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Mechanical Design 1

01 Assignment

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Mechanical Design 1

Class Section 01

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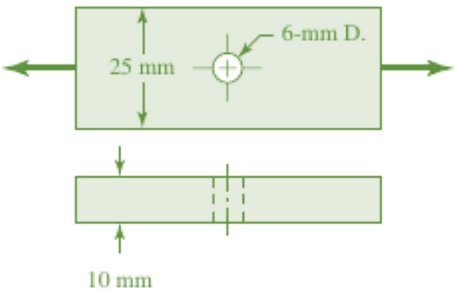
Problem 1

The cold-drawn AISI 1040 steel bar shown in the figure is subjected to a axial load fluctuating between 12 kN to 28 kN. Use the Modified Goodman, Gerber, and ASME-elliptic criteria and compare their predictions



Solution:

For this question, we are asked to use the Modified Goodman, Gerber, and ASME-elliptic criteria and compare their predictions.

Table A–20

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

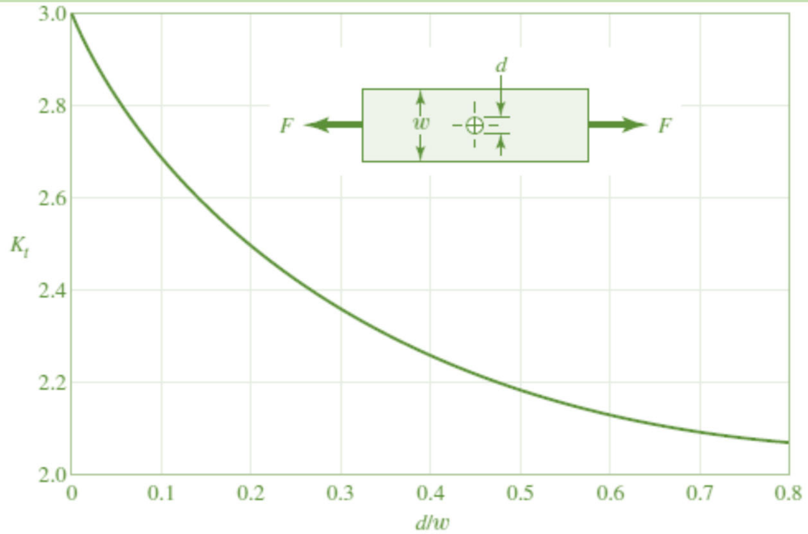
1 UNS No.	2 SAE and/or AISI No.	3 Process-ing	4 Tensile Strength, MPa (kpsi)	5 Yield Strength, MPa (kpsi)	6 Elongation in 2 in, %	7 Reduction in Area, %	8 Brinell Hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

$$S_{ut} = 590 \ \text{MPa} = 85 \ \text{kpsi}$$

$$S_y = 490 \ \text{MPa}$$

Figure A–15–1

Bar in tension or simple compression with a transverse hole. $\sigma_0 = F/A$, where $A = (w - d)t$ and t is the thickness.



$$\frac{d}{w} = \frac{6 \ \text{mm}}{25 \ \text{mm}} = 0.24$$

$$\Rightarrow K_t = 2.44$$

Figure 6–20

Notch-sensitivity charts for steels and UNS A92024-T wrought aluminum alloys subjected to reversed bending or reversed axial loads. For larger notch radii, use the values of q corresponding to the $r = 0.16$-in (4-mm) ordinate. *(From George Sines and J. L. Waisman (eds.),* Metal Fatigue, *McGraw-Hill, New York. Copyright © 1969 by The McGraw-Hill Companies, Inc. Reprinted by permission.)*

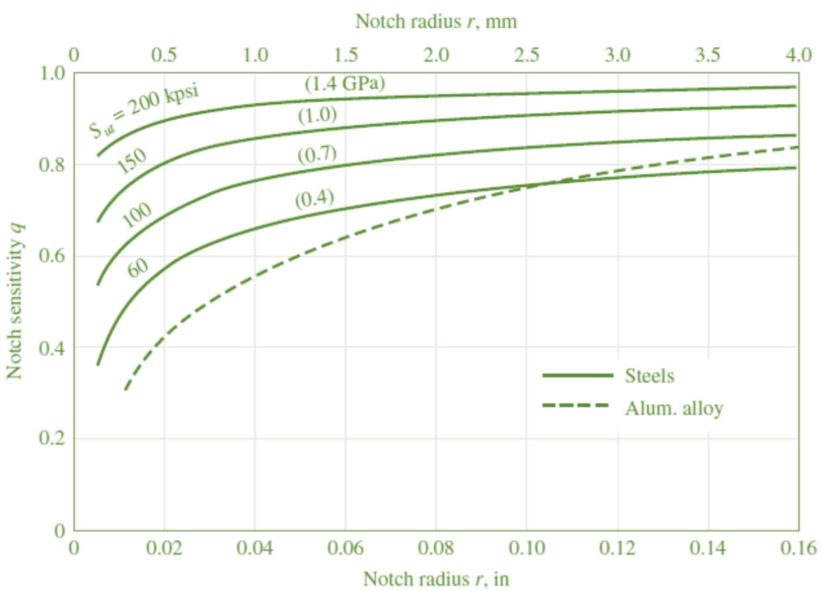


Figure 6-20:

