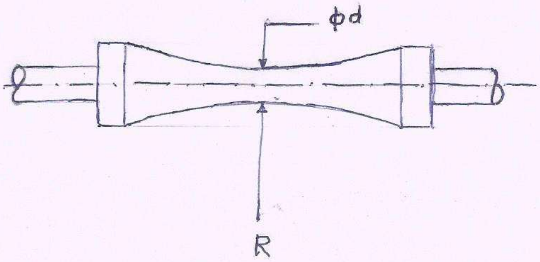
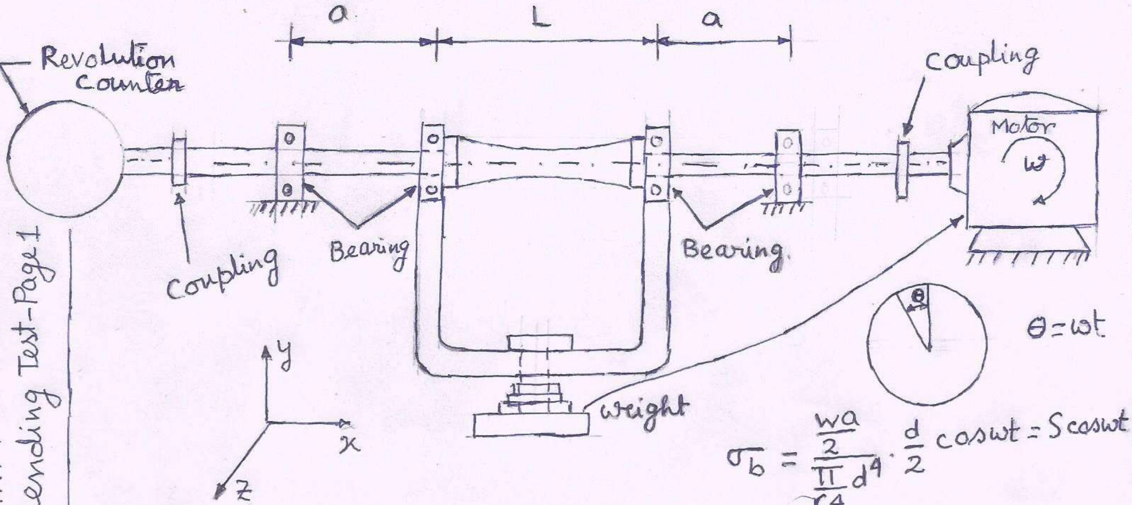
R. R. Moore's rotating bending test



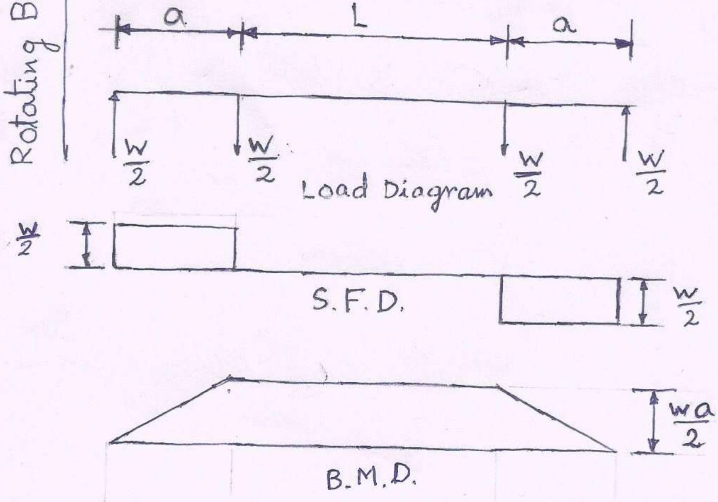
characteristics of ~~surface~~ specimen:

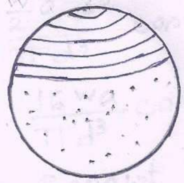
1. Surface finish - Mirror polished.
2. Radius R is 250 mm. very large to have negligible effect of stress concentration.
3. Neck of dia d = 7.5 mm. It is the weakest cross-section.



