First Semester Examination
2019/2020 Academic Session

December 2019 / January 2020

EMM 331 – Solid Mechanics
[Mekanik Pepejal]

Duration : 3 hours
[Masa : 3 jam]

Please check that this paper contains **THIRTEEN [13]** printed pages including appendixes before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **TIGA BELAS [13]** mukasurat bercetak beserta lampiran sebelum anda memulakan peperiksaan.]*

INSTRUCTIONS : Answer **ALL FIVE [5]** questions.
*[**ARAHAN** : Jawab **SEMUA LIMA [5]** soalan.]*

Answer Questions In **English** OR **Bahasa Malaysia**.
*[Jawab soalan dalam **Bahasa Inggeris** ATAU **Bahasa Malaysia**.]*

Answer to each question must begin from a new page.
[Jawapan bagi 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 soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.

1. [a] **With the help of sketches, provide brief answers to the following questions:**

Dengan bantuan lakaran, berikan jawapan ringkas bagi soalan di bawah:

(i) **Define strain energy and indicate the difference between elastic and plastic strain energy in a closed loop cyclic stress-strain graph.**
Takrifkan tenaga terikan dan tunjukkan perbezaan antara tenaga terikan elastik dan plastik pada graf tegasan-terikan berkitar yang tertutup.

(ii) **Distinguish between modulus of toughness and modulus of resilience.**
Bezakan antara modulus keliatan dan modulus kebingkasan.

(30 marks/*markah***)**

[b] **A beam having a stiffness EI and GJ, is bent in an L-shape in the horizontal plane as shown in Figure 1 [b]. Determine the deflection under the vertical end load F at point A.**

Sebuah rasuk yang mempunyai kekakuan EI dan GJ, dibengkokkan mengikut bentuk-L pada satah mendatar seperti tertera pada Rajah 1 [b].Tentukan perubahan bentuk pada titik beban menegak F pada titik A.

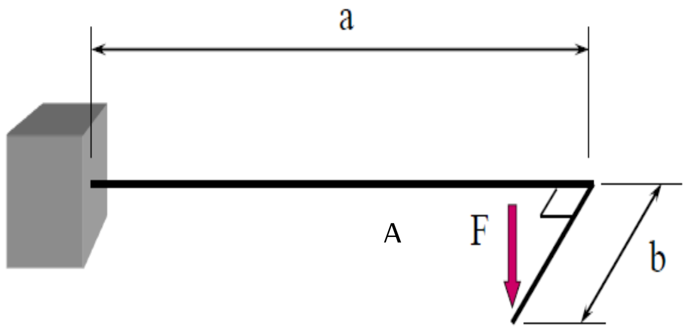

Figure 1 [b]
Rajah 1 [b]

(70 marks/*markah***)**

2. [a] **A steel has shown a cyclic softening behaviour under a tension-compression test at high temperature. With the aid of stress-strain graphs:**

Suatu keluli menunjukkan sifat pelembutan berkitar dalam ujikaji tegangan-mampatan pada suhu tinggi. Dengan bantuan graf tegasan-terikan:

(i) **Explain basic parameters of stress-strain graph, under cyclic plasticity behaviour, such as stress, strain and plastic strain range.**
Terangkan parameter-parameter asas pada graf tegasan-terikan, yang berada di bawah sifat plastik berkitar, seperti julat tegasan, terikan dan terikan plastik.

(ii) **Describe the cyclic softening behaviour of the steel under a strain-controlled and a stress-controlled test.**
Berikan gambaran sifat pelembutan berkitar bagi keluli berkenaan dalam keadaan ujikaji terikan terkawal dan ujikaji tegasan terkawal.

(35 marks/*markah*)

[b] **In an engineering component made of steel, the most severely stressed point is subjected to the following state of stress as shown below where all stresses are in MPa and the yield strength of the steel is 1000 MPa. Based on the given data:**

Pada sebuah komponen kejuruteraan yang diperbuat daripada keluli, titik tegasan paling tinggi mempunyai keadaan tegasan seperti ditunjukkan di bawah yang mana semua tegasan dalam unit MPa dan kekuatan alah keluli berkenaan ialah 1000 MPa. Berdasarkan data yang diberi:

(i) **Sketch the 3 dimensional Mohr's circle for the stress state, and**
Lakarkan bulatan Mohr 3 dimensi bagi keadaan tegasan ini.