$$q = 0.83$$

$$K_f = 1 + q(K_t - 1) = 1 + (0.83) \times (2.44 - 1) = 2.1952$$

$$\sigma_{max} = \frac{F_{max}}{A} = \frac{(28 \ \text{kN})}{(10 \ \text{mm}) \times [(25 \ \text{mm}) - (6 \ \text{mm})]} = 147.37 \ \text{MPa}$$

$$\sigma_{min} = \frac{F_{min}}{A} = \frac{(12 \ \text{kN})}{(10 \ \text{mm}) \times [(25 \ \text{mm}) - (6 \ \text{mm})]} = 63.16 \ \text{MPa}$$

$$n_y = \frac{S_y}{\sigma_{max}} = 3.32$$

$$\sigma_m = K_f \frac{\sigma_{max} + \sigma_{min}}{2} = 231.07 \text{ MPa}$$

$$\sigma_a = K_f \left|\frac{\sigma_{max} - \sigma_{min}}{2}\right| = 92.42 \text{ MPa}$$

$$S'_e = 0.5 S_{ut} = 0.5 \times (590 \text{ MPa}) = 295 \text{ MPa}$$

Table 6–2

Parameters for Marin Surface Modification Factor, Eq. (6–19)

Surface Finish	Factor a S_{ut}, kpsi	Factor a S_{ut}, MPa	Exponent b
Ground	1.34	1.58	−0.085
Machined or cold-drawn	2.70	4.51	−0.265
Hot-rolled	14.4	57.7	−0.718
As-forged	39.9	272.	−0.995

From C.J. Noll and C. Lipson, "Allowable Working Stresses," *Society for Experimental Stress Analysis,* vol. 3, no. 2, 1946 p. 29. Reproduced by O.J. Horger (ed.) *Metals Engineering Design ASME Handbook,* McGraw-Hill, New York. Copyright © 1953 by The McGraw-Hill Companies, Inc. Reprinted by permission.

And from the question and Table 6-2, I can know that

$$k_a = a S_{ut}^b = 4.51 \times (590 \text{ MPa})^{-0.265} = 0.832$$

$$k_b = 1$$

$$k_c = 0.85$$

Therefore,

$$S_e = k_a k_b k_c S'_e = (0.832) \times (1) \times (0.85) \times (295 \text{ MPa}) = 208.5 \text{ MPa}$$

Using Modified Goodman criteria:

$$S_m = \frac{(S_y - S_e) S_{ut}}{S_{ut} - S_e} = \frac{[(490 \text{ MPa}) - (208.5 \text{ MPa})] \times (590 \text{ MPa})}{[(590 \text{ MPa}) - (208.5 \text{ MPa})]} = 435.35 \text{ MPa}$$

$$S_a = S_y - S_m = [(490 \text{ MPa}) - (435.35 \text{ MPa})] = 54.65 \text{ MPa}$$

$$r_{crit} = \frac{S_a}{S_m} = \frac{54.65 \text{ MPa}}{435.35 \text{ MPa}} = 0.126$$

For this situation,

$$\frac{S_a}{S_m} = \frac{92.42 \text{ MPa}}{231.07 \text{ MPa}} = 0.4$$

Therefore,

$$\frac{S_a}{S_e} + \frac{S_m}{S_{ut}} = \frac{1}{n}$$

$$\frac{(92.42\ \text{MPa})}{(208.5\ \text{MPa})} + \frac{(231.07\ \text{MPa})}{(590\ \text{MPa})} = \frac{1}{n}$$

$$\Rightarrow n = 1.20$$

Using Gerber – Langer criteria:

$$S_m = \frac{S_{ut}^2}{2S_e}\left[1 - \sqrt{1 + \left(\frac{2S_e}{S_{ut}}\right)^2 \left(1 - \frac{S_y}{S_e}\right)}\right]$$

$$= \frac{(590\ \text{MPa})^2}{2 \times (208.5\ \text{MPa})}\left\{1 - \sqrt{1 + \left[\frac{2 \times (208.5\ \text{MPa})}{(590\ \text{MPa})}\right]^2 \left[1 - \frac{(490\ \text{MPa})}{(208.5\ \text{MPa})}\right]}\right\}$$

$$= 358.46\ \text{MPa}$$

$$S_a = S_y - S_m = [(490\ \text{MPa}) - (358.46\ \text{MPa})] = 131.53\ \text{MPa}$$

$$r_{crit} = \frac{S_a}{S_m} = \frac{131.53\ \text{MPa}}{358.46\ \text{MPa}} = 0.367$$

