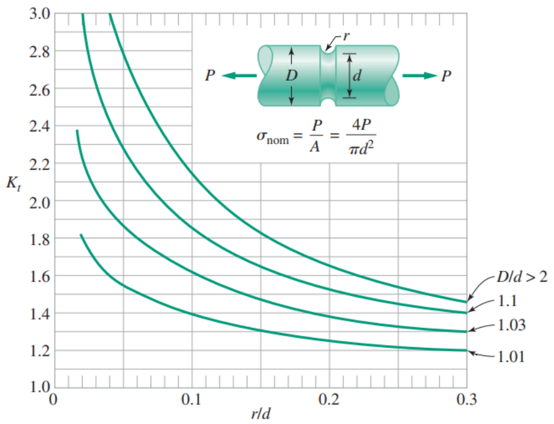
Fatigue of Structures – Assignment 2

Problem 1

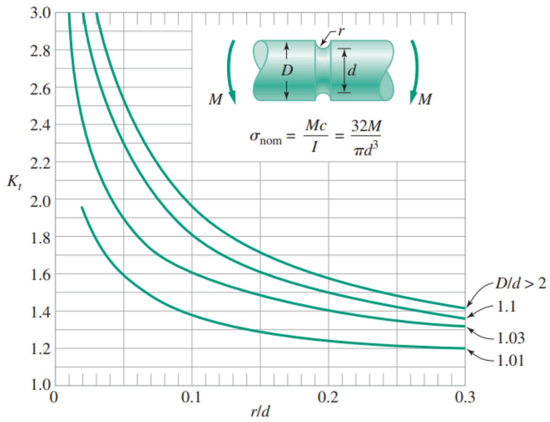
A shaft with a groove has a diameter D = 80 mm, d = 40 mm and r = 4.0 mm.

a) Determine K_t values for axial loading, bending and torsion. Compare K_t values and discuss the reasons for possible differences. The axial, bending and torsion loads are 100 kN, 10 kNm 1 kNm, respectively.

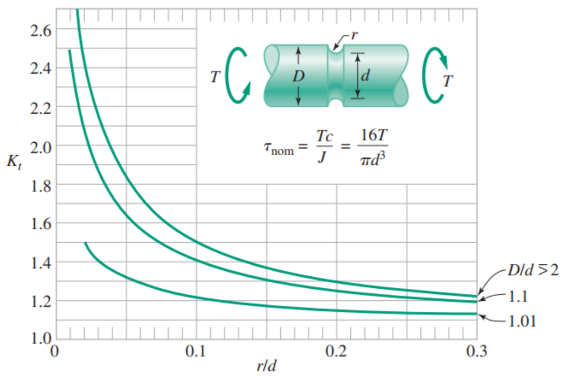
b) Estimate the fatigue notch factor K_f for axial loading (Load ratio R=-1) when the shaft is made of the following steels: 1) HR steel 1020, 2) quenched and tempered 4340 (HB 350), see Table 1. Compare K_f values and discuss the reasons for possible differences.



(a)



(b)



(c)

Figure 1 Stress concentration factor K_t for axial loading (a), bending (b) and torsion (c)

Table 1 Material properties of selected Engineering Alloys

TABLE A.2 Monotonic, Cyclic, and Strain–Life Properties of Selected Engineering Alloys[a–c]

