- **Fatigue of Metals**
- **Copper Alloys**

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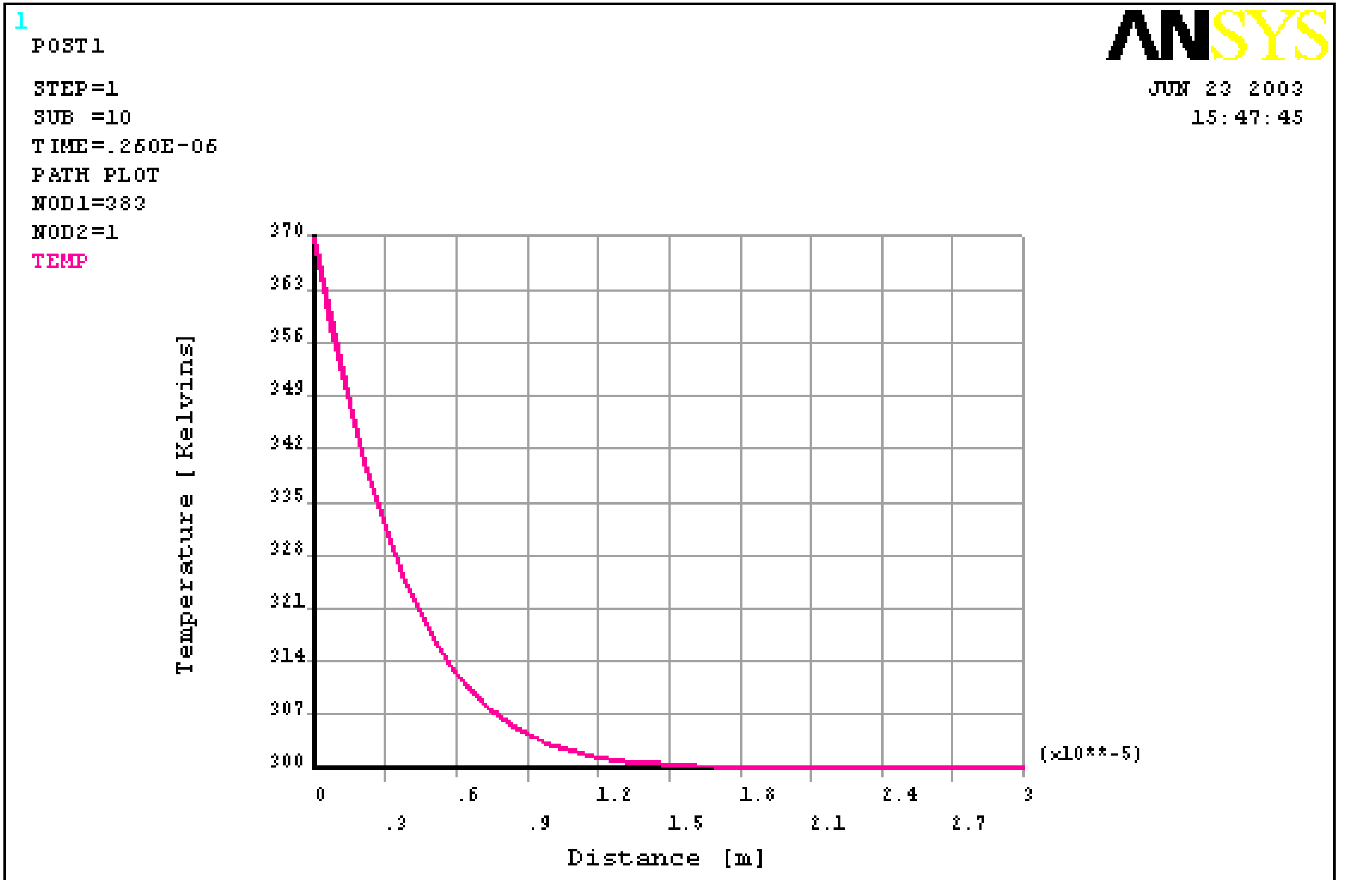
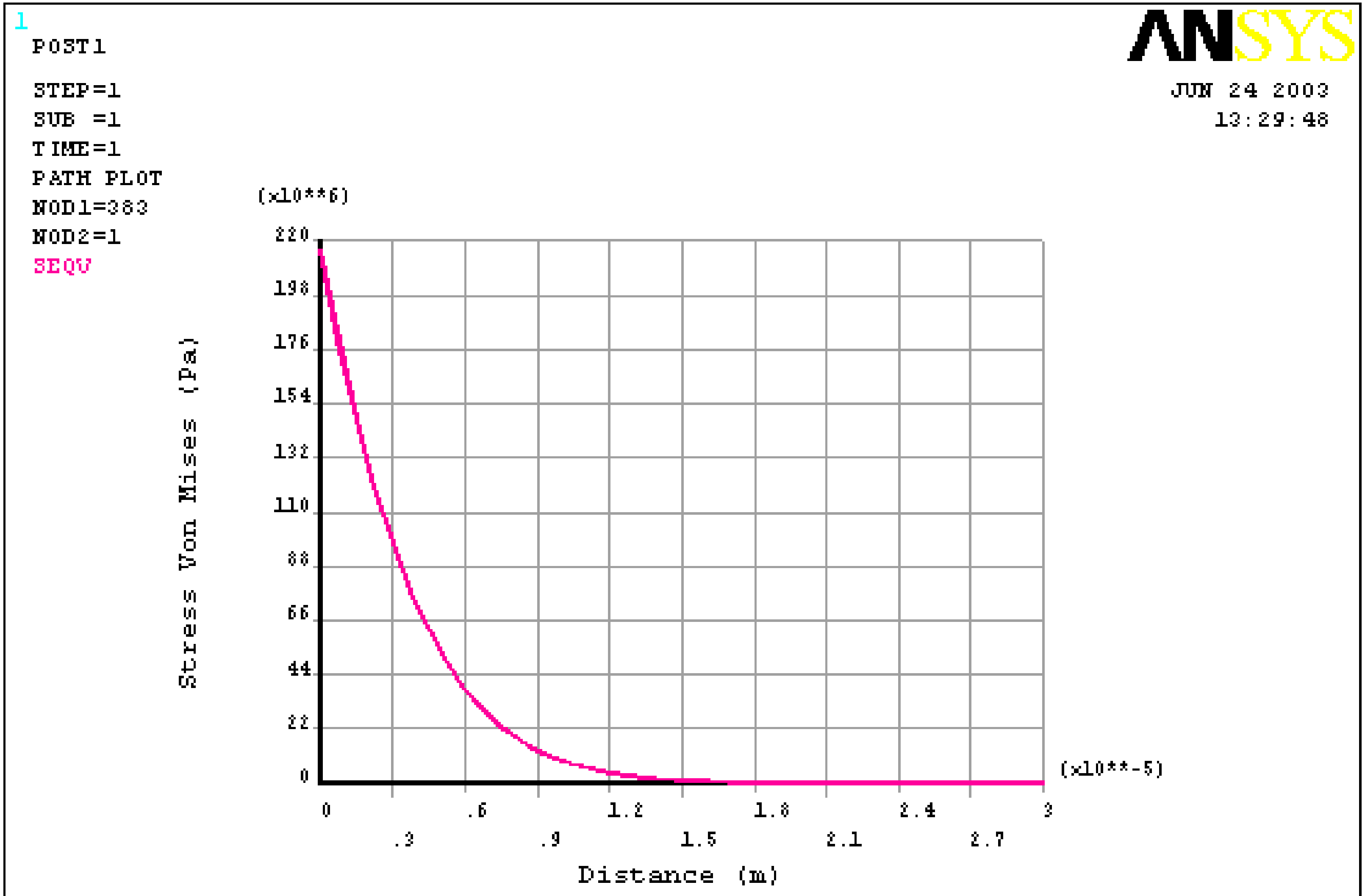
Temperature Profile of HDS Structure



