Building Tomorrow's Society

Bâtir la Société de Demain

Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

DURABILITY OF INTERNALLY CURED CONCRETE USING RECYCLED CONCRETE AGGREGATES: EXPERIMENTAL & FEASIBILITY STUDY

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Abstract: Concrete curing is of paramount importance in order for concrete to meet performance requirements. Conventionally, curing has been conducted by means of water sparkling, wet burlap or a curing compound. For performance and environmental reasons, internal curing has been gaining increased attention. However, more data is needed for the effectiveness of this curing technique when used in various concrete mixtures. This investigation addresses potential utilization of internal curing in high performance concrete (HPC). Internal curing was introduced by means of recycled aggregates incorporated into HPC mixtures. Conventional mixtures were prepared and were thoroughly cured either by water or by a curing compound or left non cured. Fresh concrete properties were assessed including slump, and unit weight, and durability tests as shrinkage assessment, rapid chloride permeability test (RCPT) and abrasion resistance. Experimental work is backed up with a simplified feasibility analysis with case study, incorporating initial and future costs to better judge potential of this technique. The outcome of this study uncovers that the addition of pre-wetted recycled concrete aggregates can prompt an enhancement in concrete workability and durability accompanied by a reduced shrinkage. Compressive and flexural strengths decreased with the increased replacement dosages, however several dosages were tested to reach a figure of optimum replacement. Results of this study reveal the potential of this technology in saving fresh water as well as the costs saved in maintenance and rehabilitation works.

Keywords: (Internal, Curing, High Performance, Concrete, Recycled)

1 INTRODUCTION

After placing and finishing of concrete, maintaining adequate moisture and temperature is of paramount importance; this happens through a process referred to as Curing. Concrete curing aids the chemical reaction between cement and water called hydration (Kovler et. al, 2007). The American concrete Institute (ACI) defines curing as the process by which hydraulic-cement concrete matures and develops hardened properties as a result of continued hydration of the cement in the presence of adequate water and heat (ACI 308R). Hence, an incomplete hydration process will affect both the strength and durability of produced concrete. Curing has a strong influence on hardened concrete; adequate curing will aid achieving desired durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicers (ACI 308R). Water loss, during or after concrete finishing (i.e. evaporation), may delay or prevent sufficient hydration. Proper curing should retain water or compensate water loss in the concrete to allow for a full hydration process. This will allow for strength development of concrete. Figure 1 shows the effect of different curing periods on strength gain; it improves quickly at early ages, and then continues slowly for an indefinite period.

There is an additional aspect of curing, which is sometimes overlooked. Curing is carried out not only to promote hydration, but also to minimize shrinkage (Kovler et. al, 2007). Water loss will cause the concrete to shrink introducing tensile stresses that may cause surface cracking. In High performance concrete (HPC); concrete with high cement content and low w/c ratio, a major concern is self-desiccation, which is internal drying of concrete due to the consumption of water by hydration (Neville 1996; Parrot 1986; Patel et al. 1988, Spears 1983). Self desiccation results in hindered strength development, reduced durability and potential for autogenous shrinkage and cracking (Schlitter, 2010). If no sufficient water is provided, the paste can self-desiccate preventing concrete from achieving targeted properties. Appropriate mitigation methods to reduce shrinkage in combination with careful curing practices should be used to minimize and control shrinkage (Huo and Wong 2000).

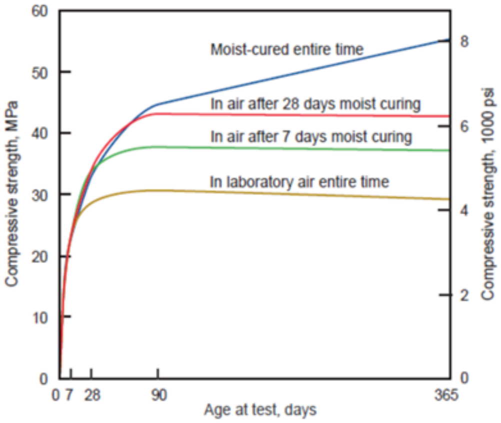

Figure 1: Effect of curing time on strength gain of concrete (Gonnerman & Shuman 1928)

There are various techniques for curing; external & Internal Curing. Most of the traditional methods are based on external curing. Generally, external curing can be grouped as follows (Aitcin 1998):

- Water Adding Curing – by supplying additional moisture to prevent/compensate water loss. This is achieved by water ponding, water spraying/sparkling, or by water coverings such as wet burlap.
- Sealed curing – by preventing the loss of moisture. This is achieved by Waterproof paper, plastic sheeting, and membrane forming compounds (also known as curing compounds)

