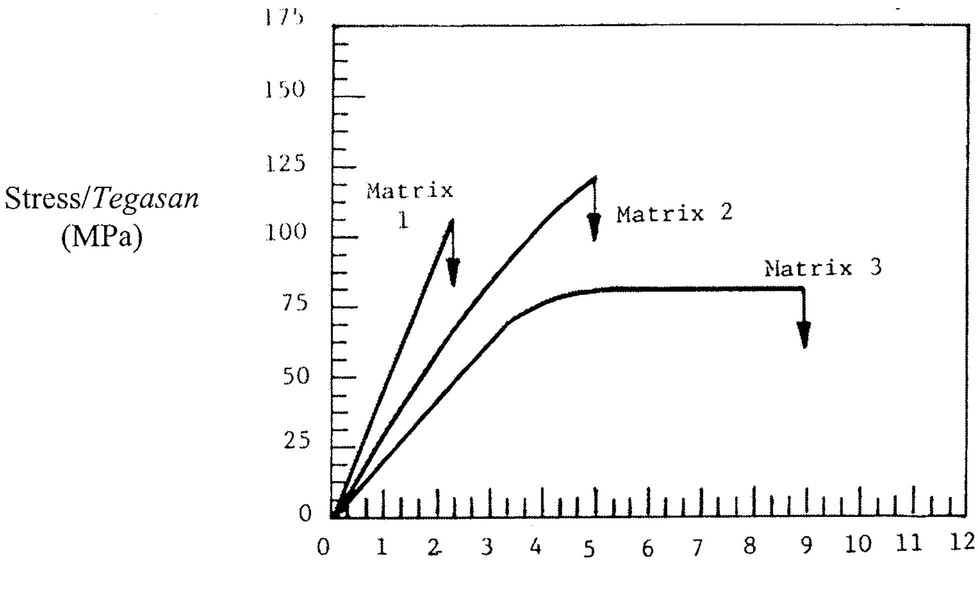


Figure Q5 (a)/*Rajah Q5 (a)*

(b) Tensile stress-strain diagram of a $[0/90_4]_S$ AS-4 carbon fiber/epoxy laminate is shown in **Figure Q5 (b)**. The longitudinal and transverse modulus of a 0^0 unidirectional laminate of the same material are 142 and 10.3 GPa, respectively.

*Rajah tegangan tegasan-terikan $[0/90_4]s$ AS-4 gentian karbon/epoksi yang berlapis ditunjukkan dalam **Rajah Q5(b)**. modulus longitud dan melintang untuk 00 eka-arah bahan berlapis yang sama bahannya adalah 142 dan 10.3 GPa.*

(i) Determine the initial axial modulus of the $[0/90_4]_S$ laminate and compare it with the theoretical value. How would this value change if the 90^0 layers are at the outside or the laminate construction is changed to $[0_2/90_3]_S$?

Tentukan modulus awal paksi bagi $[0/90_4]s$ berlapis dan bandingkan dengan nilai yang dapat secara teori. Bagaimana nilai ini berubah sekiranya 90^0 lapisan ini berada di luar atau pembinaan berlapis diubah menjadi $[0_2/90_3]s$?

(30 marks/*markah*)

(ii) The knee in the stress-strain diagram is at a strain of 0.005 mm/mm. However, the ultimate longitudinal and transverse strains of the 0^0 unidirectional laminate are at 0.0146 and 0.006 mm/mm, respectively. Explain what might caused a lower strain at the knee.

Lutut dalam rajah tegasan-terikan berada pada terikan 0.005 mm/mm. bagaimanapun, terikan muktamad longitud dan melintang 0^0 eka-arah berlapis berada pada 0.0146 dan 0.006 mm/mm. Terangkan, apakah punca yang menyebabkan terikan yang rendah pada lutut.

(20 marks/*markah*)

(iii) Describe the reason for the non-linear portion of the stress-strain diagram.

Jelaskan sebab mengapa terdapat bahagian tidak linear dalam rajah tegasan-terikan.

(10 marks/*markah*)

