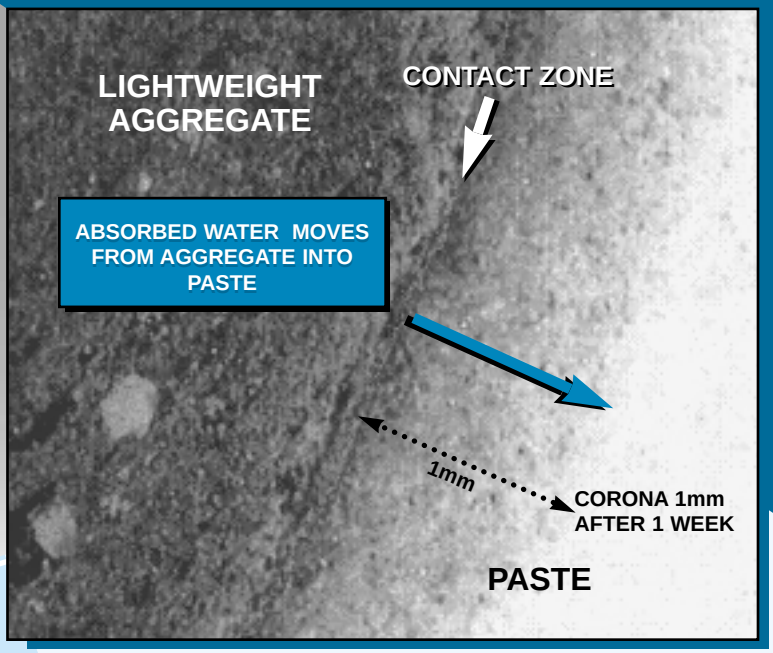
INTERNAL CURING
Using Expanded Shale, Clay and Slate Lightweight Aggregate



ESCSI

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The text and references are from ASTM 169D *Significance of Test and Properties of Concrete and Concrete Making Materials*, Chapter 46 – "Lightweight Concrete and Aggregate," American Society of Testing Materials, West Conshohocken, PA 2006. The figure (I) was developed by ESCSI and is not in Chapter 46.

Internal Curing

Lightweight aggregate batched at a high degree of absorbed water may be substituted for normalweight aggregates to provide "internal curing" in concrete containing a high volume of cementitious materials. High cementitious concretes are vulnerable to self-desiccation and early-age cracking, and benefit significantly from the slowly released internal moisture. Field experience has shown that high strength concrete is not necessarily high performance concrete and that high performance concrete need not necessarily be high strength. A frequent, unintended consequence of high strength concrete is early-age cracking. Blending lightweight aggregate containing absorbed water is significantly helpful for concretes made with a low ratio of water-to-cementitious material or concretes containing high volumes of supplementary cementitious materials that are sensitive to curing procedures. This process is often referred to as water entrainment.

Time dependent improvement in the quality of concrete containing prewet lightweight aggregate is greater than with normalweight aggregate. The reason is better hydration of the cementitious materials provided by moisture available from the slowly released reservoir of absorbed water within the pores of the lightweight aggregate. The fact that absorbed moisture in the lightweight aggregate is available for internal curing has been known for more than four decades. The first documentation of improved long term strength gains made possible by the use of saturated normalweight aggregates, was reported in 1957 by Paul Klieger [2], who, in addition, commented in detail on the role of absorbed water in lightweight aggregates for extended internal curing.

In his 1965 report, "Concrete Strength Measurement – Cores vs. Cylinders," presented to the National Sand and Gravel Association and the National Ready Mixed Concrete Association, Bloem [3] states, "Measured strength for lightweight concrete cylinders was not reduced by simulated field curing methods employed. This would tend to support the suggestion that the high absorption of lightweight aggregate may have the beneficial effect of supplying curing water internally." This was confirmed by Campbell and Tobin [4] in their comprehensive program which compared strengths of cores taken from field cured exposed slabs with test results obtained from laboratory specimens cured strictly in accordance with ASTM C 31. Their tests confirmed that availability of absorbed moisture in lightweight aggregate produced a more forgiving concrete that was less sensitive to poor field curing conditions. Addressing the long term service performance of lightweight concrete, Holm [5] cited the improved integrity of the contact zone between the lightweight aggregate and the matrix. The improved quality was attributed to internal curing, and better cement hydration and pozzolanic activity at the interface, and reduction in stress concentrations resulting from elastic compatibility of the concrete constituents.

The benefits of internal curing go far beyond any improvements in long-term strength gain, which from some combinations of materials may be minimal or non-existent. **The principal contribution of internal curing results in the reduction of permeability that develops from a significant extension in the time of curing.** Powers [6] showed that extending the time of curing increased the volume of cementitious products formed which caused the capillaries to become segmented and discontinuous.