For this situation,

$$\frac{S_a}{S_m} = \frac{92.42\ \text{MPa}}{231.07\ \text{MPa}} = 0.4$$

Therefore,

$$n_f = \frac{1}{2}\left(\frac{S_{ut}}{\sigma_m}\right)^2 \frac{\sigma_a}{S_e}\left[-1 + \sqrt{1 + \left(\frac{2\sigma_m S_e}{S_{ut}\sigma_a}\right)^2}\right] =$$

$$= \frac{1}{2} \times \left[\frac{(590\ \text{MPa})}{(231.07\ \text{MPa})}\right]^2 \times \frac{(92.42\ \text{MPa})}{(208.5\ \text{MPa})}$$

$$\times \left\{-1 + \sqrt{1 + \left[\frac{2 \times (231.07\ \text{MPa}) \times (208.5\ \text{MPa})}{(590\ \text{MPa}) \times (92.42\ \text{MPa})}\right]^2}\right\} = 1.49$$

Using ASME-elliptic-Langer criteria:

$$n_f = \sqrt{\frac{1}{\left(\frac{\sigma_a}{S_e}\right)^2 + \left(\frac{\sigma_m}{S_y}\right)^2}} = \sqrt{\frac{1}{\left[\frac{(92.42\ \text{MPa})}{(208.5\ \text{MPa})}\right]^2 + \left[\frac{(231.07\ \text{MPa})}{(490\ \text{MPa})}\right]^2}} = 1.54$$

Comparison:

1. The mean stress that is about half of the yield strength.
2. The Modified Goodman predict failure larger than the other two.

Problem 2

A part is loaded with a combination of bending, axial, and torsion such that the following stresses are created at a particular location:

- Bending: Completely reversed, with a maximum stress of 60 MPa
- Axial: Constant stress of 20 MPa
- Torsion: Repeated load, varying from 0 MPa to 50 MPa

Assume the varying stresses are in phase with each other. The part contains a notch such that $K_{f,bending}$ = 1.4, $K_{f,axial}$ = 1.1, and $K_{f,torsion}$ = 2.0. The material properties are S_y = 300 MPa and S_u = 400 MPa. The completely adjusted endurance limit is found to be S_e = 200 MPa. Find the factor of safety for fatigue based on infinite life. If the life is not infinite, estimate the number of cycles. Be sure to check for yielding

Solution:

For this question, we are asked to find the factor of safety for fatigue based on infinite life. If the life is not infinite, estimate the number of cycles. Be sure to check for yielding.

For bending,

$$\sigma_m = 0$$

$$\sigma_a = 60 \text{ MPa}$$

For axial:

$$\sigma_m = 20 \text{ MPa}$$

$$\sigma_a = 0$$

For torsion:

$$\sigma_m = 25 \text{ MPa}$$

$$\sigma_a = 25 \text{ MPa}$$

Therefore, considering that the bending, torsional, and axial stresses have alternating and midrange components, the von Mises stresses for the two stress elements can be written as

$$\sigma_a' = \left\{\left[\left(K_f\right)_{bending}(\sigma_a)_{bending} + \left(K_f\right)_{axial}\frac{(\sigma_a)_{axial}}{0.85}\right]^2 + 3\left[\left(K_{fs}\right)_{torsion}(\tau_a)_{torsion}\right]^2\right\}^{\frac{1}{2}}$$

$$= \left\{\left[(1.4)\times(60\ \ \text{MPa}) + (1.1)\times\frac{(0\ \ \text{MPa})}{0.85}\right]^2 + 3\times[(2)\times(25\ \ \text{MPa})]^2\right\}^{\frac{1}{2}}$$

$$= 120.6\ \ \text{MPa}$$

$$\sigma_m' = \left\{\left[\left(K_f\right)_{bending}(\sigma_m)_{bending} + \left(K_f\right)_{axial}(\sigma_m)_{axial}\right]^2 + 3\left[\left(K_{fs}\right)_{torsion}(\tau_m)_{torsion}\right]^2\right\}^{\frac{1}{2}}$$

$$= \left\{\left[(1.4)\times(0\ \ \text{MPa}) + (1.1)\times\frac{(20\ \ \text{MPa})}{0.85}\right]^2 + 3\times[(2)\times(25\ \ \text{MPa})]^2\right\}^{\frac{1}{2}}$$

$$= 89.35\ \ \text{MPa}$$

Using Modified Goodman criteria:

Therefore,

$$\frac{S_a'}{S_e} + \frac{S_m'}{S_{ut}} = \frac{1}{n}$$

$$\frac{(120.6\ \ \text{MPa})}{(200\ \ \text{MPa})} + \frac{(89.35\ \ \text{MPa})}{(400\ \ \text{MPa})} = \frac{1}{n}$$

$$\Rightarrow n = 1.21$$

Check

$$n_y = \frac{S_y}{\sigma_{max}} = \frac{S_y}{\sigma_a' + \sigma_m'} = \frac{(300\ \ \text{MPa})}{(120.6\ \ \text{MPa}) + (89.35\ \ \text{MPa})} = 1.43$$

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