UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2009/2010

November 2009

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

Duration : 3 jam
Masa : 3 jam

ARAHAN KEPADA CALON :
INSTRUCTION TO CANDIDATES:

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

Answer **FIVE (5)** questions. All questions carry the same marks.
*Jawab **LIMA (5)** soalan. Semua soalan membawa jumlah markah yang sama*

Student must answer the questions in English.
Pelajar mesti menjawab soalan dalam Bahasa Inggeris.

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

In the event of any discrepancies, the English version shall be used.
Sekiranya terdapat sebarang percanggahan pada kertas soalan, versi Bahasa Inggeris hendaklah digunakan pakai.

APPENDIX /*LAMPIRAN* [1 page/mukasurat]
[2 page/mukasurat]
[3 page/mukasurat]

1. (a) Sandwich composite materials consist of a number of different constituent materials. It is known that different parts of materials are responsible for distinct functions. Briefly describe the principles of the constituents of composites and their importance towards the performance of the structures with respects to their mechanical characteristic subjected to specified loading.

Sandwic bahan komposit terdiri daripada beberapa jenis juzuk bahan yang berbeza. Ia diketahui bahawa perbezaan setiap bahan mempunyai fungsi yang berlainan. Terangkan secara ringkas prinsip-prinsip unsur komposit dan kepentingannya terhadap prestasi struktur dengan merujuk kepada sifat mekanikal tertakluk kepada beban yang ditentukan.

(15 marks/*markah*)

(b) In a certain engineering application, unidirectional fibre reinforced epoxy composite has been used for structural materials. However, the composite is crucially designed so that the compressive strengths of the fibre should be as high as possible to prevent any unnecessary buckling. 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 high mechanical property (compressive strength). However, compromise should be made on the minimum weight criteria. Critically, include the justification of your answer.

Dalam aplikasi kejuruteraan tertentu, komposit fiber eka-arah yang diperkuat dengan epoxy telah digunakan sebagai bahan-bahan untuk membuat struktur bahan. Walau bagaimanapun, komposit perlu dicipta khas supaya mencapai kekuatan mampat fiber setinggi yang mungkin untuk mengelakkan 'buckling' yang tidak diperlukan. Jenis-jenis fiber yang akan dipertimbangkan adalah karbon fiber berkekuatan-tinggi, karbon fiber bermodulus tinggi dan Kevlar 49. Dengan menggunakan jadual yang diberikan, pilih salah satu dari fiber yang mempunyai sifat mekanikal yang tinggi (kekuatan mampat). Walaubagaimanapun kompromi perlu dibuat berdasarkan kriteria berat minimum. Secara kritis, sertakan justifikasi bagi jawapan anda.

Note that the compressive strength of unidirectional fiber is given by the following equation:

Ambil perhatian bahawa kekuatan mampat fiber eka-arah diberikan oleh persamaan berikut :

$$\sigma_{Euler\_buckling} = \frac{\pi^2 E}{16}\left(\frac{d}{L}\right)^2$$

Where E is the tensile modulus and d/L is the reciprocal of the aspect ratio. Note that the length, L of the fibre is remained the same for all three fibres.

Di mana E adalah modulus ketegangan dan (d/L) adalah nisbah angka salingan. Perhatikan bahawa panjang fiber L untuk ketiga-tiga jenis fiber adalah sama.

Fibres	**Diameter, d (µm)**	**Young's Modulus, E (GPa)**	**Specific gravity**
HM Carbon	8	390	1.80
HS Carbon	8	250	1.80
Kevlar™ 49	12	130	1.45

Table 1 [b]: Properties of the fibers.
Jadual 1[b]: Sifat-sifat fiber

(45 marks/*markah*)

(c) In typical fabrication of polymer matrix composite (PMC), two types of matrix systems are generally employed, namely thermoplastics and thermosetting resin. Figure 1 [c] shows the polymerisation process of thermosetting resin with respect to the curing temperature and time. Demonstrate your understanding on the curing process of thermosetting resin by comprehensively interpreting the following figure. The discussion may include the different stages of the polymerisation process of thermosetting matrix.