ΔT ≈ 70°C

Stress Profile of HDS Structure



Stress amplitude ≈ 220 MPa

CLIC Number of Cycles

f = 100 Hz
24 hours / day
30 days / month
9 months / year
20 years

=> Total lifetime: **$5*10^{10}$ Cycles**

Fatigue

- Occurs when a material experiences lengthy periods of cyclic or repeated stresses
- Failure at stress levels much lower than under static loading
- Fatigue is estimated to be responsible for approximately 90% of all metallic failures
- Failure occurs rapidly and without warning
- There is no fixed ratio between materials Yield- and Fatigue Strength
- Normally the ratio varies between 30-60%
- Fatigue Strengths are usually average values

S-N Curve

Normally data from the fatigue tests are plotted at *S-N curve*. As stress *S* versus the logarithm of the number of cycles to failure, *N*.

When the curve becomes horizontal, the specimen has reached its <u>*fatigue (endurance) limit*</u>, ferrous and titanium alloys.

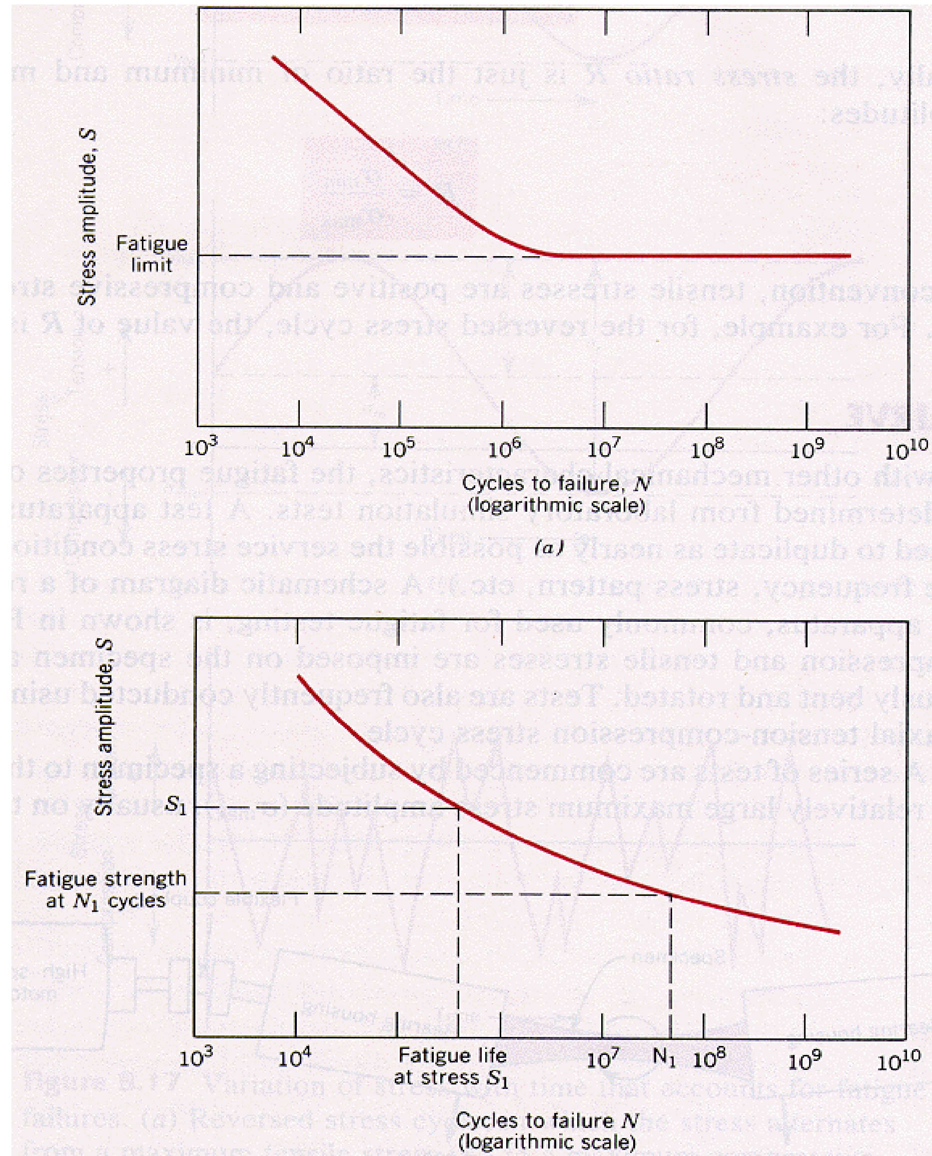
> This value is the maximum stress which can be applied over an infinite number of cycles.

> The fatigue limit for steel is typically 35 to 60% of the tensile strength of the material.

<u>*Fatigue strength*</u> is a term applied for nonferrous metals and alloys (Al, Cu, Mg) which do not have a fatigue limit.

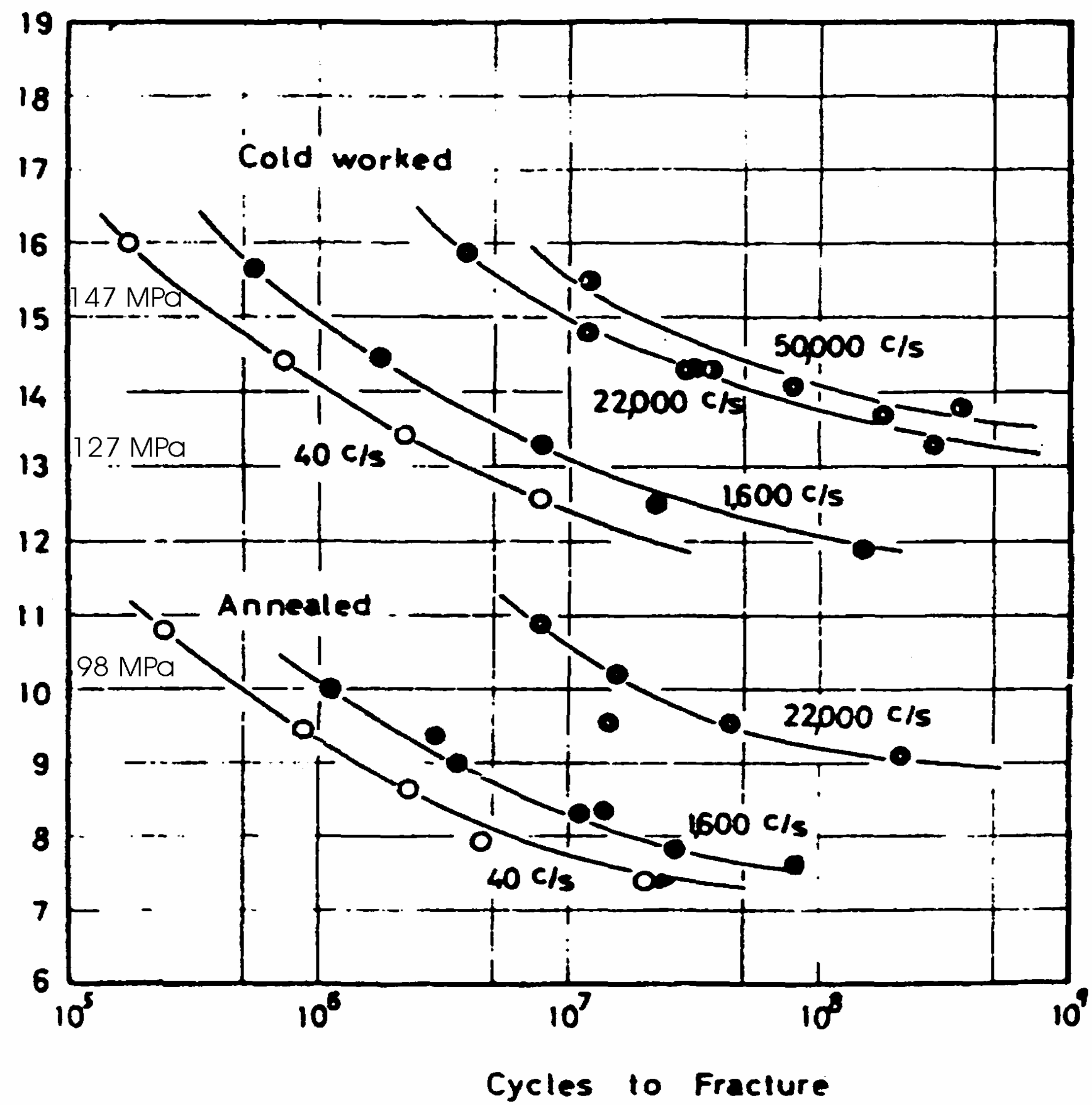
> The fatigue strength is the stress level the material will fail at after a specified number of cycles (e.g. 10^7 cycles). In these cases, the S-N curve does not flatten out.

