Fatigue of Structures – Assignment 3

Problem 1

Data points for the monotonic stress-strain curve of 7075-T6 aluminium during axial stress are given in Table 1. The elastic modulus for the material is given as E = 72000 MPa.

a) Determine the plastic strain ε_p for each point and plot σ vs $\boldsymbol{\varepsilon_p}$ on a log-log graph. Determine the constants *H* and *n* for the Ramberg-Osgood material model (Power law hardening model); see Lecture 5. Plot the resulting $\boldsymbol{\varepsilon}$=f(σ) line and test data using a linear-linear graph. Determine the 0.2% offset yield strength (i.e., ε=0.002). **Suggestion:** remember definition of strain contribution (total, elastic, plastic); first graph is for only plastic strain, and it could be useful to find H and n.

b) If material properties for cyclic stress-strain curve are H' = 950 MPa, and n' = 0.12, does this material cyclically harden or soften? Construct and compare the monotonic and cyclic stress-strain curves for strain between 0 and 2%. The 2% strain means 0.02 mm/mm.

Table 1 Test data points for the stress-strain curve of 7075-T6 aluminium

Stress σ [MPa]	Strain ε [mm/mm]
330	0.00474
400	0.00630
472	0.01260
535	0.03350
553	0.04659
579	0.07490

Problem 2

A notched component has K_t = 2.5. The component is axial loaded until nominal stress S = 200 MPa. The component is then unloaded to a nominal stress of S = 0 MPa. The stress-strain behaviour is presented Ramberg-Osgood model. The material properties are the following: E = 202000 MPa, H' = 1260 MPa, and n' = 0.21.

a) Determine the local stress σ and local strain ε at the notch at S = 200 MPa. Use Neuber's rule.

b) Determine the residual local stress and local strain at the notch at S = 0 MPa. Use Neuber's rule. Determine the same local stress and strain values using also Glinka's Rule and discuss the differences.

Problem 3

Completely reversed, strain-controlled fatigue tests of a steel with E = 210000 MPa was carried out. The data of the tests are presented in Table 2.

a) Estimate $\sigma_{f'}$, $\varepsilon_{f'}$, b and c for this material (linear regression).

b) Estimate H' and n' based on the data in the table (linear regression). Compare these values (numerical and graphical formats) with those obtained using $n' = b/c$ and $H'=\sigma_{f'}/((\varepsilon_{f'})^{b/c})$; see details in the lecture note L6.

Table 2 Test data points for strain-controlled fatigue tests of a steel

Total strain [mm/mm]	Stress [MPa][1)]	Fatigue life [Cycles]
ε_a	σ_a	N_f
0.0202	631	427
0.0100	574	1410
0.0045	505	8450
0.0030	472	25000
0.0023	455	150000

[1] Value for the stable σ–ε curve

Problem 4

Using the material properties given in Table 3 (see next page), analyse fatigue life of smooth specimens of Man-Ten.

a) Determine the total, elastic and plastic strain for 200 and 200 000 reversals to failure ($2N_f$).
Suggestion: $\varepsilon_a = \varepsilon_{a,e} + \varepsilon_{a,p}$ and these depends on 2Nf and other constants of Table 3;

b) Using the Smith-Watson-Topper mean stress correction, plot the estimated ε_a-N curves for σ_m = 0 MPa, σ_m = +140 MPa. Discuss the differences in ε-N curves.
Suggestion: check SWT relation for strain-life curve (see also p.764 Dowling's book, eq. 14.30); assume that hysteresis loop is not influenced by mean stress; strain-stress amplitudes can be derived based on the cyclic stress strain curve (H', n'); remember the definition of σ_{max} in SWT equation; SWT relation should be solved iteratively.

