Use of High-intensity Ultrasound for Synthesis and Modification of Advanced Materials

Tatiana Prozorov Final Seminar April 15, 2004

Irradiation of liquids with high-intensity ultrasound produces transient cavitation: nucleation, growth and violent collapse of bubbles. The implosive bubble collapse generates localized hot spots with temperatures as high as 5000 K, pressures of about 800 atm, and cooling rates exceeding 10^{10} K/s.[1,2] This produces intense shock waves which propagate in the liquid at velocities well above the speed of sound. In the case of slurries, these shockwaves lead to an extremely rapid mass transfer and induce high velocity collisions between solid particles suspended in ultrasonically irradiated liquids. Such interparticle collisions result in extreme heating at the point of impact, which can lead to localized melting and significant increase in the rates of solid-liquid reactions.[3,4]

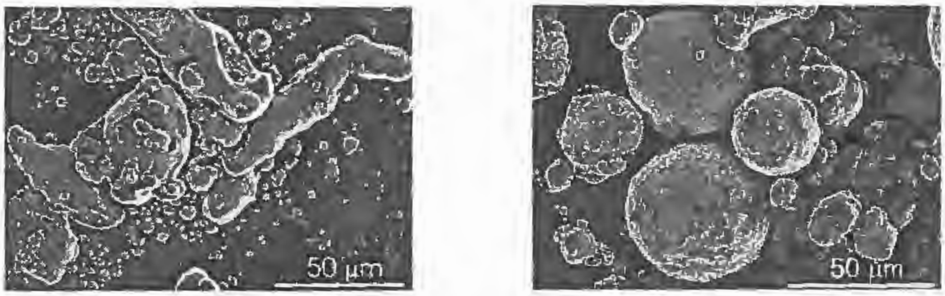
Ultrasound irradiation of decane and heptane slurries containing various loadings of ~5 μm zinc powder produces dense 50 - 70 μm rounded zinc agglomerates, consisting roughly of 1000 fused particles (Figure 1 A). Volatility of the slurry solvent and concentration of slurries had a moderate effect on the nature of the interparticle collisions. The size of the solid particle is critical to the effective interparticle collisions, as shown in Figure 2. Particles smaller than a few micrometers or larger than a few tens of micrometers do not collide with sufficient energy to cause localized melting. Ultrasonic irradiation of mixtures of appropriate size particles with those normally too large to undergo fusion on the impact, leads to efficient agglomeration of larger particles mediated by the smaller ones (Figure 1 B).

The effects of cavitation in this phenomenon of interparticle collisions are caused by the shockwaves generated in the liquid, and not by extreme temperatures of the sonochemical hot-spot.[5]

Applications of superconductors are determined by the critical current density, above which a superconductor becomes resistive and dissipates energy. To increase this critical value, small defects are deliberately introduced into the superconductor's bulk. These defects prevent motion of Abrikosov vortices ("vortex pinning"), which prevents dissipation. Ultrasonic irradiation of slurries composed of high-boiling alkanes and polycrystalline superconductors leads to a dramatic change in grain morphology without significant effect on the bulk chemical composition. This allows formation of materials with superior intergrain coupling and enhanced critical currents.[6]

Ultrasonic irradiation of alkane slurries containing polycrystalline superconducting materials in the presence of $Fe(CO)_5$ or $Mo(CO)_6$ leads to embedding of in situ produced ferromagnetic Fe_2O_3 or Mo_2O_5 nanoparticles into the bulk superconducting material thus creating novel nanocomposite materials.[6,7] Studies conducted on obtained Fe_2O_3-MgB_2 nanocomposites exhibit significant enhancement of magnetic flux pinning.[6,7] Similar study focused on the most promising high-T_c superconductors, such as $YBa_2Ca_3CuO_{7-\delta}$ and $Bi_2Sr_2CaCu_2O_{8+x}$.[8]

The challenge of this project is in the extreme sensitivity of superconductivity in high-T_c superconductors to the minute changes in chemical composition and complex annealing protocols. Several novel sonochemical effects can be used to further improve the method. For example, sonication of $YBa_2Ca_3CuO_{7-\delta}$ slurries with enforced oxygen flow produces material with enhanced transition temperature due to saturation of surface layers with oxygen. The developed method could become one of the major techniques to produce practically useful superconducting materials at temperatures of liquid nitrogen.



(A) (B)

Figure 1. SEM images of (A) dense agglomerates formed after ultrasonic irradiation of spherical 5 micrometer-sized fine Zn powder and (B) agglomerates formed after ultrasonic irradiation of mixture of coarse and fine Zn powders. Here the larger Zn particles are welded by the smaller particles upon interparticle collisions.

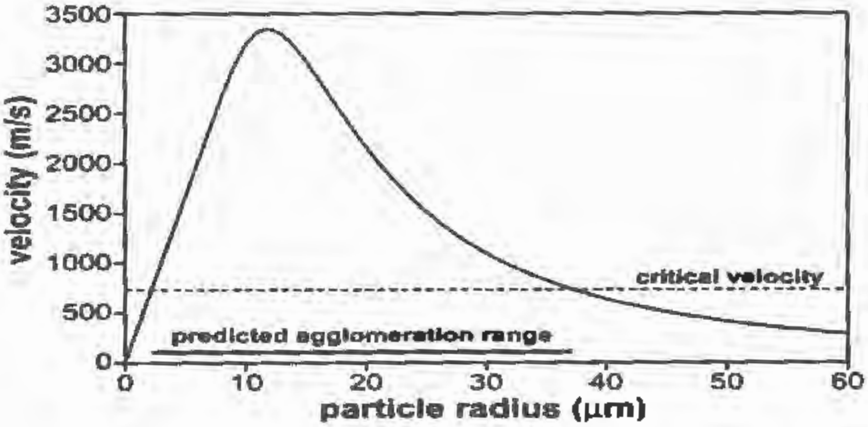


Figure 2. Calculated velocity as a function of Zn particle size. The critical velocity necessary for the collisional agglomeration determines the particle size range over which agglomeration will occur.

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