$\theta = \omega t$

$$\sigma_b = \frac{\frac{Wa}{2}}{\frac{\pi}{64}d^4}\cdot\frac{d}{2}\cos\omega t = S\cos\omega t$$





N = Failure life in cycles

$N = N_1 + N_2 + N_3$

N_1 = Fracture Initiation

N_2 = Fracture Propagation

N_3 = Sudden failure by fragmentation

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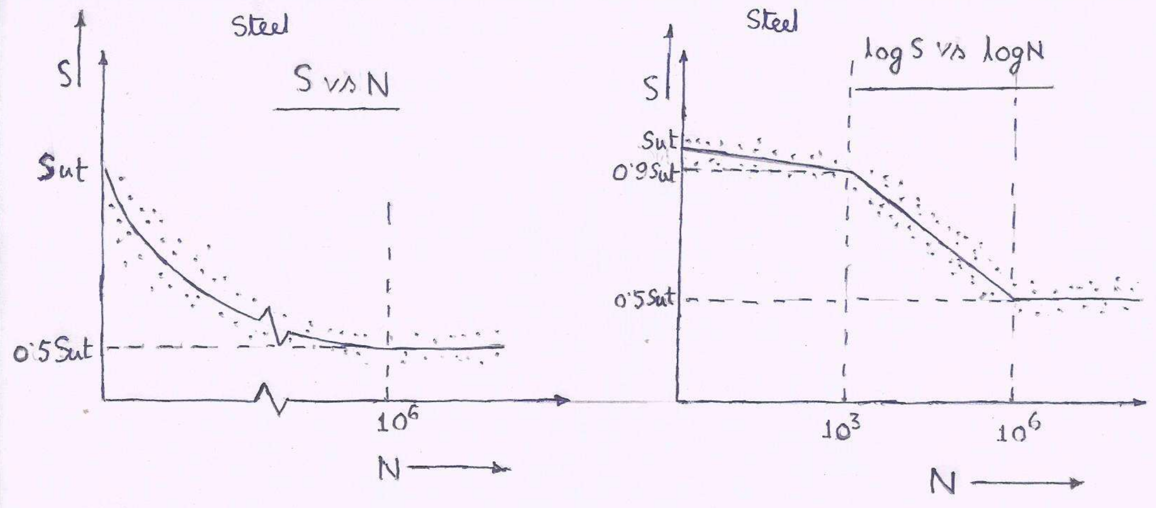
S is computed from strength of material formula.

Mean curve drawn through the data are presented below:



Discussion:

1. The specimen does not include the effect of macroscopic stress risers.
2. It does not include effect of rough surface finish.
3. Test can not predict results if diameter be more than or less than 7.5 mm.
4. The curve drawn is a mean curve and so it can not predict with reliability other than 50%.
5. Test does not predict effects if other type of fatigue loads such as tension-compression fatigue load or torsional fatigue load be present.
6. Test does not predict effects if the mean stress be non-zero.

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Note: S for life cycles N is denoted as S_N. If $N = 10^3$, S for life cycles 10^3 is denoted as S_{10^3} or S_{1000}. Similarly S for life cycles 10^6 is denoted as S_{10^6} or $S_{1000000}$.

Note: It is observed that the curve become horizonal in S vs N plot. This point is reached at fatigue life of 10^6 cycles approximately. For steel material, the corresponding value of S is 0.5Sut. This value of S is referred as endurance limit of material. If the value of S be more than endurance limit of material, the specimen have finite life and if the value of S be less than the endurance limit of material, the specimen will have life of infinite number of cycles. Se or σe are preferrably used as symbol for the endurance limit of material.

Note: If the life of a component be less than 10^3 cycles, this is considered as low cycle fatigue. If the life of a component be more than 10^3, it is consided as high cycle fatigue

Fatigue life up to cycle 10^3 cycle is low cycle fatigue. Beyond 10^3 cycle, fatigue life is called high cycle fatigue. Fatigue life up to 10^6 cycle is called finite life fatigue and beyond 10^6 cycle is called infinite life fatigue.