Table 3 Monotonic, cyclic and strain-life properties of selected engineering alloys (From Dowling's *Mechanical Behaviour of Materials, p.751*) σ_0 is the yield strength; σ_u is the "ultimate" strength

Material	Source	Tensile Properties				Cyclic σ-ε Curve			Strain–Life Curve			
		σ_o	σ_u	$\tilde{\sigma}_{fB}$	% RA	E	H'	n'	σ'_f	b	ε'_f	c
(a) Steels												
SAE 1015 (normalized)	(8)	228 (33.0)	415 (60.2)	726 (105)	68	207,000 (30,000)	1349 (196)	0.282	1020 (148)	−0.138	0.439	−0.513
Man-Ten[2] (hot rolled)	(7)	322 (46.7)	557 (80.8)	990 (144)	67	203,000 (29,500)	1096 (159)	0.187	1089 (158)	−0.115	0.912	−0.606
RQC-100 (roller Q & T)	(2)	683 (99.0)	758 (110)	1186 (172)	64	200,000 (29,000)	903 (131)	0.0905	938 (136)	−0.0648	1.38	−0.704
SAE 1045 (HR & norm.)	(6)	382 (55.4)	621 (90.1)	985 (143)	51	202,000 (29,400)	1258 (182)	0.208	948 (137)	−0.092	0.260	−0.445
SAE 4142 (As Q, 670 HB)	(1)	1619 (235)	2450 (355)	2580 (375)	6	200,000 (29,000)	2810 (407)	0.040	2550 (370)	−0.0778	0.0032	−0.436
SAE 4142 (Q & T, 560 HB)	(1)	1688 (245)	2240 (325)	2650 (385)	27	207,000 (30,000)	4140 (600)	0.126	3410 (494)	−0.121	0.0732	−0.805
SAE 4142 (Q & T, 450 HB)	(1)	1584 (230)	1757 (255)	1998 (290)	42	207,000 (30,000)	2080 (302)	0.093	1937 (281)	−0.0762	0.706	−0.869
SAE 4142 (Q & T, 380 HB)	(1)	1378 (200)	1413 (205)	1826 (265)	48	207,000 (30,000)	2210 (321)	0.133	2140 (311)	−0.0944	0.637	−0.761
AISI 4340[2] (Aircraft Qual.)	(3)	1103 (160)	1172 (170)	1634 (237)	56	207,000 (30,000)	1655 (240)	0.131	1758 (255)	−0.0977	2.12	−0.774
AISI 4340 (409 HB)	(1)	1371 (199)	1468 (213)	1557 (226)	38	200,000 (29,000)	1910 (277)	0.123	1879 (273)	−0.0859	0.640	−0.636
Ausformed H-11 (660 HB)	(1)	2030 (295)	2580 (375)	3170 (460)	33	207,000 (30,000)	3475 (504)	0.059	3810 (553)	−0.0928	0.0743	−0.7144
(b) Other Metals												
2024-T351 Al	(1)	379 (55.0)	469 (68.0)	558 (81.0)	25	73,100 (10,600)	662 (96.0)	0.070	927 (134)	−0.113	0.409	−0.713
2024-T4 Al[3] (Prestrained)	(4)	303 (44.0)	476 (69.0)	631 (91.5)	35	73,100 (10,600)	738 (107)	0.080	1294 (188)	−0.142	0.327	−0.645
7075-T6 Al	(5)	469 (68.0)	578 (84)	744 (108)	33	71,000 (10,300)	977 (142)	0.106	1466 (213)	−0.143	0.262	−0.619
Ti-6Al-4V (soln. tr. & age)	(1)	1185 (172)	1233 (179)	1717 (249)	41	117,000 (17,000)	1772 (257)	0.106	2030 (295)	−0.104	0.841	−0.688
Inconel X (Ni base, annl.)	(1)	703 (102)	1213 (176)	1309 (190)	20	214,000 (31,000)	1855 (269)	0.120	2255 (327)	−0.117	1.16	−0.749

Notes: [1]The tabulated values either have units of MPa (ksi), or they are dimensionless. [2]Test specimens prestrained, except at short lives, also periodically overstrained at long lives. [3]For nonprestrained tests, use same constants, except $\sigma'_f = 900(131)$ and $b = -0.102$.

Sources: Data in (1) [Conle 84]; (2) author's data on the ASTM Committee E9 material; (3) [Dowling 73]; (4) [Dowling 89] and [Topper 70]; (5) [Endo 69] and [Raske 72]; (6) [Leese 85]; (7) [Wetzel 77] pp. 41 and 66; (8) [Keshavan 67] and [Smith 70].