<u>*Fatigue life*</u> N_f, is the number of cycles that will cause failure at a constant stress level.



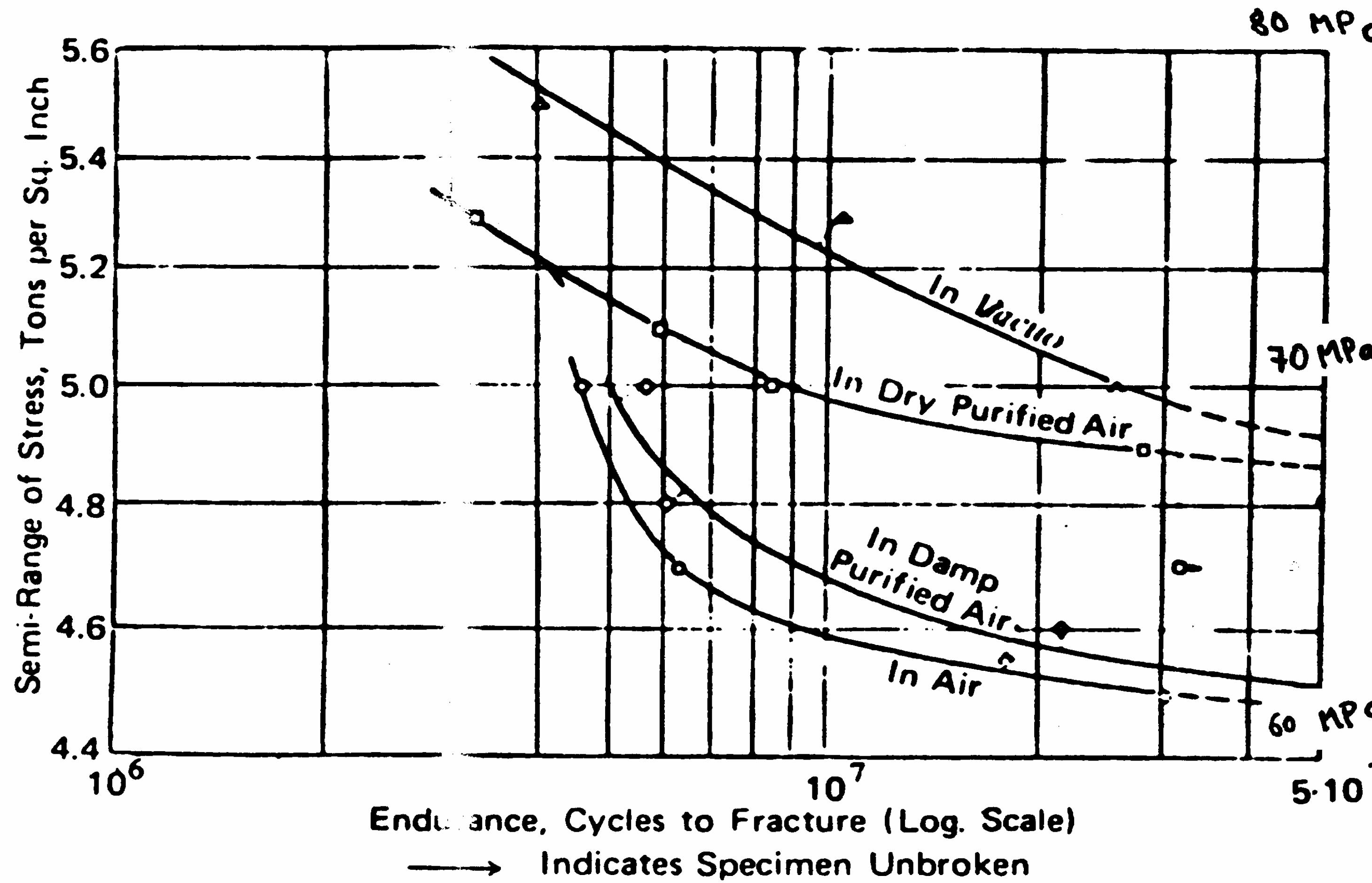
Things that have an effect on fatigue strength