Dalam pembuatan polimer komposit matriks (PMC) biasa, terdapat dua jenis sistem matriks yang lazimnya digunapakai, iaitu termoplastik dan termosetting resin. Rajah 1(c) menunjukkan hubungan antara proses pempolimeran termosetting resin dengan suhu pengawetan dan masa. Tunjukkan sejauh mana pemahaman anda tentang proses pengawetan bagi termosetting resin dengan mentafsir rajah yang berikut. Perbincangan hendaklah mengambil kira perbezaan peringkat dalam proses pempolimeran termosetting matriks.

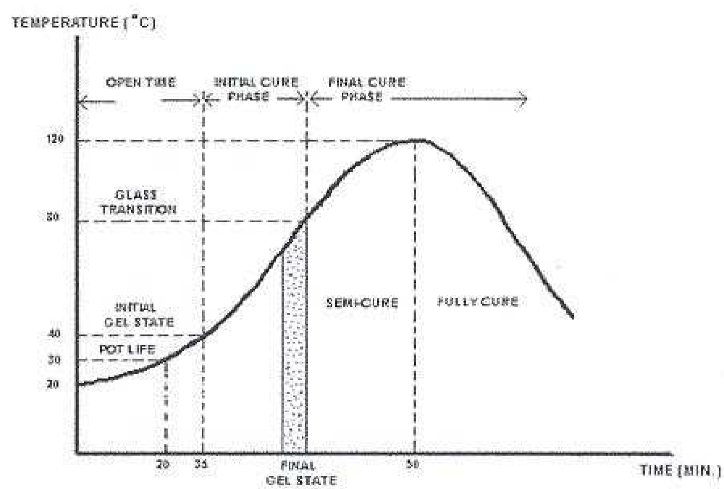

Figure 1 [c] : Polymerisation process of thermosetting resin with respect to the curing temperature and time.

Rajah 1[c] : Hubungan proses pempolimeran termosetting resin dengan suhu pengawetan dan masa

(40 marks/*markah*)

2. (a) Given the construction of the sandwich beam as in Figure 2 [a], the flexural rigidity of the structure, D is given as:

Rajah 2(a) menunjukkan senibina rasuk sandwic , ketegaran lenturan struktur D diberikan oleh persamaan berikut :

$$D = \int Ez^2 dz = \frac{E_f t_f^3}{6} + \frac{E_f t_f d^2}{2} + \frac{E_c t_c^3}{12} = 2D_f + D_0 + D_c$$

Where
Dimana

E_f = Young's modulus of the facing = 75 GPa
Ef = modulus Young permukaan = 75 GPa

E_c = Young's modulus of the core = 115 MPa
Ec = modulus Young teras = 115 MPa

t_f = thickness of the facing = 3 mm
tf = ketebalan permukaan = 3 mm

t_c = thickness of the core = 15 mm
tc = ketebalan teras = 15 mm

d = the distance between the centroids of the facing ($d = t_f + t_c$)
d = jarak antara permukaan centroids ($d = t_f + t_c$)

Based on the values given above, re-evaluate the equation and justify that the flexural rigidity of the sandwich is largely dependent on the second term of the equation rather than those of the first and third terms. Also, show how this equation can be simplified.

Berasaskan nilai yang diberi di atas, buat penilaian semula terhadap persamaan tersebut dan kemukakan alasan bahawa ketegaran lenturan sandwic sangat bergantung pada bahagian kedua persamaan berbanding bahagian pertama dan ketiga. Selain itu, tunjukkan bagaimana persamaan ini boleh dipermudahkan.

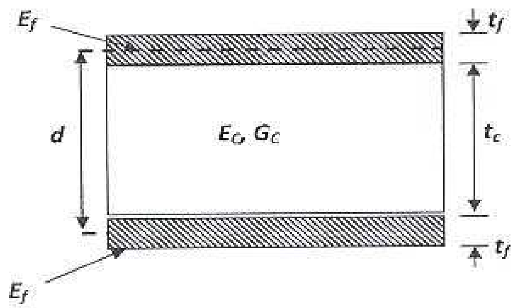

Figure 2 [a]: Sign convention for sandwich beams
Rajah 2[a] : Tanda konvensyen untuk rasuk sandwic

(60 marks/*markah*)

(b) A typical sandwich structure consists of a core bonded in between two faceplates using adhesive. A wide range of sandwich structures can be constructed by combining various faceplates and core materials. However, the selection of materials should comply with the principles and design criteria in order to achieve a good quality of the structure. Therefore, writes a summary based on your understanding of the selection criteria of the material for faceplate, core and adhesive with regards to their mechanical requirement, principles and design aspects.