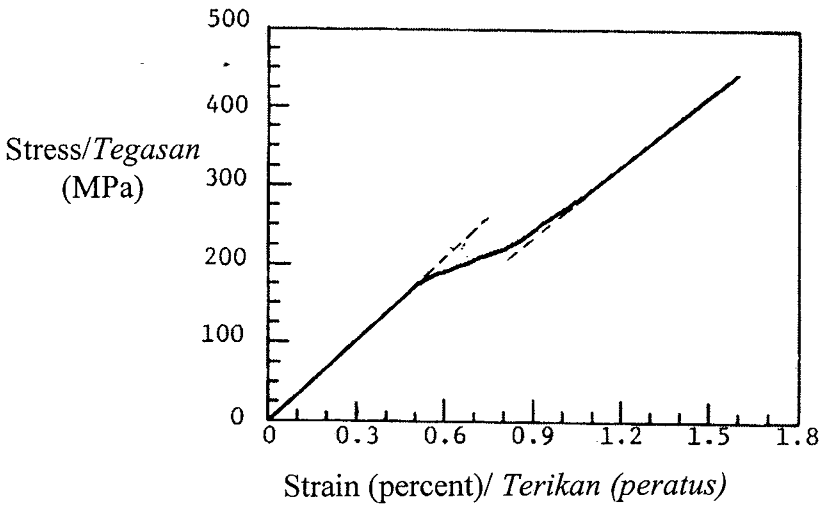


Figure Q5 (b)/*Rajah Q5 (b)*

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APPENDIX/*LAMPIRAN*

Table 1.1 Tensile Properties of Some Metallic and Structural Composite Materials

Material[a]	Specific gravity	Modulus, GPa (Msi)	Tensile strength, MPa (ksi)	Yield strength, MPa (ksi)	Ratio of modulus to weight,[b] 10^6 m	Ratio of tensile strength to weight,[b] 10^3 m
SAE 1010 steel (cold-worked)	7.87	207 (30)	365 (53)	303 (44)	2.68	4.72
AISI 4340 steel (quenched and tempered)	7.87	207 (30)	1722 (250)	1515 (220)	2.68	22.3
AL 6061-T6 aluminum alloy	2.70	68.9 (10)	310 (45)	275 (40)	2.60	11.7
AL 7178-T6 aluminum alloy	2.70	68.9 (10)	606 (88)	537 (78)	2.60	22.9
Ti-6A1-4V titanium alloy (aged)	4.43	110 (16)	1171 (170)	1068 (155)	2.53	26.9
17-7 PH stainless steel (aged)	7.87	196 (28.5)	1619 (235)	1515 (220)	2.54	21.0
INCO 718 nickel alloy (aged)	8.2	207 (30)	1399 (203)	1247 (181)	2.57	17.4

Table 1.1 (continued)

Material[a]	Specific gravity	Modulus, GPa (Msi)	Tensile strength, MPa (ksi)	Yield strength, MPa (ksi)	Ratio of modulus to weight,[b] 10^6 m	Ratio of tensile strength to weight,[b] 10^3 m
High-strength carbon fiber-epoxy (unidirectional)	1.55	137.8 (20)	1550 (225)	—	9.06	101.9
High-modulus carbon fiber-epoxy (unidirectional)	1.63	215 (31.2)	1240 (180)	—	13.44	77.5
E-glass fiber-epoxy (unidirectional)	1.85	39.3 (5.7)	965 (140)	—	2.16	53.2
Kevlar 49 fiber-epoxy (unidirectional)	1.38	75.8 (11)	1378 (200)	—	5.60	101.8
Boron fiber-6061 Al alloy (annealed)	2.35	220 (32)	1109 (161)	—	9.54	48.1
Carbon fiber-epoxy (quasi-isotropic)	1.55	45.5 (6.6)	579 (84)	—	2.99	38

[a]For unidirectional composites, the reported modulus and tensile strength values are measured in the direction of fibers.
[b]The modulus-weight ratio and the strength-weight ratios are obtained by dividing the absolute values with the specific weight of the respective material. Specific weight is defined as weight per unit volume. It is obtained by multiplying density by the acceleration due to gravity.

Table 2.1 Properties of Selected Commercial Reinforcing Fibers

Fiber	Typical diameter, (μm)[a]	Specific gravity	Tensile modulus, GPa (Msi)	Tensile strength, GPa (ksi)	Strain to failure, (%)	Coefficient of thermal expansion (10^{-6}/°C)[b]	Poisson's ratio
Glass							
E-glass	10 (round)	2.54	72.4 (10.5)	3.45 (500)	4.8	5	0.2
S-glass	10 (round)	2.49	86.9 (12.6)	4.30 (625)	5.0	2.9	0.22
PAN carbon							
T-300[c]	7 (round)	1.76	231 (33.5)	3.65 (530)	1.4	−0.6 (longitudinal) 7–12 (radial)	0.2
AS-1[d]	8 (round)	1.80	228 (33)	3.10 (450)	1.32		
AS-4[d]	7 (round)	1.80	248 (36)	4.07 (590)	1.65		
T-40[c]	5.1 (round)	1.81	290 (42)	5.65 (820)	1.8	−0.75 (longitudinal)	
IM-7[d]	5 (round)	1.78	301 (43.6)	5.31 (770)	1.81		
HMS-4[d]	8 (round)	1.80	345 (50)	2.48 (360)	0.7		
GY-70[e]	8.4 (bilobal)	1.96	483 (70)	1.52 (220)	0.38		
Pitch carbon							
P-55[c]	10	2.0	380 (55)	1.90 (275)	0.5	−1.3 (longitudinal)	
P-100[c]	10	2.15	758 (110)	2.41 (350)	0.32	−1.45 (longitudinal)	
Aramid							
Kevlar[f] 49	11.9 (round)	1.45	131 (19)	3.62 (525)	2.8	−2 (longitudinal) 59 (radial)	0.35