(ii) **Analyze the material's yielding condition based on Tresca and von-Mises criteria.**
Analisa keadaan alahan keluli ini berdasarkan kriteria Tresca dan kriteria von-Mises.

$$\sigma_{ij} = \begin{pmatrix} 400 & -100 & 0 \\ -100 & 200 & -50 \\ 0 & -50 & -600 \end{pmatrix}$$

(65 marks/*markah*)

3. [a] (i) **Explain stress concentration concept using flow lines analogy. Also, suggest methods of reducing stress concentration effect for the plate shown in Figure 3 [a-i].**

Terangkan konsep penumpuan tegasan dengan menggunakan analogi aliran bendalir. Juga cadangkan kedah-kaedah bagi pengurangan kesan penumpuan tegasan bagi plat yang ditunjukkan pada Rajah 3 [a-i].

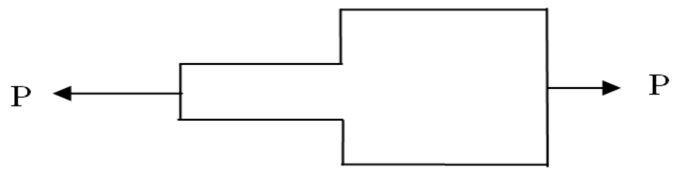

Figure 3 [a-i]
Rajah 3 [a-i]

(20 marks/*markah***)**

(ii) **A built-up shaft shown in Figure 3 [a-ii] is designed to rotate at 600 rpm. If the radius at the transition on the shaft is r = 7.2 mm, and the allowable shear stress for the material is 55 MPa, determine the maximum power the shaft can transmit. Please refer to Appendix 2 for stress concentration factor graph (Power, P=2πfT)**

Sebuah aci bergabung seperti Rajah 3 [a-ii] direka untuk berputar pada 600 rpm. Jika jejari pada peralihan aci ialah r = 7.2 mm, dan tegasan ricih yang dibenarkan untuk bahan berkenaan ialah 55 MPa, tentukan kuasa maksimum yang boleh dipindahkan oleh aci. Sila rujuk pada Lampiran 2 untuk graf faktor penegasan tegasan. (Kuasa, P=2πfT)

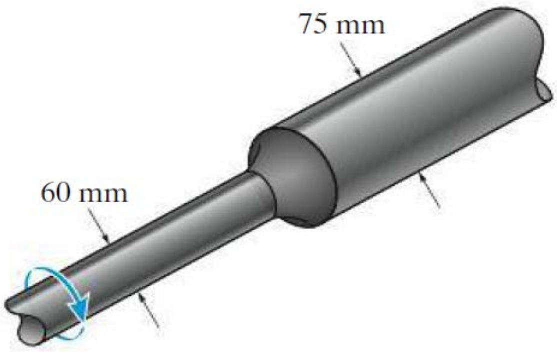

Figure 3 [a-ii]
Rajah 3 [a-ii]

(30 marks/*markah***)**

[b] **A long thin walled pipe constrained by end fittings made of polyvinylchloride is subjected to a steady internal pressure of p = 700 kN/m^2 at temperature, T = 20℃ as shown in Figure 3 [b].**

Suatu paip polivinilklorida yang mempunyai dinding nipis yang di kekang pada kedua-dua hujungnya dikenakan tekanan dalaman p = 700 kN/m^2 pada suhu T = 20℃ digambarkan pada Rajah 3 [b].

(i) **If a tensile stress σ = of 17.5 MN/m^2 is not to be exceeded and the internal radius, r, is 100 mm, determine a suitable thickness, t, of the pipe.**
Sekiranya tegasan tegangan yang dikenakan tidak melebihi σ = 17.5 MN/m^2 dan jejari dalaman, r, paip ialah 100 mm, tentukan ketebalan, t, paip itu.

(ii) **Assuming the pipe is allowed to endure a 0.5% of maximum creep strain, ε_{cr}, calculate the modulus of elasticity $E(t)$. Then propose the increase of the pipe in diameter, Δd, at 1000 hours.**
Sekiranya paip dianggapkan dapat mengalami terikan rayapan maksima, ε_{cr} sebanyak 0.5%, cadangkan perubahan diameter paip, Δd, selepas 1000 jam.

