Ultrasonic measurements during solidification: preliminary results and implications for the inner core boundary

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Introduction

The Earth's inner-core boundary is the site of solidification of iron from the outer core.The seismic wave attenuation at the upper most part of the inner core is interpreted to arise from partially melt. In the recent years, detailed seismic structures of the inner core, such as the hemispherical variation and scattering, have been revealed from using seismic array data There have been several experimental studies devoted to understanding inner core seismic structure (e.g.,Bergman,1997;Bergman et al.2000;Brito et al.,2002), but acoustic properties of partial melt formed during solidification remains to be understood. In this study, I focus on such situation and attempt to compare with inner core seismic structure.

Experimental method

I use 28-30 weight percent ammonium chloride solution, which forms a dendritic mushy layer analogous to the solidification of liquid metal. I use an acrylic tank with an internal dimension of 18cm height, 18x1cm in cross section, which is cooled from below using a circulating bath. Ultrasonic P and S waves are generated using 1MHz transducer probes, and the waveforms are recorded at fixed time intervals during solidification. Measurements are made for both 1cm and 18cm probe distances. Vertical temperature profile is measured using thermocouple probes

Results

Solidification process:Dendritic crystals with spacings of about 0.3mm grow from the base and after about 2 hours from the beginning of the experimemt, a mushy layer of a thickness about 3cm form. Compositional convection occur within the mush, and chimneys form.

P wave properties:The mush has a large attenuation (Q=30) and a slightly faster P wave velocity due to the presence of solid (volumetric fraction 0.1). When the solid forms below the eutectic, the velocity increases in a stepwise manner, and the attenuation is small, comparable to the liquid. For long traveling distance of 18cm, velocity dispersion was observed, which probably originates from scattering.

S wave properties:No clear S wave phase was observed in the mush. For a temperature below eutectic, S-wave was observed, and a Poisson's ratio of 0.46 was obtained. Anisotropy of velocity and attenuation was also observed.

Implications for the core:Since inner core transmits S wave, the mush in the present experiments, would correspond to a layer at the base of the outer core. If such layer exists in the core, it would have zero rigidity, but would have a higher density due to the solid fraction. At high pressures of the core, the bulk modulus is comparable for liquid and solid iron. Thus,p-wave velocity of such layer would have similar or even slower velocity than the liquid part of the outer core. A slow velocity gradient at the base of the outer core has been reported (e.g, Souriau and Poupinet, 1991; Kaneshima et al.1994), and such a mushy layer can be its cause. According to our experiments , this layer has a low Q. Since all waves which travel the inner core must traverse through this layer, the present experiments suggest that previous inner core Q models may have been underestimated. The experiments also suggest that significant velocity dispersion can occur in this layer, probably caused by scattering, consistent with some observations of PKP-Cdiff (Umezu, 1990). I propose that the seismic structure of this layer deserves detailed study.

References

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