APPENDIX B:

B.1 Critical Cooling Rate & Specimen Thickness

BMG alloys are cast and quenched into many different shapes and geometries. The cooling rate that the liquid undergoes depends many factors including:

1. sample's geometry
2. thermal conductivity of the mold and of the alloy
3. liquidus temperature
4. mold temperature
5. thermal diffusivity of the alloy
6. specific heat of the alloy.

The critical cooling rate is generally taken as the slowest cooling rate that material experiences which is taken at the center of the sample.

An exact solution to the heat-flow equation for any sample geometry can be calculated. However, there are often times that only a quick assessment of cooling rate is needed. A simple cooling rate approximation can be made quickly by making a few assumptions about variables input into the heat-flow equation:

1. sample's geometry – The two common sample geometries are strip and cylinder. The cooling rate calculation can be done by assuming strip geometry first and the

cylinder casting thickness can be calculated by simply multiplying √2 to the thickness of the strip.

2. thermal conductivity of the mold and of the alloy – we can assume the mold to be a large heat reservoir with high thermal conductivity and the calculation will only need to deal with the thermal conductivity of the alloy K_t ~0.2 Watts/cm.K.
3. liquidus temperature – Assume 1000 K.
4. mold temperature – Assume 0 K.
5. thermal diffusivity of the alloy – $\kappa = K_t / C_p$.
6. specific heat of the alloy – C_p ~5 J/cm^3·K (assume Vitreloy).

The critical cooling rate Rc can be related to the critical casting thickness d_c:

$$Rc = 40(K_t / C_p)T_l/d_c^2 \qquad \text{(equation B-1)}$$

where K_t = 0.2 Watts/cm.K, Cp=5 J/cm^{3}K, and T_l = 1000K.

Finally, we approximate that

$$Rc = 1600/d_c^2, \qquad \text{(equation B-2)}$$

which is the solution for thin strip casting. If cylinder geometry is needed, the geometric correction takes a very simple form:

$$Rc(\text{strip}) \times \sqrt{2} = Rc(\text{cylinder}). \qquad \text{(equation B-3)}$$

To summarize, the experimental results of twenty BMGs with different critical casting thickness and critical cooling rates are plotted with equation B-2 in Figure B-1. The relationship holds over 4 orders of magnitude in thickness and over 7 orders of magnitude in critical casting thickness.

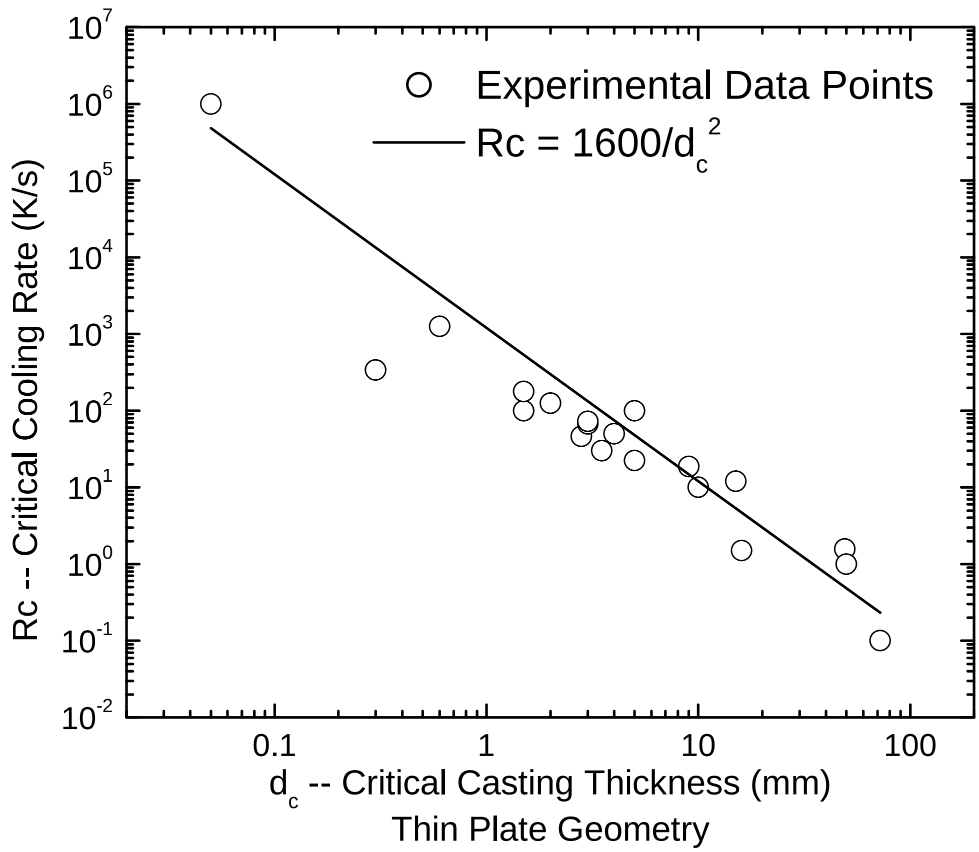

Figure B-1: Critical cooling rate approximation is plotted with experimental values. The relationship $Rc=1600/d^2$ holds true for over four orders of magnitude in casting thickness and seven orders of magnitude in critical cooling rate.