The mean creep contraction ratio ν is 0.45 and the tensile creep curves as shown in Table 3 provide the following values at 1000 hours

σ (MN/m^2)	6.9	13.8	20.7	27.6	34.5
ε_{cr} (%)	0.2	0.48	0.92	1.72	3.38

Table 3 [b]
Jadual 3 [b]

Refer to Appendix 1 for appropriate formulas to use in your solutions.

Rujuk Lampiran 1 untuk penggunaan formula yang sesuai untuk penyelesaian anda.

(50 marks/*markah*)

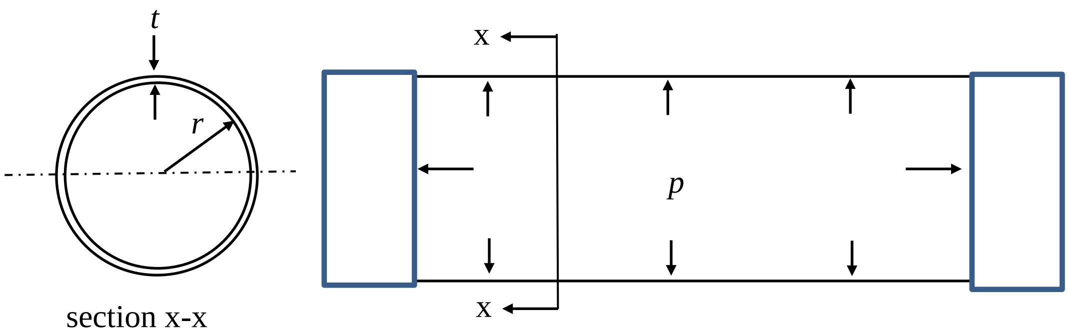

Figure 3 [b]
Rajah 3 [b]

4. [a] **Using equations 4.1 and 4.2, explain the similarity of both equations in determining the tip stress σ_{tip} of the geometric discontinuity in an infinite plate such as the ellipse as shown in Figure 4 [a] where *a* and *b* is the width and height of the ellipse respectively and ρ is the radius of the ellipse. Then, explain the limit of both concepts in the determination of tip stress σ_{tip} when the ellipse becomes sharp.**

$$\frac{\sigma_{tip}}{\sigma_{applied}} = 1 + \frac{2a}{b} \qquad 4.1$$

$$\frac{\sigma_{tip}}{\sigma_{applied}} = 1 + 2\sqrt{\frac{a}{\rho}}; \quad where\ \rho = b^2/a \qquad 4.2$$

Menggunakan persamaan 4.1 dan 4.2, terangkan kesamaan kedua-dua konsep dalam menentukan tegasan hujung σ_{tip} pada ketakselanjaran seperti elips yang digambarkan oleh Rajah 4 [a] yang mana a dan b adalah lebar dan tinggi elips dan ρ adalah jejari elips. Kemudian terangkan had kedua-dua konsep dalam menentukan tegasan hujung σ_{tip} apabila elips menjadi tajam.

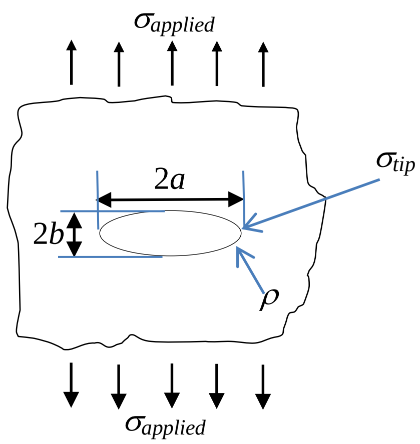

Figure 4 [a]
Rajah 4 [a]

(40 marks/*markah*)

[b] **In a fracture toughness test involving three-point bending, the following information was recorded: support span = 180 mm; specimen thickness = 22.8 mm; specimen width = 44.72 mm; crack length = 21.92 mm; fracture force = 19.8 kN. Justify whether these data are suitable for measuring critical fracture toughness, K_{Ic} for the material. The yield stress of the material is 350 MN/m^2.**

Maklumat daripada suatu ujian keliatan patah bagi specimen lenturan tiga-titik di dapati seperti berikut: Panjang penyokong = 180 mm; ketebalan specimen = 22.8 mm; kelebaran specimen = 44.72 mm; Panjang retak = 21.92 mm; daya patah = 19.8 kN. Tentusahkan bahawa maklumat yang direkodkan ini sesuai untuk penentuan keliatan patah kritikal, K_{Ic} bahan tersebut. Tegasan alah untuk bahan yang digunakan adalah 350 MN/m^2.