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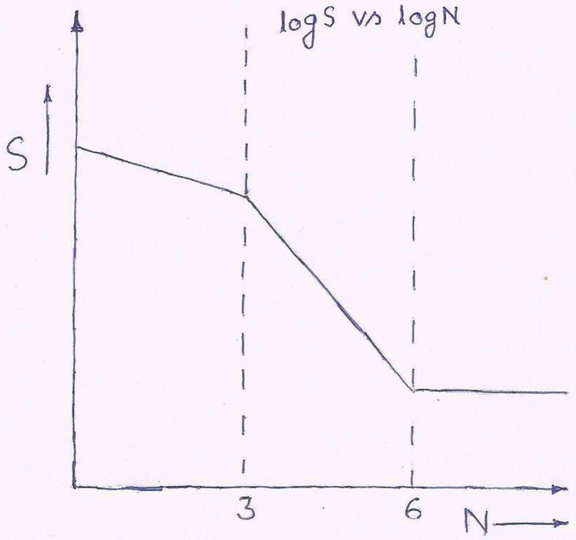
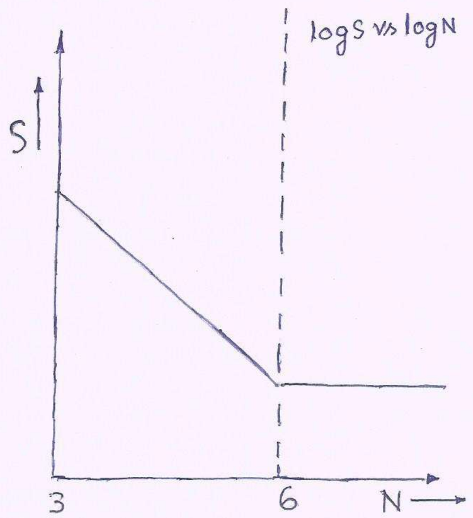
Analysis of logS vs logN plot - page 1





$$\frac{\log S_N - \log S_{10^6}}{\log N - \log 10^6} = \frac{\log S_{10^3} - \log S_{10^6}}{\log 10^3 - \log 10^6} \; ; \; \frac{\log S_N - \log S_{10^6}}{\log N - 6} = \frac{\log S_{10^3} - \log S_{10^6}}{3 - 6}$$

$$\log S_N - \log S_{10^6} = \frac{\log S_{10^3} - \log S_{10^6}}{-3} \times (\log N - \log 10^6)$$

$$\log \frac{S_N}{S_{10^6}} = \log \frac{S_{10^3}}{S_{10^6}} \times \frac{6 - \log N}{3} = \frac{6 - \log N}{3} \log \frac{S_{10^3}}{S_{10^6}}$$

$$\log \frac{S_N}{S_{10^6}} = \log\left[\left(\frac{S_{10^3}}{S_{10^6}}\right)^{\left(\frac{6-\log N}{3}\right)}\right] \; ; \; \frac{S_N}{S_{10^6}} = \left(\frac{S_{10^3}}{S_{10^6}}\right)^{\left(\frac{6-\log N}{3}\right)}$$

$$S_N = S_{10^6}\left(\frac{S_{10^3}}{S_{10^6}}\right)^{\left(\frac{6-\log N}{3}\right)}$$

$$\frac{\log S_N - \log S_{10^6}}{\log N - \log 10^6} = \frac{\log S_{10^3} - \log S_{10^6}}{\log 10^3 - \log 10^6} \; ; \; \frac{\log S_N - \log S_{10^6}}{\log S_{10^3} - \log S_{10^6}} = \frac{\log N - \log 10^6}{\log 10^3 - \log 10^6}$$

$$\cancel{\log \frac{S_N}{\log S_{10^6}}} \quad \frac{\log \frac{S_N}{S_{10^6}}}{\log \frac{S_{10^3}}{S_{10^6}}} = \frac{\log N - 6}{3 - 6} \; ; \; \frac{\log N - 6}{-3} = \frac{\log(S_N/S_{10^6})}{\log(S_{10^3}/S_{10^6})}$$

$$\log N - 6 = -3 \frac{\log(S_N/S_{10^6})}{\log(S_{10^3}/S_{10^6})} \; ; \; \log N = 6 - 3 \frac{\log(S_N/S_{10^6})}{\log(S_{10^3}/S_{10^6})}$$

$$\log N = \log 10^{\left[6 - 3 \frac{\log(S_N/S_{10^6})}{\log(S_{10^3}/S_{10^6})}\right]} \; ; \; N = 10^{\left[6 - 3 \frac{\log(S_N/S_{10^6})}{\log(S_{10^3}/S_{10^6})}\right]}$$

Effect of reliability: (C_R - Strength reduction factor for reliability)

Definition of reliability:

If 98 identical components out of 100 idential components be able to perform the identical function of stipulated time, we say that the reliability of the component is 98%.