- Grain size
- Corrosion
- Frequency



Things that have an effect on fatigue strength

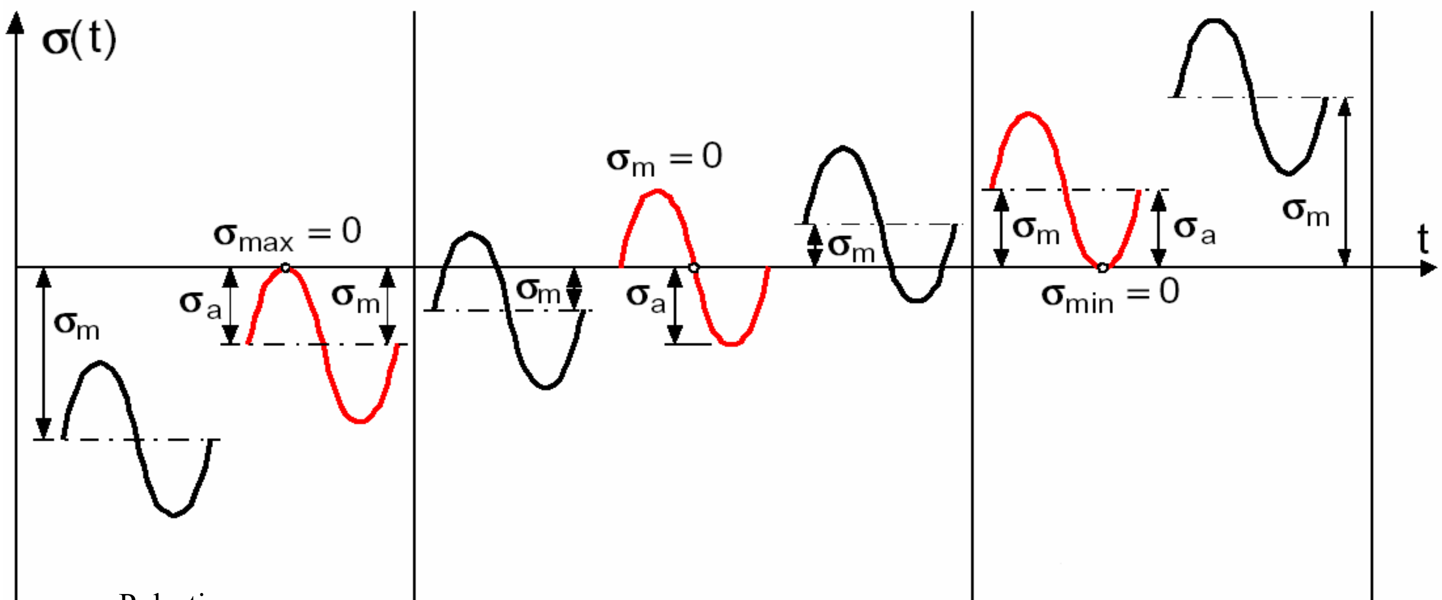
- Grain size
- Corrosion
- Frequency
- Vacuum



The effect of air and water vapor on the fatigue life of annealed copper.

Things that have an effect on fatigue strength

- Grain size
- Corrosion
- Frequency
- Vacuum
- The Average Mean Stress



Pulsating compression stress

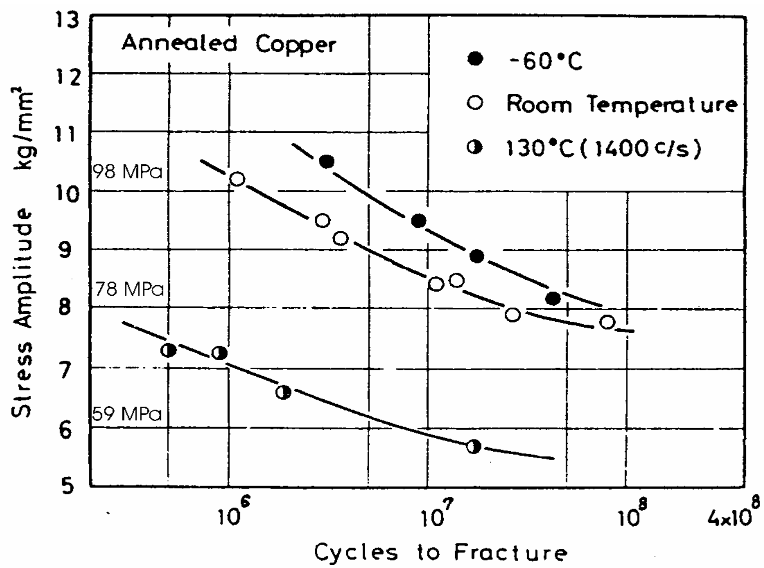
Pulsating reversed stress

Pulsatin g tension stress

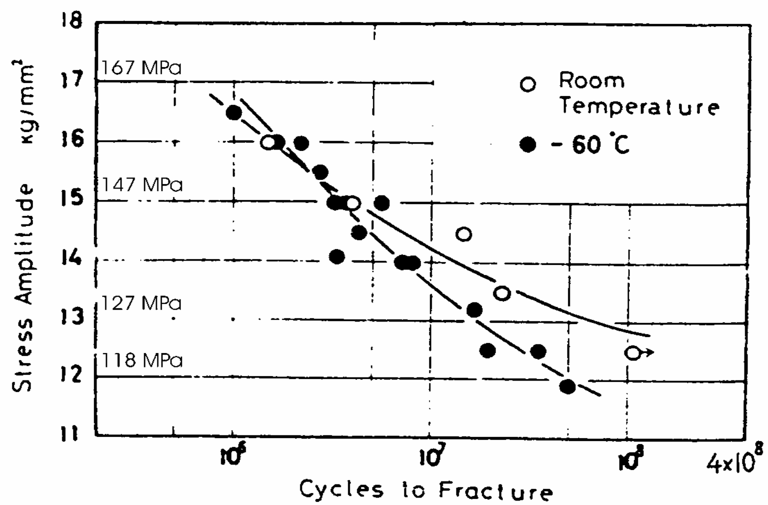
Things that have an effect on fatigue strength