Internal curing is another concept of curing concrete, which is basically incorporation of a component that serves as curing agent to the concrete mix. As defined by ACI as 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). Internal curing can be classified as follows:

- Internal Water Curing – embedded component is a water reservoir that gradually releases water into the system. The most popular methods are pre-wetted light weight aggregates and super absorbent polymers (SAP).
- Internal Sealing – component is meant to delay or prevent water loss from the system by adding special types of chemicals to mixing water (Kovler et. al, 2007)

Internal curing proved to be promising in producing concrete with increased resistance to early-age cracking and enhanced durability (Bentz et. al, 2010). This is due to the enhanced curing reach inside the concrete section as illustrated in Figure 2, conventional external curing provides curing mainly to outer concrete surface whereas in internal curing, water is simultaneously distributed inside of concrete and hence provide more uniform and extended curing of concrete (Abou-Zeid, 2015)

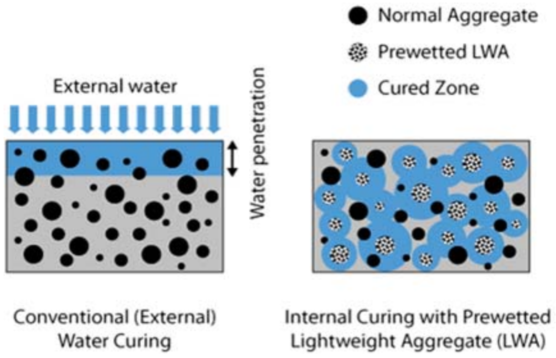

Figure 2: Illustration of the difference between external & internal curing (Wiess, 2011)

2 RESEARCH MOTIVATION

The main objectives of this study are to examine the potential use of pre-wetted/saturated lightweight and recycled concrete aggregates as reservoirs to provide internal curing for high performance concrete, HPC

This study is of crucial importance particularly in countries of economical rise up. The need for infrastructure will increase the need for high productivity and high performing structures without compromising durability or feasibility. In addition to many countries scarcity of water resources, makes it very important to use resources wisely. Two main aspects have the major contribution behind this research: (1) The need for durable structures for strategic projects, and (2) Feasibility and Environmental aspects that should be carefully studied and adapted.

3 EXPERIMENTAL WORK

3.1 Materials

Ordinary Portland cement (ASTM C 150 Type I) was used. The cement was produced by Lafarge cement Egypt in Ain Sokhna plant. The cement had a specific gravity of 3.15 and a Blaine fineness of 313 m2/kg. The Bogue compounds of the cement were as follows: C3S = 61.07%, C2S = 14.99%, C3A = 2.06% and C4AF = 15.03%. Siliceous sand was used in all concrete mixtures. Fine aggregates were obtained from natural Wadi Sand, Bani Youssef. The sand had a fineness modulus of 2.547, a saturated surface dry specific gravity of 2.64 and a percent absorption of 0.52%. The conventional coarse aggregates used was a crushed dolomite aggregate. Coarse aggregates were obtained from OCI Crusher, Attakah. The dolomite had a maximum nominal size of 20 mm, a saturated surface dry specific gravity of 2.57 and a percent absorption of 1.98%. Concrete chunks resulting from the demolition of concrete which had an original strength 25-30 MPa was used. Recycled concrete aggregates were obtained from crushed concrete from demolishing works of science building in AUC’s old campus, Tahrir square. The crushed material had a maximum size of 38 mm, a saturated surface dry specific gravity of 2.36 and absorption of 5.3%. Perlite was obtained from The Egyptian Company for Manufacturing Perlite plant, located in industrial district of Burj Al Arab city, Alexandria. Perlite had a specific gravity of only 0.32, and absorption of 32% Pumice was obtained from Laval minning and quarrying company, Greece. Its pumice quarry is located in Yali, Nissiros, a natural pumice deposit located in northern Greece. Pumice had a specific gravity of 1.1, and absorption of 18%. The admixture used was a common ASTM C494 Type G admixture, its commercial name is BASF MasterRheobuild 2270. The product is a modified lignosulfonate based with an approximate solid content of 39% and a specific gravity of 1.21. Curing compound used was BASF MasterKure 181, with specific gravity of 0.82.