Material	Process Description	S_u MPa (ksi)	HB	E GPa (ksi $\cdot 10^3$)	$\%RA$	S_y/S_y' MPa (ksi)	K/K' MPa (ksi)	n/n'	$\varepsilon_f/\varepsilon_f'$	σ_f/σ_f' MPa (ksi)	b	c
						Steel						
1010	HR sheet	331 (48)	—	203 (29.5)	80	200/— (29)/—	534/867 (78)/(126)	0.185/0.244	1.63/0.104	—/499 —/(72)	−0.100	−0.408
1020	HR sheet	441 (64)	109	203 (29.5)	62	262/— (38)/—	738/1962 (107)/(284)	0.190/0.321	0.96/0.377	—/1384 —/(201)	−0.156	−0.485
1038[c]	Normalized	582 (84)	163	201 (29.5)	54	331/342 (48)/(50)	1106/1340 (160)/(195)	0.259/0.220	0.77/0.309	898/1043 (130)/(151)	−0.107	−0.481
1038[c]	Q&T	649 (94)	195	219 (31.5)	67	410/364 (60)/(53)	1183/1330 (172)/(193)	0.221/0.208	1.10/0.255	1197/1009 (174)/(146)	−0.097	−0.460
Man-Ten	HR sheet	510 (74)	—	207 (30)	64	393/372 (57)/(54)	—/786 —/(114)	0.20/0.11	1.02/0.86	814/807 (118)/(117)	−0.071	−0.65
RQC-100	HR sheet	931 (135)	290	207 (30)	64	883/600 (128)/(87)	1172/1434 (170)/(208)	0.06/0.14	1.02/0.66	1330/1240 (193)/(180)	−0.07	−0.69
1045	Annealed	752 (109)	225	— —	44	517/— (75)/—	—/1022 —/(148)	—/0.152	0.58/0.486	—/916 —/(133)	−0.079	−0.520
1045	Q&T	1827 (265)	500	207 (30)	51	1689/— (245)/—	—/3371 —/(489)	0.047/0.145	0.71/0.196	—/2661 —/(386)	−0.093	−0.643
1090[c]	Normalized	1090 (158)	259	203 (29.5)	14	735/545 (107)/(79)	1765/1611 (256)/(234)	0.158/0.174	0.15/0.250	—/1310 —/(190)	−0.091	−0.496
1090[c]	Q&T	1147 (166)	309	217 (31.5)	22	650/627 (94)/(91)	1895/1873 (275)/(272)	0.165/0.176	0.24/0.700	—/1878 —/(273)	−0.120	−0.600
1141[c]	Normalized	789 (115)	229	220 (32)	47	493/481 (72)/(70)	1379/1441 (200)/(209)	0.187/0.177	0.64/0.602	1117/1326 (162)/(192)	−0.103	−0.581
1141[c]	Q&T	925 (134)	277	227 (33)	59	814/591 (118)/(86)	1205/1277 (125)/(185)	0.074/0.124	0.88/0.309	1405/1127 (204)/(164)	−0.066	−0.514
4142	Q&T	1413 (205)	380	207 (30)	48	1378/— (200)/—	—/2266 —/(387)	0.051/0.124	0.65/0.637	—/2143 —/(311)	−0.094	−0.761
4142	Q&T	1929 (280)	475	207 (30)	35	1722/— (250)/—	—/2399 —/(348)	0.048/0.094	0.43/0.331	—2161 —/(314)	−0.081	−0.854
4340	HR	827 (120)	243	193 (28)	43	634/— (92)/—	—/1337 —/(194)	—/0.168	0.57/0.522	—/1198 —/(174)	−0.095	−0.563
4340	Q&T	1240 (180)	350	193 (28)	57	1178/— (171)/—	1580/1887 (229)/(274)	0.066/0.137	0.84/1.122	—/1917 —/(278)	−0.099	−0.720
4340	Q&T	1468 (213)	409	200 (29)	38	1371/— (199)/—	—/1996 —(290)	—/0.135	0.48/0.640	—/1879 —/(273)	−0.086	−0.636
0030	Cast	496 (72)	137	207 (30)	46	303/320 (44)/(46)	—/738 —/(107)	—/0.136	0.62/0.280	750/655 (109)/(95)	−0.083	−0.552
8630	Cast	1144 (166)	305	207 (30)	29	985/682 (143)/(99)	—/1502 —/(218)	—/0.122	0.35/0.420	1268/1936 (184)/(281)	−0.121	−0.693
304	Annealed	572 (83)	—	190 (27.5)	—	276/— (40)/—	—/2275 —/(330)	—/0.334	—/0.174	—/1267 —/(184)	−0.139	−0.415
304	CD	951 (138)	327	172 (25)	69	744/— (108)/—	—/2270 —/(329)	—/0.176	1.16/0.554	—/2047 —/(297)	−0.112	−0.635
						Aluminum						
2024-T3	—	469 (68)	—	70 (10)	24	379/427 (55)/(62)	455/655 (66)/(95)	0.032/0.065	0.28/0.22	558/1100 (81)/(160)	−0.124	−0.59
5456-H311	—	400 (58)	95	69 (10)	35	234/— (34)/—	—/817 —/(118)	—/0.145	0.42/1.076	—/826 —/(120)	−0.115	−0.797
7075-T6	—	579 (84)	—	70 (10)	34	469/524 (68)/(76)	827/— (120)/—	0.11/0.146	0.41/0.19	745/1315 (108)/(191)	−0.126	−0.52
A356	Cast	283 (41)	93	70 (10)	5.7	229/295 (33)/(43)	388/379 (56)/(55)	0.083/0.043	0.06/0.027	274/594 (40)/(86)	−0.124	−0.530
						Others						
AZ91E-T6	Cast Mg.	318 (46)	—	45 (6.5)	13	142/180 (21)/(26)	639/552 (92)/(80)	0.137/0.184	0.14/0.089	356/831 (52)/(121)	−0.148	−0.451
Incon 718	Aged	1304 (189)	—	204 (29.5)	—	1110/— (161)/—	—/1986 —/(288)	—/0.112	—/3.637	—/2295 —/(333)	−0.100	−0.894

[a] These values do not represent final fatigue design properties. J1099 states, "Information presented here can be used in preliminary design estimates of fatigue life, the selection of materials and the analysis of service load and/or strain data."