Struktur sandwic biasanya terdiri daripada teras terikat yang terletak di antara dua plat-leper dengan menggunakan pelekat. Pelbagai jenis struktur sandwic boleh dibina dengan menggabungkan jenis plat-leper dan bahan teras. Walau bagaimanapun, pemilihan bahan-bahan harus mengikut prinsip dan kriteria reka bentuk bagi menghasilkan struktur yang berkualiti tinggi. Oleh itu, tuliskan satu ringkasan/kesimpulan berdasarkan pemahaman anda tentang kriteria pemilihan plat-leper, teras dan pelekat tertakluk kepada keperluan, prinsip dan aspek reka cipta mekanikal.

(40 marks/*markah*)

3. (a) The amount of fibres in a composite sample can be determined by a burn-out test; the burn-out eliminates all the resin and as a result, only the fibres remain. Given a scenario, in which a composite sample plus its container weighs 67.343 grams before burn-out and 65.598 grams after burn-out. The container weighs 62.022 grams. Based on the information given, compute correctly the fibre weighs fraction W_f and matrix weight fraction W_m.

Jumlah fiber dalam sampel komposit boleh ditentukan oleh ujian bakar; ujian bakar akan menyingkirkan semua resin dan hanya meninggalkan fiber. Pertimbangkan scenario berikut, di mana satu sampel komposit berserta bekas yang mempunyai berat sebelum bakar seberat 67.343 gram dan 65.598 gram selepas dibakar. Berat bekas ialah 62.022 gram. Berdasarkan maklumat yang diberi, kira dengan tepat pecahan berat fiber W_f dan pecahan berat matriks W_m.

(15 marks/*markah*)

(b) Using the simple square arrangement in Figure 3 [b], verify that fibres with square cross section can be packed to higher fibre volume fractions than fibres with round cross sections. Compare the fibre surface area per unit volume fraction for each cross section. In addition, explain the significance of the surface area calculations.

Dengan menggunakan susunan segi empat ringkas dalam Rajah 3[b], tentukan fiber yang mempunyai keratan rentas bersegi boleh disusun untuk menjadi pecahan fiber berisipadu tinggi berbanding fiber keratan rentas bulat. Buat perbandingan pecahan permukaan fiber per unit isi padu untuk setiap keratan rentas. Selain itu, terangkan manfaat pengiraan kawasan permukaan.

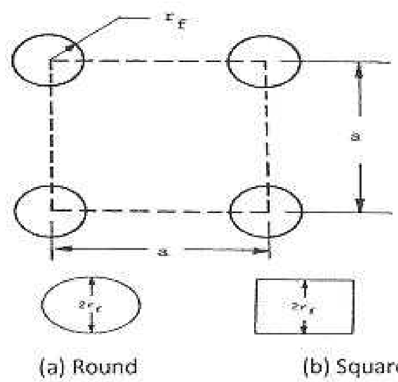

Figure 3[b]: Simple square unit, representative of fibre packing arrangement.
Rajah 3[b]: Unit segi empat ringkas, mewakili susunan fiber dalam bungkusan

(25 marks/*markah*)

(c) Consider a unidirectional composite consists of AS-4 carbon fibres and 3501-6 epoxy matrix with the properties as listed in Appendix 1 and Appendix 2, respectively. In addition, Appendix 3 also shows the properties of typical unidirectional composites.

Dengan anggapan bahawa komposit eka-arah mengandungi AS-4 fiber karbon dan 3501-6 matrik epoxi. Sifat bahan untuk kedua-dua bahan masing-masing disenaraikan dalam Lampiran 1 dan Lampiran 2. Selain itu, Lampiran 3 juga menunjukkan sifat-sifat tipikal komposit.