As evident from the graph, the reliability of mean curve is 50%. All material properties are determined with 50% reliability. If we want more reliability, we have to multiply properties ~~to~~ with a factor C_R less than 1.0.

Reliability	Factor C_R
50%	1.000
90%	0.897
95%	0.868
99%	0.814
99.9%	0.753
99.99%	0.702
99.999%	0.659

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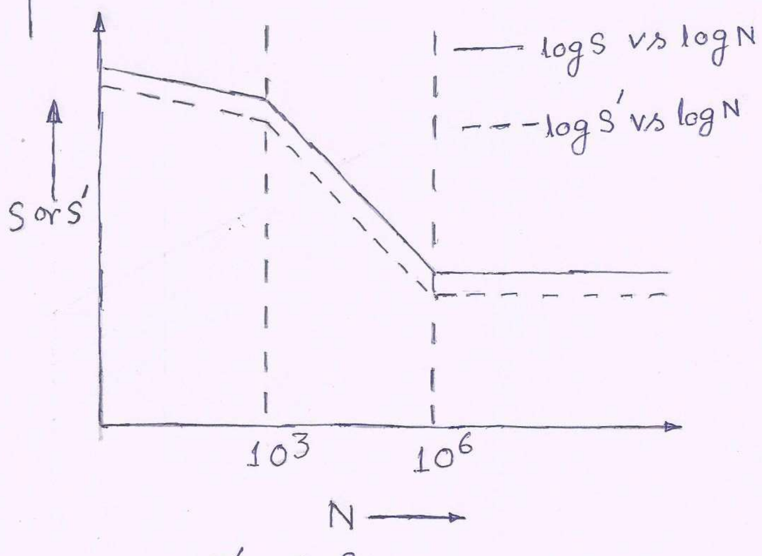
Effect of relibility - page 1

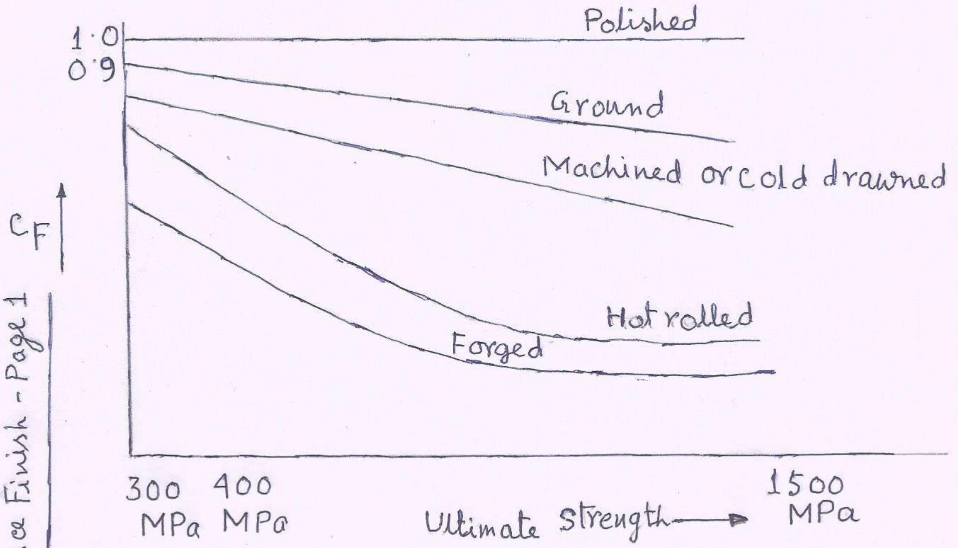


Here: $S_N' = C_R S_N$

Note: S_N is R.R.Moore's strength and S_N' is modified strength.

Effect of surface finish : (C_F – strength reduction factor for surface finish)

If we make a series of tests on specimens of same materials but with different surface finish like polished, ground, machined, hot rolled, forged etc, we find that the endurance limit is strongly dependent on the surface finish. C_F is found to ~~vary~~ depend on ultimate strength of material.



