REAL DEFECTS FOR VERIFICATION OF
ULTRASONIC TESTING MODELS

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INTRODUCTION

Most ultrasonic inspections are based on idealized calculations of ultrasonic responses. The adequacy of a proposed inspection is determined by the accuracy of the calculations and the model of the assumed flaw. For generalized cases, the calculations can be quite difficult.

Direct experimentation is obviously the best source of data to compare with theoretical or computer results. A large amount can be carried out on blocks with drilled holes and saw cuts. But drilled holes and saw cuts are not real inclusions and cracks, which have irregular shapes and varied surface conditions. They do not provide the confidence needed for evaluation of complicated situations. As a result, blocks have been built at great expense incorporating real fatigue cracks and lack of fusion. These give valuable information, but they are limited to special cases. Slag inclusions or porosity samples must be destructively analyzed to evaluate the actual condition, which is expensive and destroys the test block. It is not practical to provide the quantity and variety of real flaw data that would illuminate theoretical results and allow empirical modeling.

The problem of verification of internal flaws can be solved by using transparent blocks. Glass test blocks have been made and used in imaging internal wave patterns\(^1\). These blocks are not easy to build or modify in an ordinary lab, but ice is easy to work with.

PRODUCTION OF TEST BLOCKS

The production of test blocks requires the ability to make large blocks of clear ice. If water is simply placed in a large container in a freezer, the resulting ice will be opaque because of the trapped air bubbles. After the top freezes over, it will rupture as freezing progresses, and the container may also rupture. Commercial clear ice is produced by having a continuous stream of bubbles in the water. This prevents the dissolved gas concentration from reaching the bubble nucleation point and keeps the top from freezing.

In the absence of a compressed air supply for a bubbler, an alternate technique may be used. First, deionized water is degassed by boiling.
Boiling under vacuum, at room temperature, is faster and easier than boiling over heat, at atmospheric pressure. It works as well. When degassed water is frozen, about half the volume will freeze as clear ice before bubbles begin to form. At that point, the unfrozen portion is emptied out and replaced by freshly degassed precooled water. During freezing, the top is kept clear of ice by covering the top of the container with insulation.

Figure 1 shows a block grown in this manner without changing the water when bubble formation began. During freezing, the gas concentration in the remaining liquid increases until bubbles are nucleated essentially simultaneously over the freezing surface. A few begin sooner, but most of the bubbles which appear outside the central area are reflected or refracted views of the central mass.

During the process, various defects can be introduced. Surface connected cracks are easiest. A partially completed block is like a bowl. It can be emptied and left to cool to freezer temperature. If room temperature water is added to the bowl, the thermal stress will cause cracking, and the water will then proceed to freeze into a solid block with surface cracks to the depth of the original bowl wall thickness. Internal porosity can be created by allowing the ice to freeze past the point where bubbles begin to form, although this porosity is uncontrolled, and if the water has been thoroughly degassed, the first bubbles to form become nucleation centers and grow into very long thin bubbles as freezing progresses.
Internal cracks and controlled porosity are also simple to make. As a first step, a piece of ice with a suitable crack is selected or a container of non-degassed water is frozen. Its porosity will vary continuously from the outside to the center. The frozen blocks are easily sliced up with a fine jet of water.

A suitably porous piece and/or a cracked piece are then cooled to freezer temperature. At the same time, a block of clear ice is being frozen. While the freezing is progressing, the water is emptied and the defect samples are pressed against the wet ice. Because they are well below freezing, they will quickly adhere to the ice. The cold water is returned to the vessel, freezing continues and the flaws are embedded. Figure 2 shows a test block with an embedded planar porosity region and surface connected cracks.

**SCALING MEASUREMENTS**

The speed of sound in ice is 3980 m/sec for longitudinal waves and 1990 m/sec for shear waves. In steel, the corresponding values are 5850 and 3230 m/sec. The velocity ratios are 0.680 and 0.616, respectively. These ratios enter into several relations useful in scaling differences in ultrasonic responses from defects in ice and steel.

![Figure 2: Planar Porosity and Surface Connected Cracks](image-url)
The far field spread of a beam from a transducer (or of a reflection from a defect) is determined by the ratio of transducer (or defect) size to wavelength. This means that to get identical results at any frequency it is necessary to scale the transducer and defect sizes by the velocity ratios. In many cases it may be more desirable to keep the sizes the same in steel and ice and reduce the frequency used in ice by the velocity ratio. In either case, the distances would be the same and the transit time in steel will be reduced by the velocity ratio. With this scaling, the same defect in the two materials will give the same distance-amplitude curve and the same variation of response with beam angle.

Angled beams are commonly used in inspection of steel, using lucite wedges. The angles used are determined from the relation \((\sin A_1)/V_1 = (\sin A_2)/V_2\), where \(A_1\) and \(A_2\) are angles in the two materials and \(V_1\) and \(V_2\) are the wave velocities. Shear waves in steel are commonly generated by mode conversion of longitudinal waves in lucite, whose wave velocity is 2680 m/sec. A longitudinal wave in lucite, incident on steel at the critical angle of 27 degrees, will produce longitudinal waves in the steel parallel to the surface. At greater angles of incidence, only shear waves can be generated. At this critical angle, the shear wave angle is 34 degrees, so it is possible to generate shear waves of any greater angle with no longitudinal wave interference.

For longitudinal waves in lucite on ice, the critical angle is 42 degrees. At this angle, shear waves will be generated at 30 degrees.

In both cases, because the ratio of shear to longitudinal velocities is so close (0.55 in steel, 0.50 in ice), any mode conversion process in either material will be very similar to the process in the other. However, the shear velocity in ice is lower than the longitudinal velocity in lucite, so it is not possible to create angled shear beams in ice much beyond 45 degrees using lucite wedges. If high angle shear beams are required they can be generated with a shear transducer.

REFERENCE