(i) Based on the information listed in Appendix 1, 2 and 3, determine the longitudinal modulus E_l of the composite using the rule of mixture equation. Compare the value from that of the Appendix 3 and discuss what might cause the difference.

Berasaskan maklumat yang disenaraikan dalam Lampiran 1, 2 dan 3, tentukan modulus longitud E_l untuk komposit tersebut dengan menggunakan persamaan hukum campuran. Bandingkan nilai tersebut dengan nilai dalam Lampiran 3 dan bincangkan apakah punca yang menyebabkan nilainya berbeza.

(ii) Similarly, based on the information listed in Appendix 1, 2 and 3, determine the transverse modulus E_2 of the composite using the mechanics of materials approach. Also, compare the value from that of the Appendix 3 and discuss what might cause the difference.

Berasaskan maklumat yang disenaraikan dalam Lampiran 1, 2 dan 3, tentukan modulus melintang E_2 untuk komposit dengan menggunakan pendekatan mekanik bahan. Buat perbandingan nilai tersebut dengan nilai dalam Lampiran 3 dan bincangkan apakah punca yang menyebabkan nilainya berbeza.

(60 marks/*markah*)

4. (a) The load-strain data obtained in a tensile test of a unidirectional carbon fibre-epoxy composite are given in the following table. Specimen dimensions are as follows: length = 254 mm, width = 12.7 mm, and thickness = 1.4 mm. Plot the stress vs. strain responses in a graph paper and subsequently determine the tensile modulus for each fibre orientation.

Jadual berikut menunjukkan senarai data load-strain yang diperolehi dari ujian ketegangan komposit eka-arah karbon fibre-epoxi . Dimensi spesimen adalah seperti berikut: panjang = 254 mm, lebar = 12.7 mm, dan tebal = 1.4 mm. Dengan menggunakan kertas graf, Lakarkan ketegasan melawan keterikan dan selepas itu tentukan modulus tegangan untuk setiap orientasi fiber.

Axial strain %	**Load (N)**		
	0^0	**45^0**	**90^0**
0.05	2130	130	67
0.10	4270	255	134
0.15	6400	360	204
0.20	8620	485	333
0.25	-	565	396

Table 4 [a]: Result of tensile test of a unidirectional CFRP/epoxy composite.
Jadual 4[a] : Keputusan ujian ketegangan bagi komporit eka-arah CFRP/epoxi.

(60 marks/*markah*)

(b) The following longitudinal tensile strength data (in MPa) were obtained for a $[0/\pm45/90]_S$ E-glass fibre-epoxy laminate: 520.25, 470.27, 457.60, 541.18, 566.35, 489.82, 524.55, 557.87, 490.00, 498.99, 496.95, 510.84, and 558.76. Determine the average tensile strength, the standard deviation and coefficient of variation.

Berikut adalah data kekuatan tegangan longitud (dalam MPa) diperoleh untuk (0 /±45/90) fibre-epoxy e-glass laminate : 520.25, 470.27, 457.60, 541.18, 566.35, 489.82, 524.55, 557.87, 490.00, 498.99, 496.95, 510.84, dan 558.76. Tentukan purata kekuatan tegangan, sisihan piawai dan pekali berlainan.

(40 marks/*markah*)

5. (a) Consider a carbon fibre/epoxy composite laminate in pre-preg forms fabricated using a bag moulding process as shown schematically in Figure 5 [a(i)]. The composite then, will be cured by using an autoclave technique with a two-stage cure cycle as shown in Figure 5[a(ii)]. Critically interprets the graph by analysing every sections of the stage. Your discussion should include the temperature, pressure and vacuum distribution profiles as well as viscosity state of the resin.

Rajah 5[a(i)] menunjukkan gambar rajah skema untuk proses pengacuan beg bagi lapisan yang disaluti dengan karbon fiber/epoxi komposit dalam bentuk pre-preg. Kemudian, komposit akan diawetkan dengan menggunakan teknik autoklaf dengan kitaran pengawetan dua-peringkat seperti yang ditunjukkan oleh Rajah 5[a(ii)]. Tafsirkan graf dengan membuat analisa pada setiap bahagian di setiap peringkat. Perbincangan haruslah mengambil kira suhu, tekanan, bentuk pengagihan vakum dan tahap kelikatan resin.