From the curve, it is evident that some gain in load carrying capacity that may have been anticipated by use of higher strength material is lost because of a reduction in C_F ~~and~~. High strength material can benifit most from ~~fresh~~ fine surface finish for which C_F value is high. ~~and~~ These curves are for steel material.

Shigley and Mischke has suggested a exponential equation from the curve for steel material.

$$K_a = a(S_{ut})^b$$

$$C_F = K_a$$

If C_F be more than 1, $C_F = 1.0$

surface finish	a	b
Ground	1·58	–0·085
Machined	4·51	–0·265
Hot-rolled	57·7	–0·718
Forged	272	–0·995

Note : For S_{10^3} strength, C_F is not used. For S_{10^6}, C_F is used.

Effect of size: (C_S - Strength reduction factor for size)

If we conduct experiments with specimens having same proportion as the standard specimen but the size is scaled up, we get different values for S_e. This is due to increase in the number of internal flaws. These flaws serves as stress risers.

There are ~~verious~~ ~~on~~ ~~different~~ various emperical guidelines for the delermination of C_S.

$$C_S = \left(\frac{V}{V_0}\right)^{-0.034}$$

where

V_0 = Volume of material in the standard specimen that is stressed to 95% or more of the maximum stress.

V = Volume of the part being designed that has stress equal to or more than 95% of the maximum stress.

Based on the above emperical guideline, the following working formula for circular cross-section may be ~~deased~~ deduced.

$$C_S = 1.0 - \frac{D - 7.5}{380} \quad \text{for } 7.5\,mm < D < 150\,mm$$

$$= 1.0 \quad \text{for } D \leq 7.5\,mm.$$

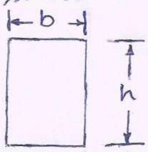
Other emperical suggestion is given below.

~~d~~ $C_S = 1.0$ for $D \leq 7.5\,mm$

$= 0.85$ for $7.5 < D \leq 50\,mm$

$= 0.75$ for $D > 50\,mm$

For reclangular cross-section, the ~~o~~ value of C_S is determined from the above ~~for~~ formula or from the above suggestion using the value of effective dimeter d_e in place of D. The effective diameter d_e is calculated by equating 95% stress area of the component to 95% stress area of specimen.



$$d_e = \sqrt{\frac{0.05hb}{0.0766}}$$

For axial push-pull type fatigue load, $C_S = 1.0$

Note: Effect of size is insignificant for S_{10^3}. $S_e' = C_S S_e$.

Effect of stress concentration: (C_c - stress reduction factor for stress concentration)

Experiments with plates of various materials subjected to cyclic load would show that the effect of hole on fatigue is not solely shape dependent but also depends on material. The property is called notch sensilivity (q).

$$C_c = \frac{1}{K_f}; \; K_f = \text{fatigue stress concentration factor}$$

$$K_f = \frac{\text{Endurance limit of notch-free specimen}}{\text{Endurance limit of notched specimen}}$$

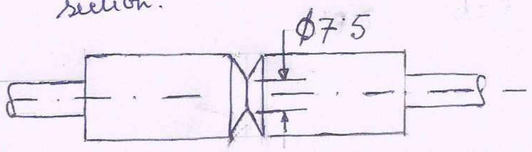
Relationship between K_f and K_{th}

$$K_f = 1.0 + q(K_{th} - 1)$$

The lendency of some normally duclite materials to behave in ~~like~~ brittle ~~material manner~~ manner in presence of notches is called notch sensilivity. This property depends on the response of the material to changes in strain, triaxiality and temperature.

$$K_{th} = \frac{\text{Theoretical peak stress in notched specimen}}{\text{Nominal stress in notched specimen}}$$

Nominal stress is calculated on the basis of net cross sectional area. Nominal stress is calculated using strength of material formula developed on the basis of concept of ~~average~~ average stress on the cross section.



