Figures of Merit for Materials - Update of ARDB 1

Starting with eq. (3') of ARDB-25, the pulsed temperature rise at the surface of a metal in the limit of skin depth $\rightarrow$ 0 and for a square pulse of length t is

$$\Delta T = \frac{\sqrt{\mu_0 f t} H^2}{\sqrt{k \rho c_\varepsilon \sigma}}$$

where
- c_ε ≡ specific heat;
- ρ ≡ density;
- k ≡ thermal conductivity;
- σ ≡ electrical conductivity;
- f ≡ frequency

H is the peak tangential magnetic field at the surface. When comparing materials for the same cavity, pulse length, etc. the relative temperature rises are in the ratio

$$\Delta T_{Rel} = \frac{1}{\sqrt{k \rho c_\varepsilon \sigma}} \qquad (1)$$

The threshold for plastic deformation is given in the paper by H. M. Musal that is summarized in ARDB-12. It is

$$\Delta T_Y = \frac{(1-\nu)Y}{E\alpha} \qquad (2)$$

where
- ν ≡ Poisson's Ratio;
- Y ≡ Yield Strength;
- E ≡ Young's Modulus;
- α ≡ Coefficient of Linear Expansion;

The table below is an EXCEL spread sheet incorporated into the WORD 6 version of this note that allows comparison of different materials.

Comparison of Materials (EXCEL Spread Sheet)*

Material	ρ	σ	**k**	c_ε	ΔT_{Rel}	α	**Y**	**E**	ν	ΔT_Y	$\Delta T_Y/\Delta T_{Rel}$
OF Copper, C10200	8.94	5.85	391.1	385.2	3.56E-09	1.76	32.3	1.19	0.35	100.2	2.81E+10
OFE Copper C10100 annealed	8.95	5.85	391	384	3.57E-09	1.73	6.9	1.17	0.345	22.3	6.26E+09
OFE Copper C10100 unanneal	8.95	5.85	391	384	3.57E-09	1.73	34.5	1.17	0.345	111.6	3.13E+10
Glidcop AL-15	8.75	4.93	335	384	4.25E-09	1.66	35	1.15	0.35	119.2	2.81E+10
Zr Copper	8.94	5.39	357	384	3.89E-09	1.8	41	1.27	0.35	116.6	3.00E+10
OFC Electrodep Copper	8.92	5.79	394	384	3.58E-09	1.66	6.9	1.15	0.35	23.5	6.57E+09

* **UNITS**

ρ ≡ density in units of 10^3 kg/m^3; σ ≡ electrical conductivity in units of 10^7 $(\Omega m)^{-1}$
k ≡ thermal conductivity in units of W/m-K; c_ε ≡ specific heat in units of J/kg-K;
ΔT_{Rel} ≡ Relative Temperature Rise (Eq. (1)); α = linear expansion coefficient in units of 10^{-5} K^{-1};
Y ≡ Yield Strength in units of 10^7 N/m^2; E ≡ Young's Modulus in units of 10^{11} N/m^2;
v ≡ Poisson's ratio; ΔT_Y ≡ Plastic Yield Temperature Rise (Eq. (2))

REFERENCES

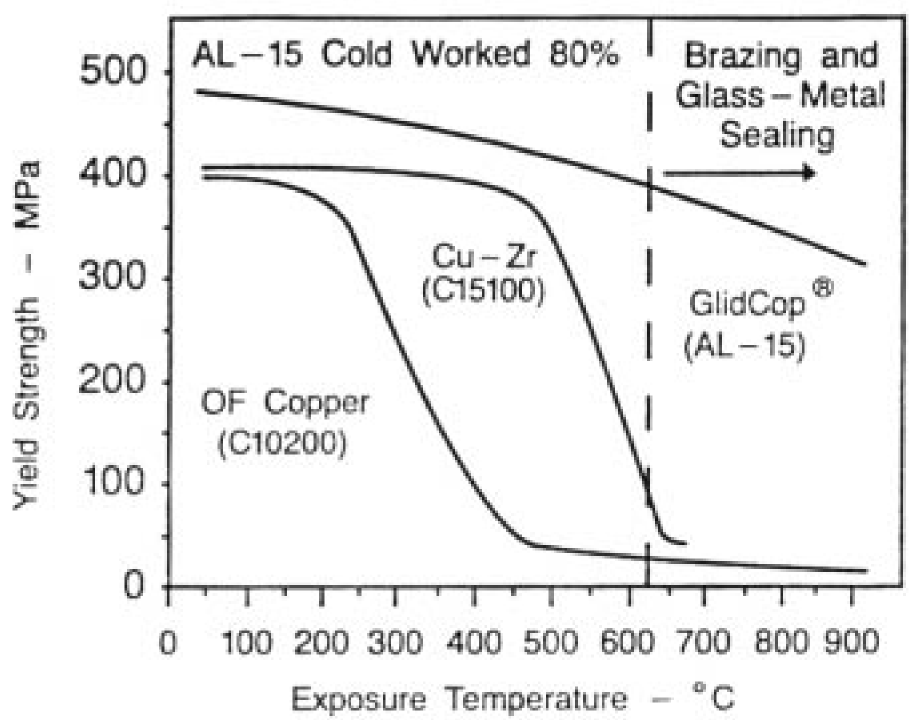
OF Copper	Source Book on Copper and Copper Alloys, Cenbase Materials CD-ROM
OFE Copper	Copper 101 data sheet from C. Pearson
Glidcop	SCM Metals Products Literature
ZrCu	Copper 150 data sheet and Hitachi literature

NOTES

k (W/m-K) = 418.6 k(cal-cm/cm^2-sec-K)
c_ε (J/kg-K) = 4186 c_ε (cal/gm-K)
Y (Nt/m^2) = 6895 Y (psi)
Young's modulus = modulus of elasticity in tension
σ (100 % IACS) = 5.79×10^7 (Ω-m)$^{-1}$

Effects of Brazing

It is clear from the results above that there can be a wide variety of results. ΔT_Y of over 100K can be achieved for some materials. However, annealing may be a critical variable since the yield strength depends strongly on the maximum temperature to which the material is exposed. See the figure below.



Softening resistance of GlidCop AL-15 versus OF copper and Zirconium Copper (Note: Properties measured at room temperature after exposure to elevated temperatures for one hour.) From Prasan K. Samal, "Brazing and Diffusion Bonding of GlidCop Dispersion Strengthened Copper" published in The Metal Science of Joining, edited by M. J. Cisleak, J. H. Perepezko, S. Kang and M. E. Glicksman