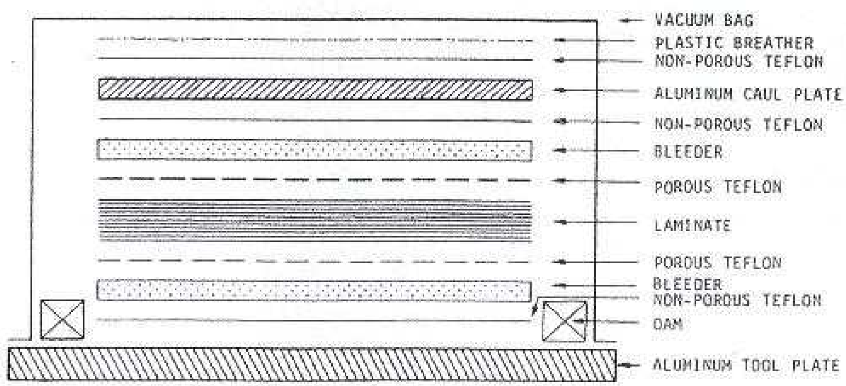

Figure 5 [a(i)]: Schematic of a bag moulding process.
Rajah 5[a(i)]: Rajah skema untuk proses pengacuan beg

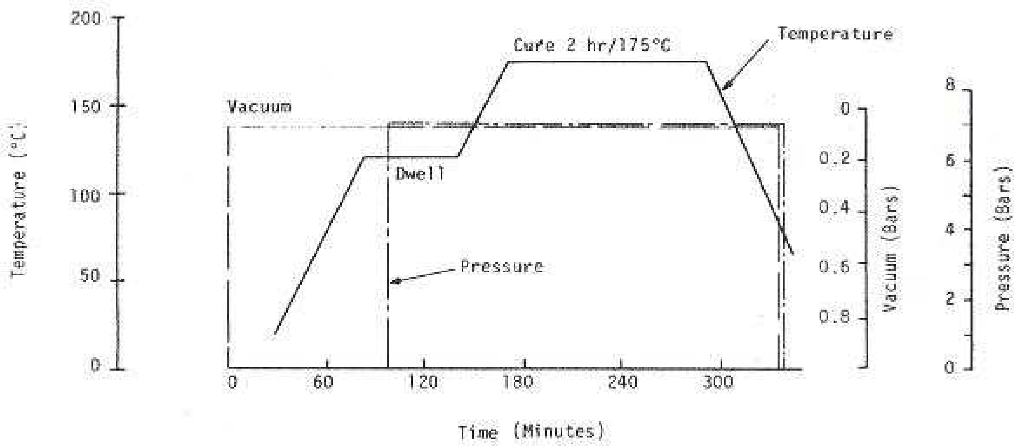

Figure 5 [a(ii)]: A two-stage cure cycle for a carbon fibre-epoxy prepreg.
Rajah 5[a(ii)] : Kitaran pengawetan dua-peringkat untuk karbon fibre-epoxy prepreg

(50 marks/*markah*)

(b) The following Figure 5[b] shows two cure cycles and the corresponding viscosity-time curves for an epoxy-based prepreg. Which of these cure cycles is expected to produce better and uniform mechanical properties. Critically, please justify your answer.

Rajah 5(b) menunjukkan dua kitaran pengawetan dan lengkung sepadan kelikatan melawan masa bagi asas epoxy pre-preg. Di mana kitaran pengawetan ini dijangka akan menghasilkan sifat mekanikal yang lebih baik dan seragam. Secara kritis, huraikan jawapan anda .