calculation of nominal stress in notched specimen:

$$\sigma_{nom} = \frac{32M}{\pi d^3}\cos\omega t = S\cos\omega t$$

Calculation of nominal stress in notch-free (original) specimen:

$$\sigma_{nom} = \frac{32M}{\pi d^3}\cos\omega t = S\cos\omega t$$

$$K_{eff} = \frac{\text{Actual peak stress in notched specimen}}{\text{Nominal stress in notched specimen}}.$$

For fatigue analysis, $K_{eff} = K_f$

$$K_f = \frac{\text{Actual Peak stress in notched specimen}}{\text{Nominal stress in notched specimen}}$$

Actual Peak stress in notched specimen $= K_f \times$ Nominal stress in notched specimen

$$= K_f(\sigma_{nom})_a = K_f\left(\frac{32M}{\pi d^3}\right)$$

$(\sigma_{nom})_a$ = Amplitude of fluctuating stress

$$q = \frac{\text{Actual increase in peak stress over nominal maximum stress}}{\text{Theoretical increase in peak stress over nominal maximum stress}}$$

$$= \frac{K_f(\sigma_{nom})_a - (\sigma_{nom})_a}{K_{th}(\sigma_{nom})_a - (\sigma_{nom})_a} = \frac{K_f - 1}{K_{th} - 1}$$

$$K_f - 1 = q(K_{th} - 1); \quad K_f = 1 + q(K_{th} - 1)$$

$$K_f = \frac{\text{Actual peak stress in notched specimen}}{\text{Nominal maximum stress in notched specimen}}$$

$$= \frac{\text{Actual peak stress in notch specimen}}{\text{Nominal maximum stress in notch-free specimen}}$$

$$K_f = \frac{\text{Endurance limit of notch-free specimen}}{\text{Endurance limit of notched specimen}}$$

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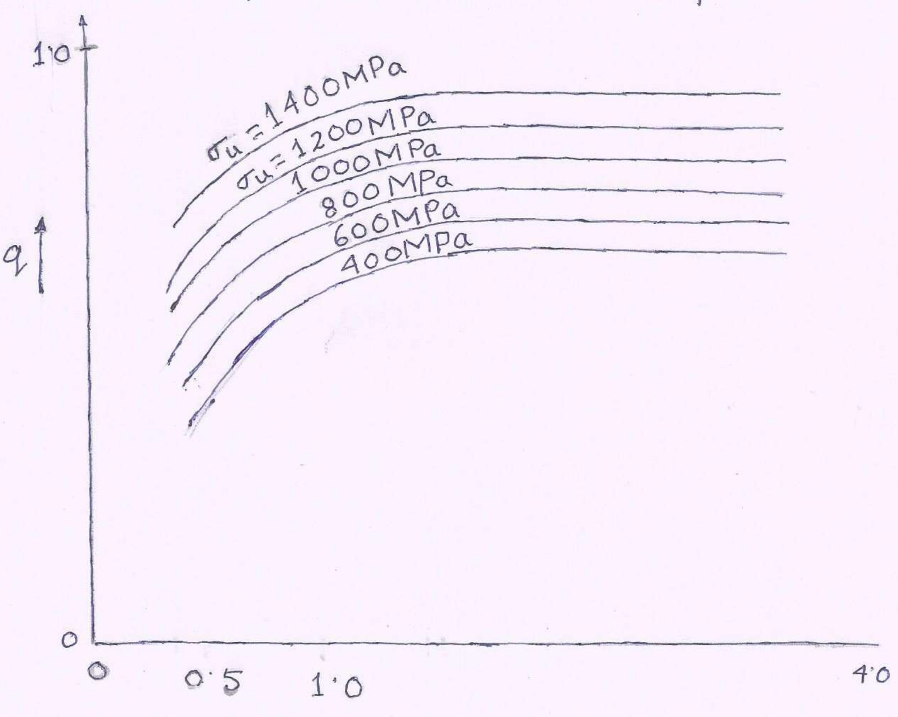
Effect of Stress concentration - page 2

$$\text{Endurance limit of notch specimen} = \frac{\text{Endurance limit of notch-free specimen}}{K_f}$$

$$S_e' = \left(\frac{1}{K_f}\right) S_e = C_c S_e \quad \text{where} \quad C_c = \frac{1}{K_f}$$



Notch Radius r →

Note: $S_e' = C_c S_e$ But C_c is not applied to S_{10^3}.