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ME 670 Exam 2

1.) Use strain rate change tests and temperature changed tests to obtain the specimens stress exponent (m), Activation energy (Q) and the back stress (τ_{back}).

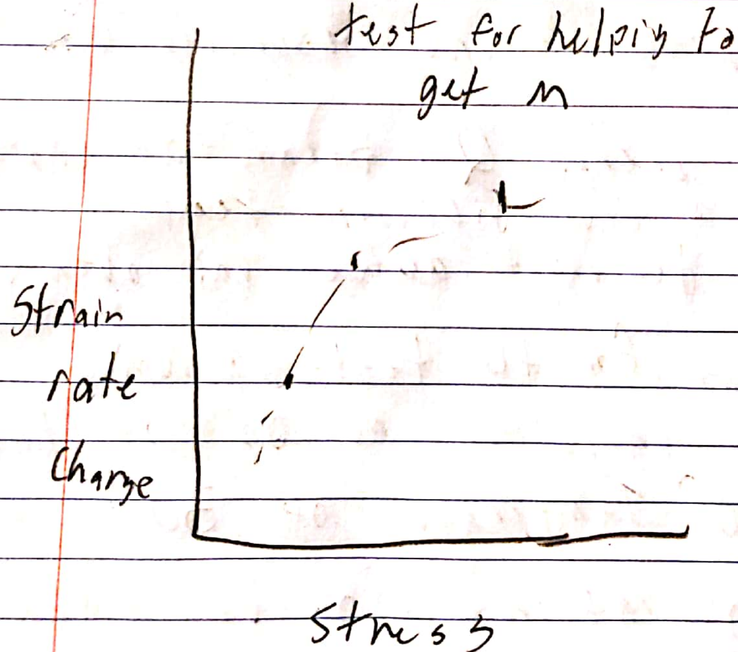
To land on an accurate stress exponent, we must first consider $\dot{\gamma} = \rho_{mobile} b B_0 \left(\frac{\tau_{eff}}{\tau_0}\right)^m e^{\frac{-Q}{kT}}$. During a tensile test at a given ~~strain rate change~~ $\rho_{mobile} b B_0 e^{\frac{-Q}{kT}}$ will not be changing significantly and you will be able to record the applied or τ_{eff} stress during the test and dividing it by the starting stress. Therefore, you can do a few tests and solve for the variable m as you can assume the ρ_{mobile}, b, B_0, k, T from the material and environment and Q can be found described below.

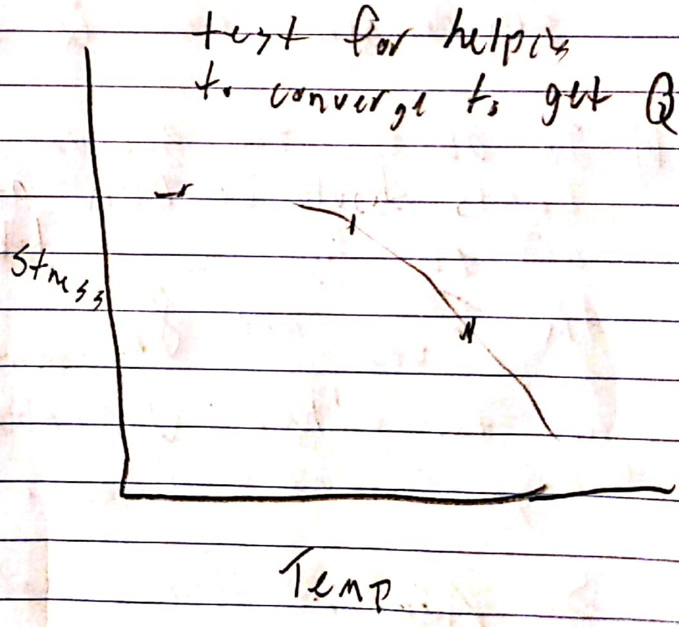
To obtain the activation energy Q, strain rate change tests should be run at a few different temperatures of the specimen like described above and obtain the τ_{eff} and $\dot{\gamma}_c$ constant for the tests assuming all the other variables including m do not change significantly. Change of Temperature of 30°C is fine.