The crack calibration factor can be calculated from Appendix 3

Faktor kalibrasi retak boleh dikira daripada Lampiran 3.

(60 marks/*markah*)

5. [a] **The concept of stress-cycles curves and the concept of fatigue crack growth have been used to determine the limit of components performance due to fatigue loading. Explain both different techniques to determine the limit of component performance due to fatigue loads and explain which concept is better to approximate fatigue failure in the presence of defects in components.**

Konsep lengkungan tegasan-kitaran dan konsep perambatan retak berkitar telah digunakan untuk menentukan had prestasi sesuatu komponen akibat daripada beban lesu. ***.*** *Terangkan perbezaan kedua-dua teknik dalam menentukan had kepada prestasi komponen akibat daripada beban lesu dan terangkan konsep manakah yang paling sesuai untuk menganggarkan kegagalan lesu pada kehadiran kecacatan dalam komponen.*

(40 marks/*markah*)

[b] **A pressure vessel support bracket is to be designed so that it can withstand a tensile loading cycle of 0-500 MN/m^2 once every day for 25 years. Which of the following steels would have the greater tolerance to initial crack length, a_i, in a pressure vessel application:**

Rekabentuk suatu kebuk tekanan hendaklah ditetapkan supaya berupaya mengalami kitar tegangan di antara 0-500 MN/m^2 sekali setiap hari selama 25 tahun. Di antara kedua-dua keluli yang diberikan di bawah, yang manakah lebih toleran kepada kepanjangan retak awal, a_i, dalam aplikasi kebuk tekanan:

(i) **A maraging steel (K_{Ic} = 82 MNm$^{-3/2}$, C = 0.15$\times$10^{-11} m/cycle/MNm$^{-3/2}$, m = 4.1)**
Keluli penuaan-martensit (K_{Ic} = 82 MNm$^{-3/2}$, C = 0.15$\times$10^{-11} m/kitar/MNm$^{-3/2}$, m = 4.1)

(ii) **A medium-strength steel (K_{Ic} = 50 MNm$^{-3/2}$, C = 0.24$\times$10^{-11} m/cycle/MNm$^{-3/2}$, m = 3.3)**
Keluli karbon-sederhana (K_{Ic} = 50 MNm$^{-3/2}$, C = 0.24$\times$10^{-11} m/kitar/MNm$^{-3/2}$, m = 3.3)

For the loading situation a geometry calibration factor Y = 1.12 may be assumed.

Bagi bebanan yang dialami retak, anggapkan factor kalibrasi retak Y = 1.12.

(60 marks/*markah*)

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APPENDIX 1
LAMPIRAN 1

Selected formulas

Selected stress-strain relation for elastic deformation

Strain	$\varepsilon = \frac{\delta}{L} = \frac{\Delta D}{D}$
Modulus of elasticity	$E = \frac{F}{\delta} = \frac{F/A}{\delta/L} = \frac{\sigma}{\varepsilon}$
General stress-strain relationships	$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \nu\left(\sigma_y + \sigma_z\right)\right]$ $\varepsilon_y = \frac{1}{E}\left[\sigma_y - \nu(\sigma_z + \sigma_x)\right]$ $\varepsilon_z = \frac{1}{E}\left[\sigma_z - \nu\left(\sigma_x + \sigma_y\right)\right]$

Selected theories of failure

Tresca:	$\sigma_o = MAX(\lvert\sigma_1 - \sigma_2\rvert, \lvert\sigma_2 - \sigma_3\rvert, \lvert\sigma_3 - \sigma_1\rvert)$
von Mises:	$\sigma_o = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$

Stress Invariants:

$$I_1 = \sigma_x + \sigma_y + \sigma_z$$
$$I_2 = \sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - \tau_{xy}{}^2 - \tau_{yz}{}^2 - \tau_{zx}{}^2$$
$$I_3 = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{yz}\tau_{zx} - \sigma_x\tau_{yz}{}^2 - \sigma_y\tau_{zx}{}^2 - \sigma_z\tau_{xy}{}^2$$

$$\sigma^3 - \sigma^2 I_1 + \sigma I_2 - I_3 = 0$$

Basic strain energy formulas

Load category	General Expression for strain energy	Particular case for constant load and geometry	Strain Energy per unit volume
Tension	$\int \frac{F^2}{2AE}dx$	$\frac{F^2 L}{2AE}$	$\frac{\sigma^2}{2E}$
Simple shear	$\int \frac{Q^2}{2AG}dx$	$\frac{Q^2 L}{2AG}$	$\frac{\tau^2}{2G}$
Torsion	$\int \frac{T^2}{2GJ}dx$	$\frac{T^2 L}{2GJ}$	$\frac{\tau_m^2}{4G}$ for circular section
Bending	$\int \frac{M^2}{2EI}dx$	$\frac{M^2 L}{2EI}$	$\frac{\sigma_m^2}{6E}$ for rectangular section