[b] "Technical Report on Low Cycle Fatigue Properties, Ferrous and Non-Ferrous Materials," SAE J1099, 1998 and 1975. With permission of the Society of Automotive Engineers.

[c] M. L. Roessle and A. Fatemi, "Strain-Controlled Fatigue Properties of Steels and Some Simple Approximations," *Int. J. Fatigue*, Vol. 22, No. 6, 2000, p. 495.

Problem 2

A plate of W = 500 mm has a circular hole of r = 25 mm (see Figure 2). This plate is made of RQC-100 steel (see Table 2) and is loaded in axial. The required fatigue life N_f is 1 000 000 cycles.

a) Determine K_{tg} and K_f.

b) Compute the allowable stress amplitude for mean stress S_m = 0 and 200 MPa (use Goodman mean stress correction equation).

c) Based on the results of b), construct a constant life diagram for N_f = 1 000 000 cycles (Haigh Diagram, see L4 slide 10).

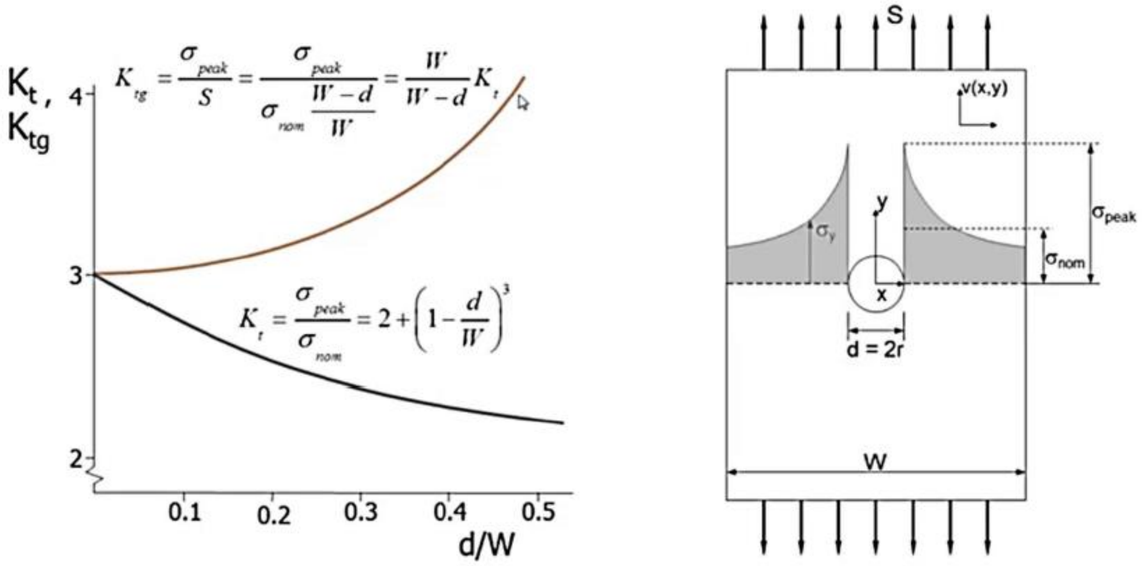


Figure 2 Stress concentration factor K_t or K_{tg} for a notched plate

Table 2 Constraints for stress-life curves: tests at zero mean stress on unnotched axial specimen

Material	Yield Strength σ_o	Ultimate Strength σ_u	True Fracture Strength $\tilde{\sigma}_{fB}$	$\sigma_a = \sigma'_f(2N_f)^b = AN_f^B$ σ'_f	A	$b = B$
(a) Steels						
AISI 1015 (normalized)	227 (33)	415 (60.2)	725 (105)	976 (142)	886 (128)	−0.14
Man-Ten (hot rolled)	322 (46.7)	557 (80.8)	990 (144)	1089 (158)	1006 (146)	−0.115
RQC-100 (roller Q & T)	683 (99.0)	758 (110)	1186 (172)	938 (136)	897 (131)	−0.0648
AISI 4142 (Q & T, 450 HB)	1584 (230)	1757 (255)	1998 (290)	1937 (281)	1837 (266)	−0.0762
AISI 4340 (aircraft quality)	1103 (160)	1172 (170)	1634 (237)	1758 (255)	1643 (238)	−0.0977

Notes: The tabulated values have units of MPa(ksi) except for dimensionless $b = B$. See Table 14.1 for sources and additional properties.