So now a system of equations can be made from the multiple strain rate changes data and the different temperature data to converge on a required M and Q that works for the measured data of the specimen.

c) To obtain the back stress, an algebraic approach is to use the variables M and Q already found and perform a high strain rate change test to exacerbate the strength of the back stress and solve.

Another approach is to perform a tensile test at a very low constant strain rate test ($\sim 10^{-6}$) and assume that the recorded instron test for $\tau_{app} = \tau_{back}$.





2) Martensite in .4%C steel: strength attributed to several mechanisms:

a) Feature size associated with the boundary strengthening component?

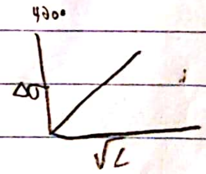
Boundary strengthening increased by 620 MPa so using hall-petch to know the required d for that amount of YS increase

Mild steel: $\sigma_0 = 70.6$ $K = .74$

$$\sigma_{ys} = \sigma_0 + \frac{K_y}{d^{1/2}} \Rightarrow d = \left(\frac{K_y}{\sigma_{ys} - \sigma_0}\right)^2 = \left(\frac{.74}{(620 - 70.6)}\right)^2 = 1.8 \cdot 10^{-6}\ \text{m}$$

feature size diameter

b) Atomic fraction carbon concentration? 400 MPa increase from solid solution strengthening.



From graph of $\Delta\tau$ vs $\sqrt{c}$ → $\Delta\tau = 4200\ \text{MPa}\sqrt{c}$

So knowing $\Delta\tau = 400$ MPa → $\sqrt{c} = \frac{400}{4200} = \boxed{.095} \Rightarrow c = .009$

bulk concentration in weight fraction

Can then compare this to the 0.4% by weight carbon concentration steel.

$$\Delta\tau_y = \underbrace{G}_{77\text{GPa}}\ \underbrace{\cancel{b}}_{=2R = .255 \cdot 10^{-9}\text{m}}\ \varepsilon^{3/2}\sqrt{c} = \frac{G\varepsilon_s^{3/2}\sqrt{c}}{700} \rightarrow \varepsilon_s = 11.3$$

$\Rightarrow$

$$= \frac{n_C}{n_C + n_{Fe}}$$

$$M_{Carbon} = \frac{f_C MW_C}{f_{Fe} MW_{Fe} + f_C MW_C}$$

So 100g steel is 99.1 g Fe and .9g C

$MW_{Fe} = 56$ $MW_C = 12$

$C_{atoms} = 6.022 \cdot 10^{23} \cdot .9 / 12 = 4.5 \cdot 10^{22}$

$Fe_{atoms} = 6.022 \cdot 10^{23} \cdot 99.1 / 56 = 10.65 \cdot 10^{23}$

At % Carbon $= C_{atoms} \cdot 100 / ((.45 + 10.65) \cdot 10^{23}) = 4.05\%$

atomic fraction of carbon $= \frac{4}{100}$

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3 Estimate strengthening increment from having a 20% volume fraction of 5 nm diameter particles. Use $f \approx r/L$ to estimate the particle spacing.

$d = 5\,nm$, $r = 2.5\,nm$, $f = .2$

So $f = \frac{r}{L} \rightarrow L = \frac{r}{f} = \frac{2.5\,nm}{0.2} = 12.5\,nm$

So strengthening increment $\tau_B \cong \frac{Gb}{L-2r} = \frac{Gb}{7.5\,nm}$ where

if $b = .255\,nm$, $\underline{\tau_B \cong \frac{1}{30} G}$

b) Knowing above, estimate increase in flow stress with $\rho = 10^4/m^2$ and $\varepsilon_{shear} = .05$; $d = 5\,nm$, $r = 2.5\,nm$, $L = 12.5\,nm$, $f = .2$, $b = .255\,nm$

