crystallization.

(4) At higher strains ($\epsilon > 80\%$) the deformation bands broaden and strain becomes homogeneous again. Only then is recrystallization retarded still more in the alloy containing small particles (M 300) as compared to that with medium size particles (M 550).

(5) Because of the reasons mentioned in 3 and 4 the time to initiate recrystallization in the finest dispersion decreases with increasing amounts of cold-work up to 80%, but thereafter increases again at higher strains.

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On the solidification of powders and large ingots – an application to Fe–25% Ni

It is interesting to relate the losses by conduction and the cooling rate during solidification of small powders. Equation 1 connects the conduction losses with those of convection and radiation:

$$q = \frac{K\Delta T}{(1/D_i) - (1/D)} = \frac{D^2}{2}\left[h_c(T - T_0) + \epsilon\sigma(T^4 - T_0^4)\right], \quad (1)$$

where q is the rate of heat flow, K is the conductivity of the powder, ΔT is the temperature difference between the outer diameter D and the inner diameter D_i, in which the solidifcation has been advanced, ϵ, σ and h_c are the emissivity of the powder, the Stephen Boltzmann constant and the convection heat transfer coefficient respectively, while T_0 is the temperature of the surrounding medium.

The convection coefficient h_c for a sphere moving through a gas under turbulent flow for all atomization processes and for small powders can be expressed as [1]

$$h_c = \lambda/D \quad (2)$$

where λ should be approximately constant for a given process and material. Assuming 7/8 of the volume of the droplet has been solidified ($D_i = D/2$) we have

$$\Delta T = \frac{D}{2k}\left[\frac{\lambda}{D}(T - T_0) + \epsilon\sigma(T^4 - T_0^4)\right]. \quad (3)$$

Also in Equation 4 the rate of heat flow is being connected with the volume fraction being solidified V_s,

$$\frac{D}{6}\rho_s H\frac{dV_s}{dt} = \left[\frac{\lambda}{D}(T - T_0) + \epsilon\sigma(T^4 - T_0^4)\right], \quad (4)$$

where ρ_s is the density of the alloy and H is the latent heat of fusion. Assuming that the initial condition is $V_s = 0$ at $t = 0$ the cooling rate $\dot{T}$ will be

$$\dot{T} = \frac{6T}{D\rho_s H}\left[\frac{\lambda}{D}(T - T_0) + \epsilon\sigma(T^4 - T_0^4)\right]. \quad (5)$$

Introducing the values for Fe–25% Ni [1] we have $\lambda = 0.5 \times 10^{-3}$ cal cm^{-1} sec^{-1} K^{-1}, $T = 1773$ K, $\epsilon = 0.33$, $\rho Cp = 1.27$ cal cm^{-1} K^{-1} and $k = 0.03$ cal cm^{-1} K^{-1}. In the extreme case of powder diameter 500 μm the error at this temperature is less than 1% which is negligible in the powder form. Introducing $\rho = 8$ g cm^{-3} and $H = 72$ cal g^{-1} we find that the cooling rate for solidification of a powder of a diameter 5 mm is 1760 K sec^{-1} in which a drop of 1355 K sec^{-1} is due to a convection cooling and the rest due to radiation. The conclusion is that since the cooling rate is high we can assume that continuous cooling occurs during powder solidification and so the undercooling should be proportional to the $\dot{T}^{1/2}$ for a specific system [2] and for low undercoolings, before nucleation occurs.

For large ingots, it was found experimentally

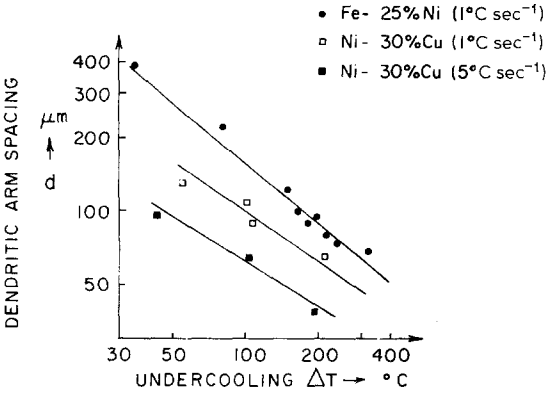

Figure 1 Dendritic arm spacing versus undercooling at different cooling rates for Ni–30% Cu [3] and Fe–25% Ni [4].

that the dendrite arm spacing is proportional to the solidification time t^p, where p is an empirical exponent. If we assume that the solidification time is almost equivalent to the time during coarsening, t_c, the dendrite arm spacing should be proportional to $[1/2(T_l - T_s)t_c]^p$ where T_l and T_s are the liquidus and solidus temperatures. Assuming that the time for recalescence is much smaller than the time for coarsening, the term $1/2(T_l - T_s)t_c$ represents approximately the area of the cooling curve during the coarsening time and between the two isotherms. It was also observed that coarsening at high temperatures requires less time than at lower ones, therefore final dendrite arm spacing should be proportional to $(\int T_m \mathrm{d}t_c)^p$ where T_m is the temperature of the melt.

Generally if both undercooling ΔT_u and coarsening cooling rate $\dot{T}_c$ are to be included in a single formula we can use the equation

$$d = C(\Delta T_u)^{-m}(\dot{T}_c)^{-n} \quad (6)$$

in which C is also an empirical constant. If we accept that the cooling rate is high and the undercooling is low, we will have $\Delta T_u \sim \dot{T}_u^{1/2}$; therefore Equation 6 becomes

$$d = c(\dot{T}_u)^{-m/2}(\dot{T}_c)^{-n}. \quad (7)$$

Applying this equation to the systems Fe–25% Ni [4] and Ni–30% Cu [3], we can find from Figure 1 that m is between $\frac{1}{2}$ and $\frac{1}{3}$. The same value of m was found for Ni–20% Cu [3].

In conclusion it is found that for powdered Fe–25% Ni conduction cooling is negligible, the dominant cooling being due to convection. For large ingots, however, the dendrite arm spacing is inversely proportional to the undercooling with a proportionality constant between $\frac{1}{2}$ and $\frac{1}{3}$.

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A note on the residual stress about a pointed indentation impression in a brittle solid

The residual stress about a permanent hardness impression in brittle solids is of considerable importance to practical and theoretical aspects of indentation fracture mechanics. Lawn and Swain [1], and Lawn *et al.* [2] have previously described the role of the stress field about a pointed indenter in the initiation and propagation of so-called "median" or normal cracks on loading, and "radial" and "lateral" cracks on unloading. In particular, the residual stress provides the driving force for lateral cracking which is primarily responsible for the observed high two- and three-body abrasive wear rates of brittle solids. Thus any complete theoretical fracture mechanics description of these types of cracks must incorporate the residual stress. The residual stress is also important because of the increasing use of pointed indenters to notch brittle solids prior to bend strength determinations [3–5]. The residual stress about the permanent impression would be expected to