It appears that in 1991, Philleo (7) was the first to recognize the potential benefits to high performance normalweight concrete possible with the addition of lightweight aggregate containing high volumes of absorbed moisture. Reduced sensitivity to poor curing conditions in concretes containing an adequate volume of prewet lightweight aggregate has also been reported [8]. Since 1995 a large number of papers addressing the role of water entrainment's influence on internal curing and autogenous shrinkage have been published of which Bentz, et al, is typical [9].

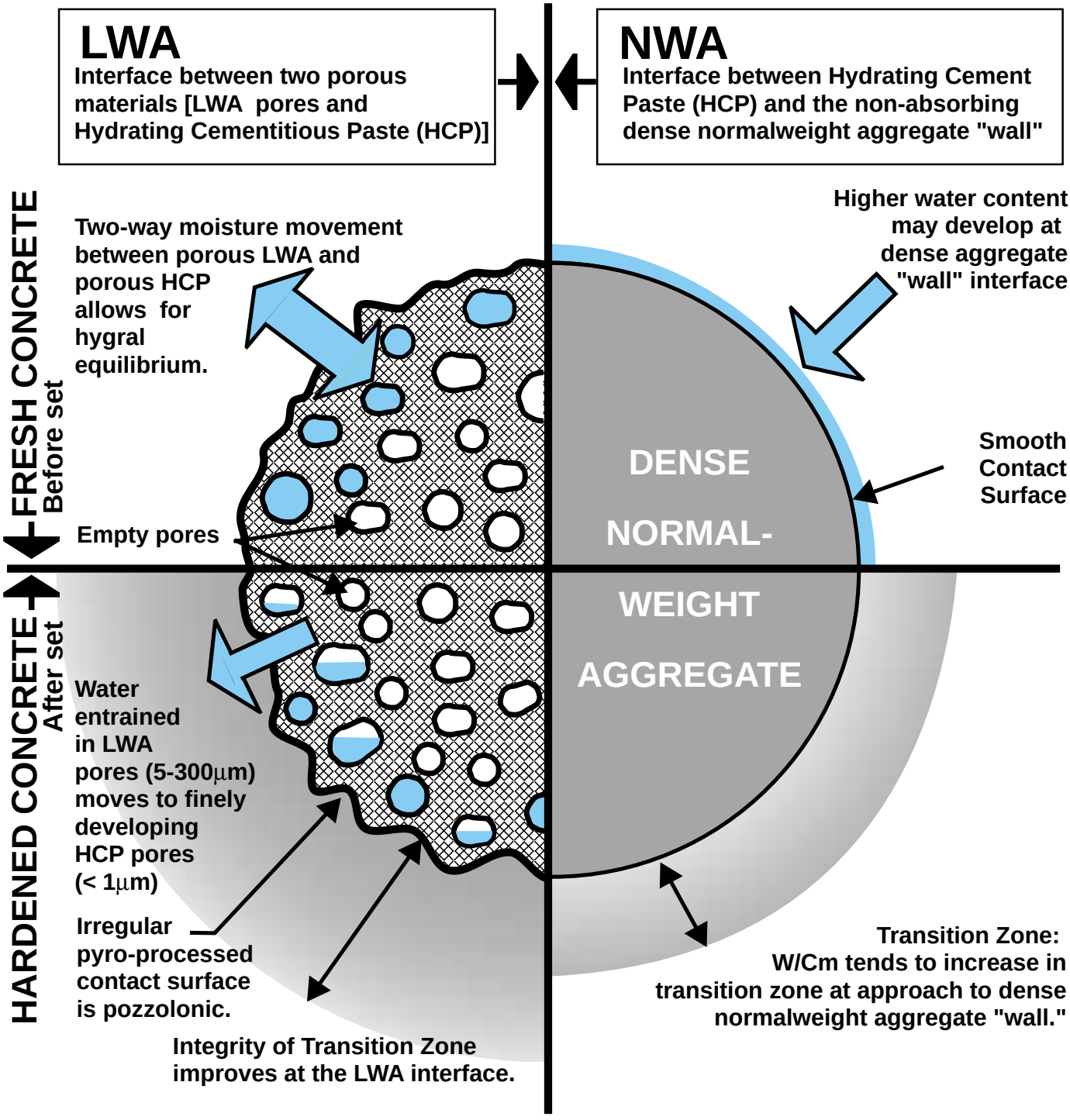
The benefits of internal curing are increasingly important when supplementary cementitious materials, (silica fume, fly ash, metokaolin, calcined shales, clays and slates, as well as the fines of lightweight aggregate) are included in the mixture. It is well known that the pozzolanic reaction of finely divided alumina-silicates with calcium hydroxide liberated as cement hydrates is contingent upon the availability of moisture. Additionally, internal curing provided by absorbed water minimizes the "plastic" (early) shrinkage due to rapid drying of concretes exposed to unfavorable drying conditions. [10]