Assuming $G \cong 27$ GPa

$\tau_{0.2} = 0.7\,G(\varepsilon)^{3/2}\left(\frac{fr}{b}\right)^{1/2} \cong 300\,MPa$ but if late stage would be ~ 260 MPa. Closer

TS of 2024-T3 = 430 MPa
TS of 6061-T6 = 310 MPa
TS of 7075-T6 = 540 MPa

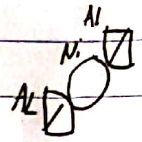
So the τ calculated for the set of parameters for increase in flow stress is within an order and is ~ 20-75% of common aluminum alloys. This means that order hardening the material with that strain and density, it can significantly increase the aluminums strength.

4) Ni-Al alloy 12% volume fraction 1μm diameter where APBE = 80 mJ/m², order Ni_3Al precipitates

$f = 0.12$, $d = 1 \cdot 10^{-6}$ m, APBE = 80 mJ/m² → Ordered → APBE → Completely perfectly ordered

↑ Precipitate

$\frac{\partial E}{\partial x} \leftarrow \partial R$



Lattice param → .357 nm → $R_{Ni} = 124$ pm $= R_{Al} \approx .25$ nm

With $R_{Al} \cong .124$ nm → $b = 2R \cong .25$ nm

So with $G \cong 44$ GPa, $X_{eq} = \frac{Gb^2}{2\pi \, APBE} = \frac{(44 \cdot 10^9)(.25 \cdot 10^{-9})^2}{2\pi(.08 \; J/m^2)} = \underline{5.5 \; nm}$

b) $\Delta\tau = \tau_{order\ hardening}$ ⟹ Need $\varepsilon_{ord} = APBE/GB$

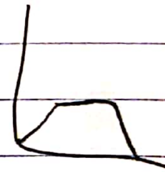
$G \approx 44$ GPa

$f = .12$

$r = 5 \cdot 10^{-7}$ m

$b \approx 2.55 \cdot 10^{-10}$ m → 3.26

so, $\varepsilon_{ord} = \frac{.08}{Gb} = \underline{.0071}$



Early or late stage? Having

↑ 1 dis can make it all the way thru before next one coming

$X_{eq} > d$ early

$X_{eq} < d$ late

with distance between dislocations being 5.5 nm while the diameter is larger at 1000 nm, it ⟹ is obvious to see that it is in late stage with a low ε_{ord}, so

$\Delta\tau \cong 0.44 G \varepsilon_{ord} f^{1/2} = 0.44(44 \text{GPa})(.0071)(.12)^{1/2}$

$= \boxed{47.6 \text{MPa}}$

c) Compare to particle looping stress? What's the yielding mechanism.

$$\tau = \frac{Gb}{r\left(\frac{\pi}{f}\right)^{1/2}} = \frac{(44 \cdot 10^{9})(.25\,nm)}{(5 \cdot 10^{-7})\left(\frac{\pi}{.12}\right)^{1/2}} = 4.3\ MPa$$

So, Particle looping stress is less, meaning that that will be the yielding mechanism because it will happen first.

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5

a) Explain why the amount of Martensite increases when stress and strain are applied.

Material tends to resist shear and strain, so when an applied stress is added to a steel, a part of the energy required to strain is from the difference in energy of the parent steel phase and the Martensite phase. So a stress adds energy (strain energy) to a material like steel that instantaneously transforms its parent phase to more of a martensite phase.

b) Load drops are observed in carbon steels when the material hits M_s. This is because of temperature formed Martensite which has its own affect of transitioning its austenite to martensite. But when you begin to strain the steel to begin strain induced Martensite transformation, experimentally it does not form as much as when below M_s because the phenomenon for martensite transformation clash. Free energy and temperature induced Martensite do not help eachother!

c) This is because of the load drop phenomenon in steels, and needs to build back up after. This is due to shear strain of the martensite as it instantaneously expands when you hit M_s and as you decrease temperature past it the flow stress after slowly recovers. The spike load drop occurs then as when martensite forms and expands, so does the ability of the whole material to allowing it to require less stress to strain it.