- Grain size
- Corrosion
- Frequency
- Vacuum
- The Average Mean Stress
- Ductility (at small values of N)
- Surface finish (Notch effect)
- Microstructure (‘Notch effect’)
- Temperature (Strength decreases increasing the temperature. Exception confirms the rule…)

Pure Copper Properties, annealed and cold worked



(a) Annealed copper



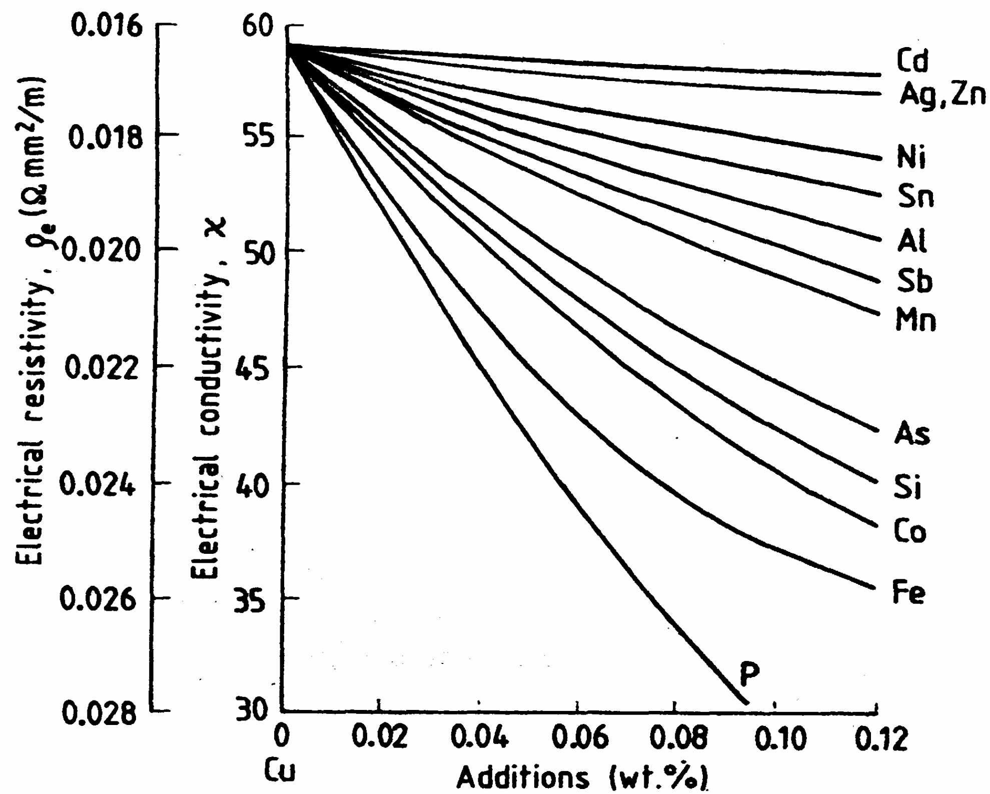
(b) Cold-worked copper

	Annealed	Cold Worked
Ultimate Tensile Strength [MPa]	240	380-415
Yield Strength [MPa]	70	345-380
Fatigue Strength at 10^8 cycles [MPA]	75	126

