Background

Concrete used in Michigan's highway infrastructure (e.g. pavements, bridges) is exposed to harsh winter conditions, being cyclically frozen and thawed in a saturated state in the presence of chemical deicers. The durability of such concrete is dependant upon many things, including the aggregate component, the hydrated cement paste (HCP) and the presence of a properly entrained air-void system (small, dispersed and closely spaced air bubbles). The research used to establish the current air content requirements as espoused in the *Guide to Durable Concrete* (ACI 201.2R) was predominantly conducted prior to 1970, and since that time many changes have occurred that significantly effect the quality/characteristics of the HCP as well as the entrained air-void system. Some changes that directly impact the HCP include the use of lower water-to-cementitious ratios (*w/cm*), finer faster-setting cements, and the extensive use of supplementary cementitious materials (SCMs) such as fly ash, ground blast furnace slag (GBFS), etc. The biggest change in the characteristics of the entrained air-void system has resulted from the introduction of air entraining agents other than those based on vinsol resins. The impact of these changes on freeze-thaw durability has been observed in a study being completed at Michigan Tech for the Wisconsin Department of Transportation. It was noted that reducing the *w/cm* measurably improved the durability of the concrete, as did the use of a synthetic air-entraining admixtures (AEAs) which produced an air-void system consisting of smaller, more dispersed bubbles. Based on this limited work, it seems reasonable to suspect that less total air is needed for low *w/cm* mixtures made with synthetic air entraining admixtures.

The major difficulty in broadly applying these results is that factors contributing to the creation of the HCP and entrained air-void system are diverse and not perfectly understood. We know for instance that lowering the *w/cm* will reduce capillary porosity, therefore increasing strength and reducing the permeability of a given concrete. But how changes in cement fineness and/or chemistry, the presence of various SCMs, and the use of the current generation of air entraining admixtures impacts the freeze-thaw (F-T) durability of HCP is not fully understood.

The entrained air-void system is created through the addition of surface-active agents acting at the water-air interface to create stable foams. Historically, naturally derived vinsol resin-based AEAs were commonly used and specifications for air-entrained concrete are based on these chemicals. As the use of AEAs derived from synthetic or other natural sources increases, changes in the nature of the resulting air-void system may make past specification practices incorrect for these concrete mixtures. The issue becomes more clouded in that AEAs may interact in an unexpected manner with other concrete constituents (e.g. cement, SCMs, admixtures), making it difficult to anticipate the quality of the HCP and air-void system in advance of construction.

Although the relationship between the F-T durability of concrete and the quality of the hydrated cement paste and the air-void system are thought to be well established, there have been sufficient changes in concrete mixtures (e.g. lower *w/cm*, the use of SCMs, synthetic versus vinsol resin AEAs, etc.) and problems in the field to warrant a study to re-examine the accepted relationships. Through a rigorous statistically-based experiment, this study will establish the relationship(s) between F-T durability (based on the

Durability Factor (DF) presented in ASTM C 666 testing…a DF of less than 80 at 300 cycles will be considered failed) and the quality of the HCP and air-void system for various concrete mixtures (made using standard MDOT mixture proportions and constituent materials representative of those commonly found in the Southeastern Michigan). Each mixture will be thoroughly characterized, including the measurement of the air content, unit weight, air-void system parameters using the Air Void Analyzer (AVA), maturity, calorimetric heat signature, microwave moisture content of fresh concrete, and strength at various ages, sorptivity, and the air-void system parameters (using the approach described in ASTM C 457) measured in the hardened concrete. In selected cases, an assessment of the HCP porosity using epifluorescence techniques will also be used.

Problem Statement

Concrete mixtures have undergone numerous changes in recent years. As the mixtures have changed, the research linking air-void system parameters to performance has not been updated. The research used to establish the current air content requirements was predominately conducted prior to 1970. Changes that have occurred in concrete over the ensuing years (such as lower *w/cm*, the use of SCMs, and synthetic versus vinsol resin AEAs) affect not only the quality of the hydrated cement paste but also the characteristics of the entrained air-void system. Problems with paste F-T damage have been identified in the field, warranting a study to re-examine the existing relationships between F-T durability and the quality of the hydrated cement paste and air-void system. The proposed study will use a rigorous statistically-based experiment to establish a relationship between F-T durability and the characteristics of the HCP and air-void system. The study will evaluate different cement types, SCMs, and AEAs that would typically be used in Michigan highway concrete mixtures.

Objectives

The objectives for this study are as follows:

- Thoroughly review the current accepted relationship between the quality of HCP and the air-void system and how it affects the F-T durability of concrete.
- Design and conduct a phased laboratory study to evaluate how recent changes in concrete mixtures impact the quality of HCP and air-void system and how this influences the F-T durability of the concrete.
- Based on the results of this experiment, make recommendations to improve the F-T durability and cost effectiveness of concrete mixtures currently being used in Michigan.
- Utilize newly available equipment to assess the *w/cm* and air-void system in fresh concrete, correlating the results with those obtained using accepted analytical techniques. Based on this research, recommendations will be made regarding potential implementation of promising equipment to improve construction quality control and quality assurance.