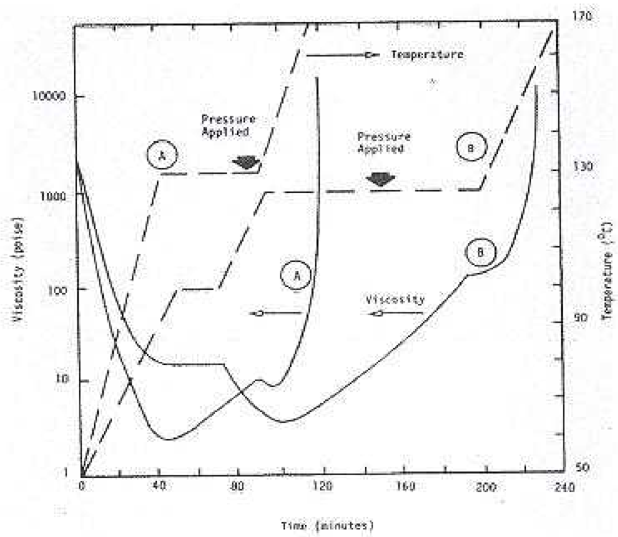

Figure 5 [b]: The cure cycles and the corresponding viscosity-time curve of epoxy-based prepreg.

Rajah 5[b]: Kitaran pengawetan dan lengkung sepadan kelikatan melawan masa bagi asas epoxy pre-preg

(50 marks/*markah*)

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APPENDIX 1

TABLE A.2 Mechanical and Thermal Properties of Representative Fibers

Property	E-Glass	S-Glass	AS-4 Carbon	T-300 Carbon	IM7 Carbon	Boron	Kevlar 49 Aramid	Silicon Carbide (Nicalon)
Longitudinal modulus, E_{lf}, GPa (Msi)	73 (10.5)	86 (12.4)	235 (34)	230 (33)	290 (42)	395 (57)	131 (19)	172 (25)
Transverse modulus, E_{tf}, GPa (Msi)	73 (10.5)	86 (12.4)	15 (2.2)	15 (2.2)	21 (3)	395 (57)	7 (1.0)	172 (25)
Axial shear modulus, G_{12f}, GPa (Msi)	30 (4.3)	35 (5.0)	27 (4.0)	27 (4.0)	14 (2)	165 (24)	21 (3.1)	73 (10.6)
Transverse shear modulus, G_{23f}, GPa (Msi)	30 (4.3)	35 (5.0)	7 (1.0)	7 (1.0)	—	—	—	—
Poisson's ratio, ν_{12f}	0.23	0.23	0.20	0.20	0.20	0.13	0.33	0.20
Longitudinal tensile strength, F_{lf}, MPa (ksi)	3450 (500)	4500 (650)	3700 (535)	3100 (450)	5170 (750)	3450 (500)	3800 (550)	2070 (300)
Longitudinal coefficient of thermal expansion, α_{lf}, 10^{-6}/°C (10^{-6}/°F)	5.0 (2.8)	5.6 (3.1)	−0.5 (−0.3)	−0.7 (−0.4)	−0.2 (−0.1)	16 (8.9)	−2 (−1.1)	3.2 (1.8)
Transverse coefficient of thermal expansion, α_{tf}, 10^{-6}/°C (10^{-6}/°F)	5.0 (2.8)	5.6 (3.1)	15 (8.3)	12 (6.7)	10 (5.6)	16 (8.9)	60 (33)	3.2 (1.8)