Selected trigonometric applications

Selected Trigonometric identities	Selected Trigonometric integrals
$\sin^2\theta = \frac{1}{2}(1 - \cos 2\theta)$	$\int \sin x\, dx = -\cos x + c$
$\cos^2\theta = \frac{1}{2}(1 + \cos 2\theta)$	$\int \cos x\, dx = \sin x + c$
$\sin\theta \cos\theta = \frac{1}{2}\sin 2\theta$	

Selected formulas for stresses for pressurized systems

Hoop stress:	$\sigma_H = \frac{pr}{t}$	for relatively thin wall vessel
Longitudinal stress:	$\sigma_L = \frac{pr}{2t}$	for relatively thin wall vessel
Hoop and Longitudinal stress	$\sigma_H = \sigma_L = \frac{pr}{t}$	for relatively thin spherical vessel

Selected basic formula for fracture and fatigue problems

Stress intensity	$K = Y\sigma\sqrt{\pi a}$
Linear elastic fracture mechanics limits	$a, B \geq 2.5\left(\frac{K_Q}{\sigma_Y}\right)^2$ $0.45 < \left(\frac{a}{W}\right) < 0.55$ $F_Q \leq 1.1F_{yield}$
Paris' Law	$\frac{da}{dN} = C(\Delta K)^m$