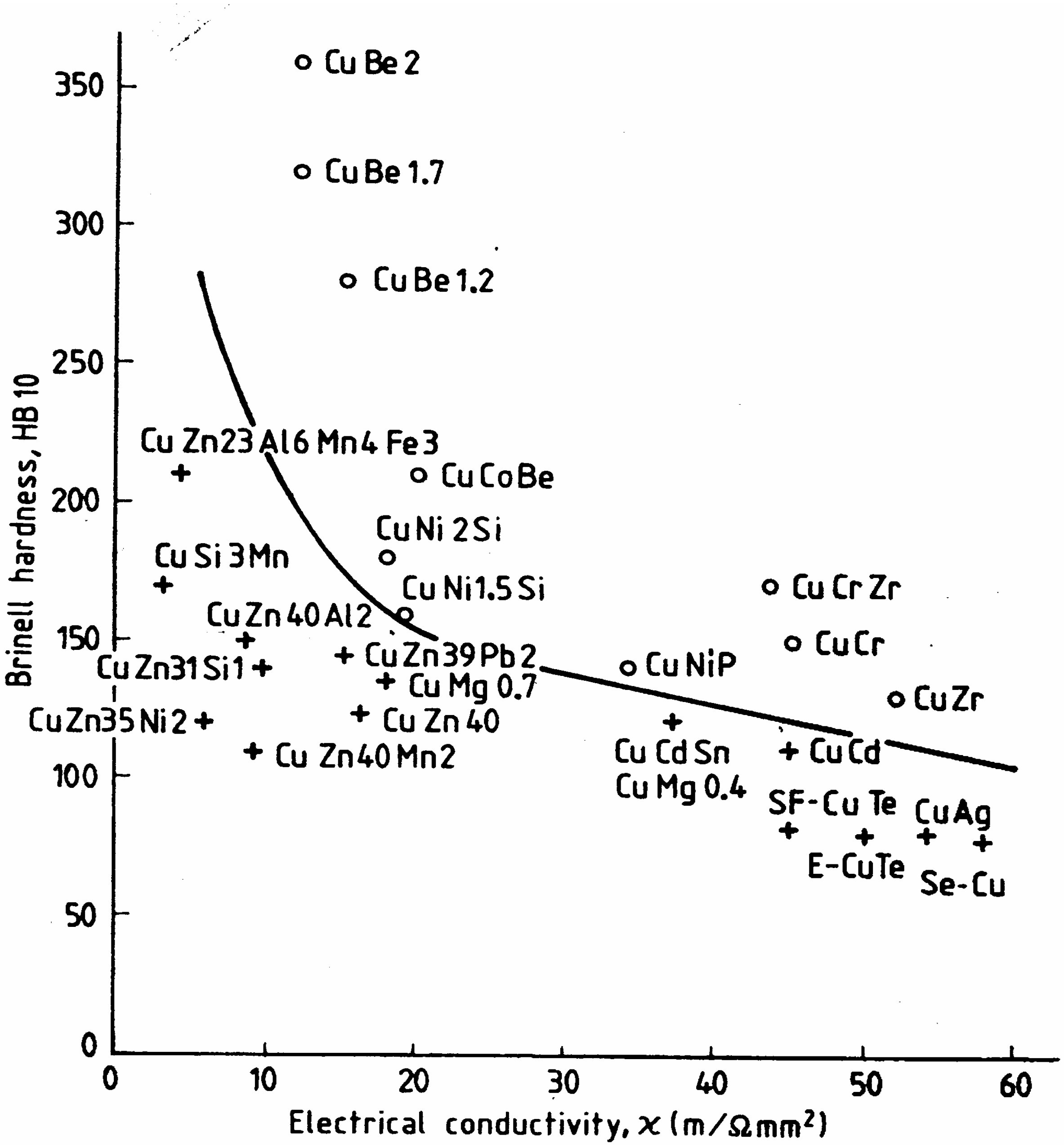
Figure. S-N curves of pure copper, Annealed and Cold Worked.

How alloying elements affect the properties of copper

- Alloying can increase the strength, hardness, electrical and thermal conductivity, corrosion resistance or change the color of a metal.
- The addition of a substance to improve one property may have unintended effects on other properties.
- The best way to increase the electrical and thermal conductivity of copper is to decrease the impurity levels.