APPENDIX 2

TABLE A.3 Properties of Typical Polymer Matrix Materials

Property	Epoxy (3501-6)	Epoxy (977-3)	Epoxy (HY6010/ HT917/DY070)	Polyesters	Vinylester (Derakane)	Polyimides	Poly-ether-ether-ketone (PEEK)
Density, ρ, g/cm^3 (lb/in^3)	1.27 (0.046)	1.28 (0.046)	1.17 (0.043)	1.1–1.5 (0.040–0.054)	1.15 (0.042)	1.4–1.9 (0.050–0.069)	1.32 (0.049)
Young's modulus, E_m, GPa (Msi)	4.3 (0.62)	3.7 (0.54)	3.4 (0.49)	3.2–3.5 (0.46–0.51)	3–4 (0.43–0.58)	3.1–4.9 (0.45–0.71)	3.7 (0.53)
Shear modulus, G_m, GPa (Msi)	1.60 (0.24)	1.37 (0.20)	1.26 (0.18)	0.7–2.0 (0.10–0.30)	1.1–1.5 (0.16–0.21)		
Poisson's ratio, ν_m	0.35	0.35	0.36	0.35	0.35		
Tensile strength, F_{mt}, MPa (ksi)	69 (10)	90 (13)	80 (11.6)	40–90 (5.8–13.0)	65–90 (9.4–13.0)	70–120 (10.1–17.4)	96 (14)
Compressive strength, F_{mc}, MPa (ksi)	200 (30)	175 (25)	104 (15.1)	90–250 (13–35)	127 (18.4)		
Shear strength, F_{ms}, MPa (ksi)	100 (15)	52 (7.5)	40 (5.8)	45 (6.5)	53 (29)		
Coefficient of thermal expansion, α_m, 10^{-6}/°C (10^{-6}/°F)	45 (25)	—	62 (3.4)	60–200 (33–110)	100–150 (212–514)	90 (50)	
Glass transition temperature, T_g, °C (°F)	200 (390)	200 (390)	152 (305)	50–110 (120–230)	—	280–320 (540–610)	143 (290)
Maximum use temperature, T_{max}, °C (°F)	150 (300)	177 (350)	—	—	—	300–370 (570–700)	250 (480)
Ultimate tensile strain, ε^u_{mt} (%)	2–5	—	—	2–5	1–5	1.5–3.0	

TABLE A.4 Properties of Typical Unidirectional Composites (Two-Dimensional)

Property	E-Glass/ Epoxy	S-Glass/ Epoxy	Kevlar/Epoxy (Aramid 49/ Epoxy)	Carbon/Epoxy (AS4/3501-6)	Carbon/Epoxy (IM6G/3501-6)
Fiber volume ratio, V_f	0.55	0.50	0.60	0.63	0.66
Density, ρ, g/cm^3 (lb/in^3)	1.97 (0.071)	2.00 (0.072)	1.38 (0.050)	1.60 (0.058)	1.62 (0.059)
Longitudinal modulus, E_1, GPa (Msi)	41 (6.0)	45 (6.5)	80 (11.6)	147 (21.3)	169 (24.5)
Transverse modulus, E_2, GPa (Msi)	10.4 (1.50)	11.0 (1.60)	5.5 (0.80)	10.3 (1.50)	9.0 (1.30)
In-plane shear modulus, G_{12}, GPa (Msi)	4.3 (0.62)	4.5 (0.66)	2.2 (0.31)	7.0 (1.00)	6.5 (0.94)
Major Poisson's ratio, ν_{12}	0.28	0.29	0.34	0.27	0.31
Minor Poisson's ratio, ν_{21}	0.06	0.06	0.02	0.02	0.02
Longitudinal tensile strength, F_{1t}, MPa (ksi)	1140 (165)	1725 (250)	1400 (205)	2280 (330)	2240 (325)
Transverse tensile strength, F_{2t}, MPa (ksi)	39 (5.7)	49 (7.1)	30 (4.2)	57 (8.3)	46 (6.7)
In-plane shear strength, F_6, MPa (ksi)	89 (12.9)	70 (10.0)	49 (7.1)	76 (11.0)	73 (10.6)
Ultimate longitudinal tensile strain, ε_{1t}^u	0.028	0.029	0.015	0.015	0.013
Ultimate transverse tensile strain, ε_{2t}^u	0.005	0.006	0.005	0.006	0.005
Longitudinal compressive strength, F_{1c}, MPa (ksi)	620 (90)	690 (100)	335 (49)	1725 (250)	1680 (245)
Transverse compressive strength, F_{2c}, MPa (ksi)	128 (18.6)	158 (22.9)	158 (22.9)	228 (33)	215 (31)
Longitudinal thermal expansion coefficient, α_1, 10^{-6}/°C (10^{-6}/°F)	7.0 (3.9)	7.1 (3.9)	−2.0 (−1.1)	−0.9 (−0.5)	−0.9 (−0.5)
Transverse thermal expansion coefficient, α_2, 10^{-6}/°C (10^{-6}/°F)	26 (14.4)	30 (16.7)	60 (33)	27 (15)	25 (13.9)
Longitudinal moisture expansion coefficient, β_1	0	0	0	0.01	0
Transverse moisture expansion coefficient, β_2	0.2	0.2	0.3	0.2	—