APPENDIX 2
LAMPIRAN 2

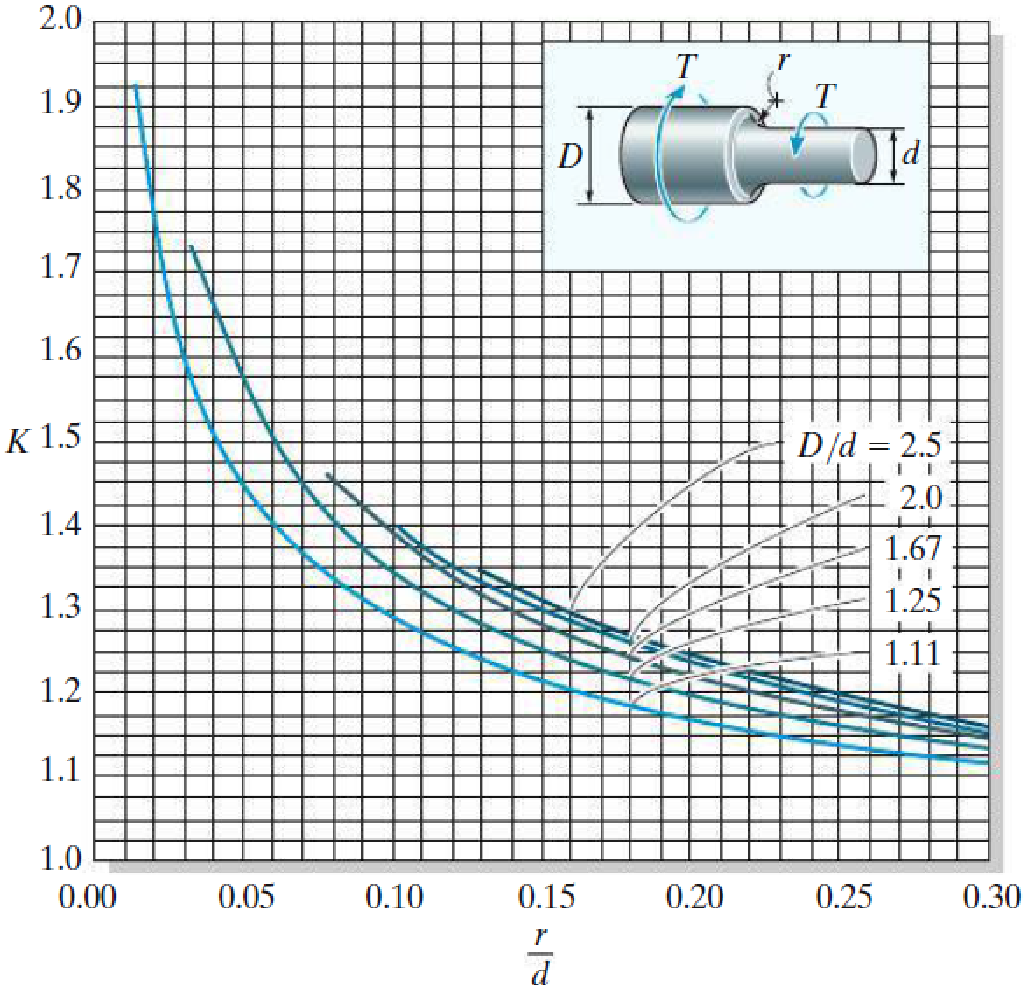


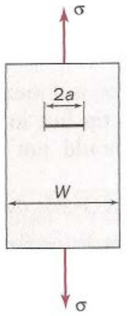
Figure A2: Stress Concentration factors for fillets in circular shafts.

APPENDIX 3

LAMPIRAN 3

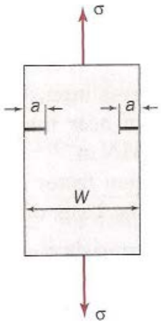
Stress intensity factor *K* formulas for selected geometries

1. Finite width plate



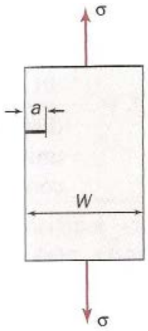
$$K = \sigma(\pi a)^{1/2}\left(\frac{W}{\pi a}\tan\frac{\pi a}{W}\right)^{1/2}$$

2. Double-edge crack



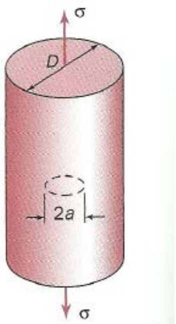
$$K = \sigma(\pi a)^{1/2}\left(\frac{W}{\pi a}\tan\frac{\pi a}{W} + \frac{0.2W}{\pi a}\sin\frac{\pi a}{W}\right)^{1/2}$$

3. Single-edge crack

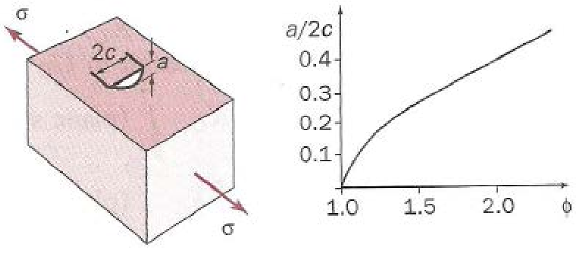
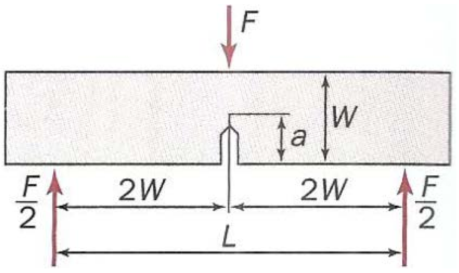


$$K = \sigma(\pi a)^{1/2}\left[1.12 - 0.23\left(\frac{a}{W}\right) + 10.6\left(\frac{a}{W}\right)^2 - 21.7\left(\frac{a}{W}\right)^3 + 30.4\left(\frac{a}{W}\right)^4\right]$$

4. Penny-shaped internal crack



$$K = \sigma(\pi a)^{\frac{1}{2}}\left(\frac{2}{\pi}\right)$$

5. Elliptical surface crack 	$K = \sigma(\pi a)^{\frac{1}{2}}\left(\frac{1.12}{\varphi^{1/2}}\right)$
6. Three-point bending 	$K = \frac{3FL}{2BW^{3/2}}\left[1.93\left(\frac{a}{W}\right)^{\frac{1}{2}} - 3.07\left(\frac{a}{W}\right)^{\frac{3}{2}} + 14.53\left(\frac{a}{W}\right)^{\frac{5}{2}} - 25.11\left(\frac{a}{W}\right)^{\frac{7}{2}} + 25.8\left(\frac{a}{W}\right)^{\frac{9}{2}}\right]$