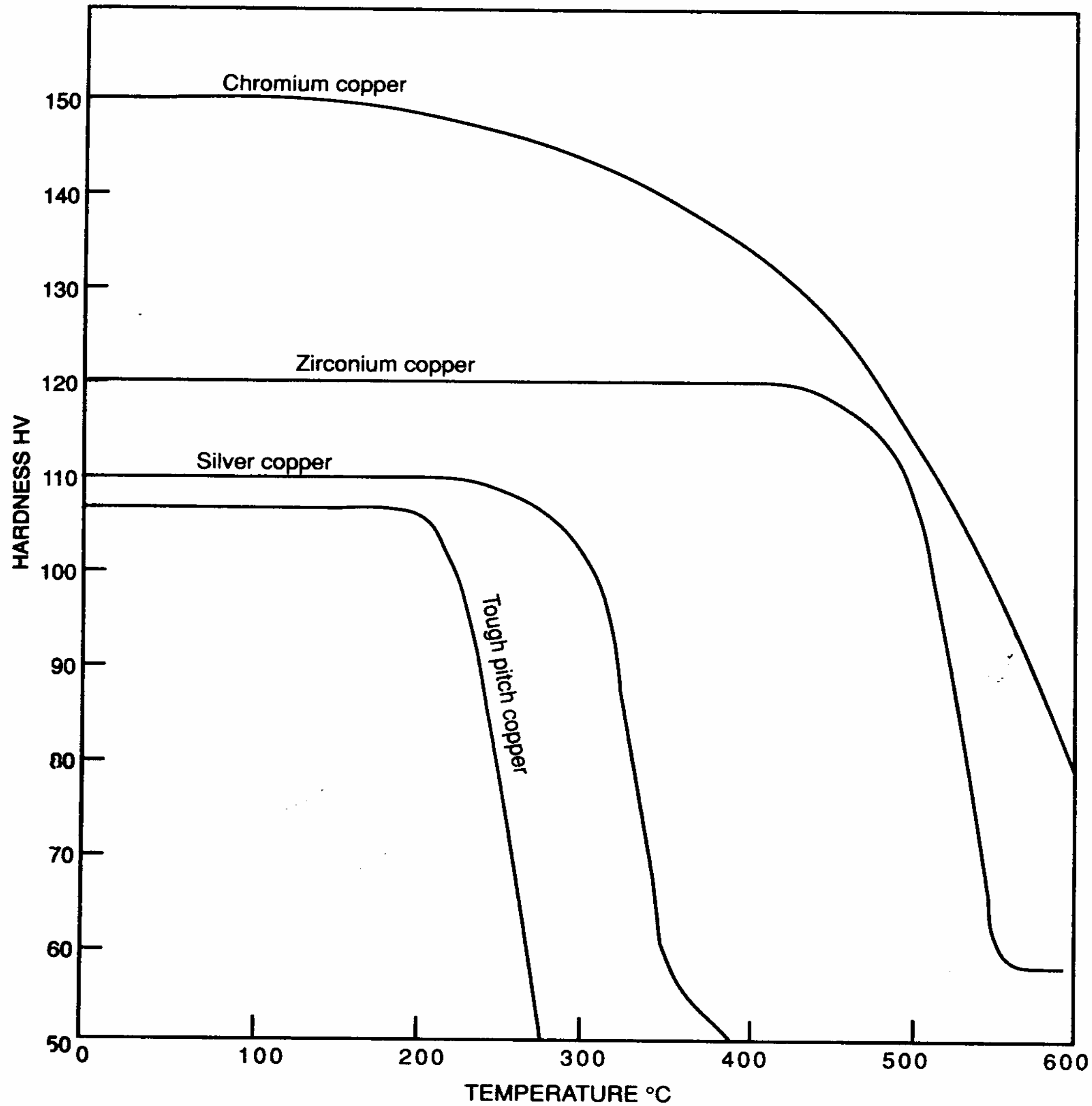


Influence of impurities on the electrical conductivity $\varkappa$ and specific electrical resistance ϱ_e of pure copper (Pawlek and Reichel, 1956).



General overview of copper alloys. Relation between Brinell hardness, HB 10 (strength, R_m) and electrical conductivity, $\varkappa$ (DKI, 1976) ○ = hardened material; + = hard-drawn material.

Effect of temperature on the softening of copper alloys



Hardness values as influenced by softening temperatures of typical tough pitch high conductivity copper, silver copper, chromium copper and zirconium copper

Properties of some Copper Alloys

(Outokumpu Poricopper Oy)

Name	CDA	Acronym	Thermal Conductivity at 20 C [W/(m*K)]	Electrical Resistivity at 20 C [µOhm*cm]	Yield Strength Cold Worked 84% 24 C [MPa]	Yield Strength Annealed 24 C [MPa]	Fatigue Strength Cold Worked Number of Cycles[300x10^6]
Oxygen-free Copper	C10200	Cu-OF	394	1.7241-1.70	341	54.5	117
Silver-Bearing Oxygen-free Copper	C10400	Cu-OFS	394	1.74-1.71	373	-	103
Electrolytic Tough-Pitch Copper	C11000	Cu-ETP	394	1.7241-1.70	345	49.6	117
Copper-Chromium	C18200	Cu-Cr1	301-343	2.3-2.0	520	-	193
Cadmium Copper	C16200		360	1.92	474	83	205
Cupro-Nickel		Cu Ni25	33.5	34	530	140	269
Aluminum Bronze		Cu Al5	75.4-83.7	10	441	186	131
Zirconium Copper	C15000	Cu-Zr	367	1.86	414	80	241

Comparison of Potential Copper Alloys

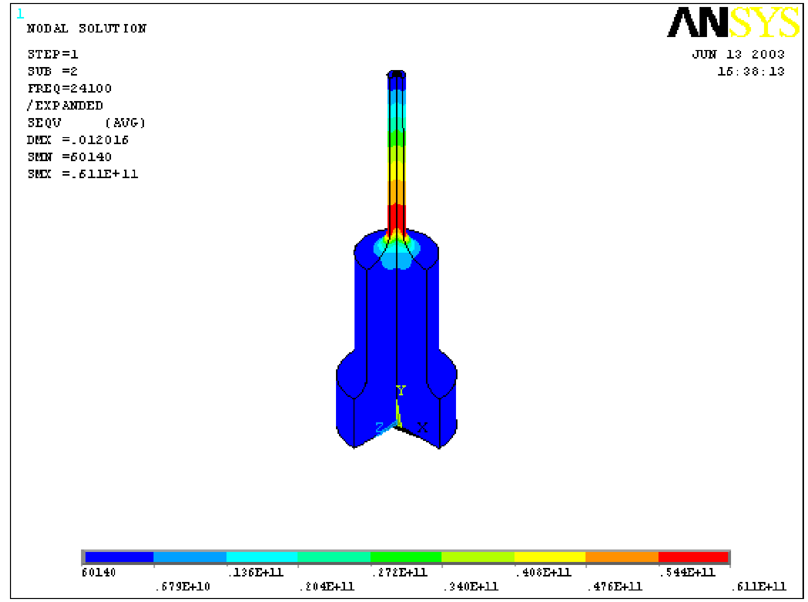
Alloy name	Cu OFE	Cu Cr	Cu Cd	Cu Zr
ΔT [°C] (HDS Structure)	71	88	80	77
$\sigma_{Thermal}$ (Thermal Stress of HDS Structure) [MPa]	234	305	244	263
$\sigma_{Fatigue}$ (Fatigue Strength at 10^8 cycles) [MPa]	117	193	205	241
$\sigma_{Thermal} / \sigma_{Fatigue}$	2	1.58	1.19	1.09

Ultrasonic Fatigue Testing

UIP250 Ultrasonic Processor 250 Watts

Frequency: 24 kHz

$86*10^6$	Cycles / hour
$2*10^9$	Cycles / day
$1.5*10^{10}$	Cycles / week
$5*10^{10}$	Cycles / 3.5 weeks



- Make specimens from different materials.
- Adjust different stress levels.
- Create conditions as realistic as possible. (Vacuum etc.)

=> Generate the S-N curves.