Contact Zone

The expression "contact zone" includes two distinctively different phenomena: (1) the mechanical adhesion of the cementitious matrix to the surface of the aggregate and (2) the variation of physical and chemical characteristics of the transition layer of the cementitious matrix close to the aggregate particle. Collapse of the structural integrity of the concrete conglomerate may come from the failure of either the aggregate or cementitious matrix, or from a breakdown in the contact zone causing a separation of the still intact phases. The various mechanisms that act to maintain continuity, or that cause separation; have not received the same attention as has the air void system necessary to protect the matrix. Aggregates are frequently dismissed as being inert fillers and, as a result, they and the associated contact zone have not received adequate attention.

In order that concrete perform satisfactorily in severe exposure conditions, it is essential that a good bond develop and be maintained between the aggregate and the enveloping mortar matrix. A high incidence of interfacial cracking or aggregate debonding will have a serious effect on durability if these cracks fill with water and subsequently freeze. Deterioration will result, with pieces of apparently sound mortar separating from the bottom of the aggregate, usually with some of the mortar remaining firmly attached to the top side of the aggregate. An equally serious consequence of microcracking is the easy path provided for the ingress for aggressive agents into the mass of the concrete, rendering ineffective the

Internal Curing at the Contact Zone



IMPROVING THE TRANSITION ZONE

"Internal curing" refers to the process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water (ACI 213-03R).

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protective layer of concrete over the reinforcing steel. The morphology and distribution of chemical elements at the transition layer in a number of mature structures that have withstood severe exposure were examined and reported by Bremner, et. al. [23].

The contact zone of lightweight aggregate concrete has been demonstrated to be significantly superior to that of normalweight concretes that do not contain supplementary cementitious material [19, 24]. This profound improvement in the quality, integrity, and microstructure stems from a number of characteristics unique to lightweight concrete that includes:

• The pozzolanic alumina/silicate surface of the fired ceramic aggregate combines with $CaOH_2$ liberated by hydration of the Portland cement.

• Reduced microcracking in the contact zone because of the elastic similarity of the aggregate and the surrounding cementitious matrix. [25]

• Hygral equilibrium between two porous materials (Lightweight aggregate and porous cementitious matrix) as opposed to the usual condition with normalweight aggregate, where bleed-water lenses form around essentially non-absorbent coarse natural aggregates. These lenses have water-to-cementitious materials ratios significantly higher than in the rest of the matrix. When supplementary cementitious materials are added, the high-quality microstructure of the contact zone around lightweight aggregate is moderately enhanced. However, when supplementary cementitious materials are used in concretes containing normalweight aggregate, this zone of weakness is profoundly improved.

While the reduction in compressive and tensile strength due to poor contact zone is important, the significance of increasing permeability is even greater. Increasing permeability inevitably leads to penetration of aggressive agents that accelerate corrosion of embedded reinforcement. The permeability of concrete is greater than the permeability of its constituents. This increase in permeability results from interfacial flaws at the aggregate surface linking up with microcracking in the transition layer.

The phenomenon of bleed water collecting and being entrapped under coarse particles of lightweight aggregate is mitigated if not eliminated. This has been verified in practice by the examination of the contact zone of lightweight concrete tensile splitting cylinders, as well as by visual examination of sandblasted vertical surfaces of building structures. This observation should not be surprising because, with structural lightweight concrete, the aggregate/matrix interface is a boundary between two porous media, while with normalweight concrete there is an abrupt transition at the dense aggregate/porous cementitious matrix interface.

Implication of Contact Zone on Failure Mechanisms

Exposed concrete must endure the superposition of dynamic forces including variable live loads, rapid temperature changes, moisture gradients, and dilation due to chemical changes. These factors cause a predominantly tensile-related failure. Yet, the uniaxial compressive strength is traditionally considered the preeminent single index of quality, despite the fact that inadequate concrete performance is seldom related to this parameter. The simplicity and ease of compression testing has diverted our focus from life-cycle performance and the development of appropriate measurement techniques that quantify durable concrete characteristics.

In general, weakest link mechanisms are undetected in uniaxial compression tests due to concrete's forgiving load-sharing characteristics in compression, because of localized yielding and the closure of temperature and volume-change cracks. **Weakest link mechanisms, however, are decisive in tensile failures in both dynamic and durability exposure conditions. In most concretes the limiting factor in the long term performance is the integrity of contact zone.**

Cover photo of the movement of absorbed water from aggregate to paste is from the Ph.D Thesis, *Autogenous Deformation and Internal Curing of Concrete*, P. Lura 2003

Rotary Kiln Expanded Lightweight Aggregate

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