The fourteem concrete mixtures had w/c of 0.35, a Type “G” admixture, and cement content of 450 kg/m^3. First set is conventional concrete mixes; which was cured in three different ways: Full curing by submerging specimens in curing tanks, the use of a curing compound and with no curing. Second set constitutes 3 mixes of prewetted recycled concrete aggregates with dosages of 10%, 15% and 25%. Recycled aggregates replaced size 1 and size 2 aggregates because of similar size to obtain similar gradation. Perlite specimens come with 5 different dosages of prewetted pelite aggregates, 3%,7%,10%,15% and 25%. Perlite aggregates replaced crushed sand because of similar size to obtain similar gradation. The remaining 3 mixes contain prewetted pumice aggregates with concentrations of 10%, 15% and 25%. Pumice lightweight aggregates replaced size 1 and size 2 aggregates because of similar size to obtain similar gradation.

3.2 Specimens

Concrete specimens for each one of the mixes. Each mix had the following specimens:

- Standard ASTM C 39 for preparing concrete cylinders (150 x 300 mm), for Rapid Chloride Permeability Test (RCPT) in 28 and 56 days.
- Standard tiles (200 x 200 x 25mm) for testing Abrasion resistance throughout age of specimen.
- Standard ASTM C157/C157M prisms of 100-mm square cross-section and approximately 285 mm long for testing shrinkage.

4 RESULTS & DISCUSSION

4.1 Slump Test

Results show that conventional concrete had the lowest slump of 130 mm. On the other hand, pre wetted perlite aggregates yielded the highest slump which ranged from 140 to 250 mm. The slump values increased as the Perlite replacement dosage increased. Both the recycled concrete and pumice acted as an intermediary between the pre-wetted perlite and the conventional mixtures, with values towards the lower side. These results can be explained in light of the water desorption, or ability to lose water, of the different aggregates used which are higher than the desorption of the conventional aggregates. Upon concrete mixing, some of the internal water within the aggregates is released; thus contributing to an increase in slump values. This can also explain the relatively lower results for the recycled aggregates compared to the perlite since the recycled aggregates had lower absorption than the perlite aggregates. Also, the recycled aggregates had somewhat rougher and more irregular surface than the perlite aggregates used. In summary, the slump test results demonstrate benefits incurred from adding saturated lightweight and recycled aggregates into the concrete mix in terms of higher slump values that reflect, on the whole, better workability. Slump values are shown in the figure 3

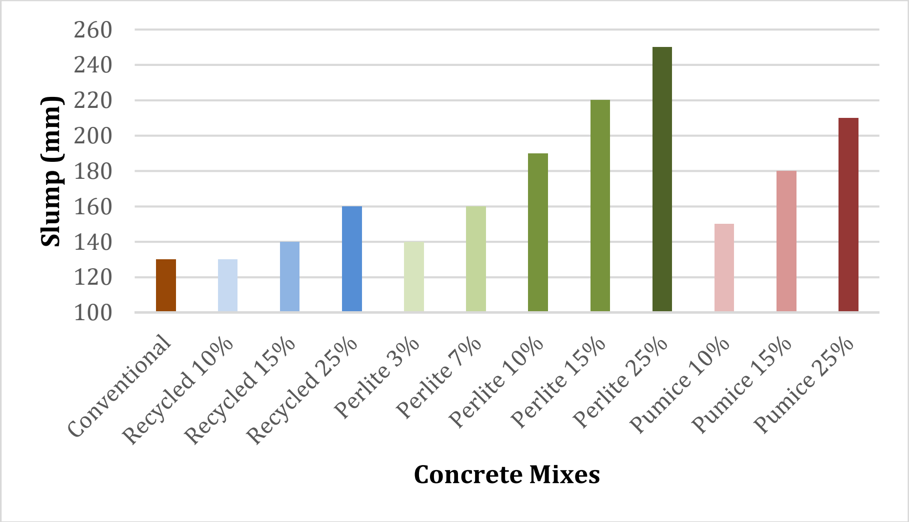

Figure 3: Slump test Results

4.2 Air Content

As shown in figure 4, air content values are in the range of 2.0 to 3.3%. Air content increased with increased dosage of pumice, recycled concrete aggregates and pumice, respectively. Apparently pumice mixes had the most entrapped air, this can be due to the relatively rough surface of these aggregate compared to the conventional concrete. Such surfaces can entrap some air together with already-existing air voids within the aggregate particles. Recycled concrete mixes had lower air content than those of pumice. Perlite had slightly lower air content than recycled concrete mixes, that can be due to the particle size of perlite and how in interlocks better in mix unlike the coarser aggregates like pumice or recycled aggregates. In summary, it can be concluded that the incorporation of pre-wetted perlite and recycled aggregates led to a slight increase in the air content values.

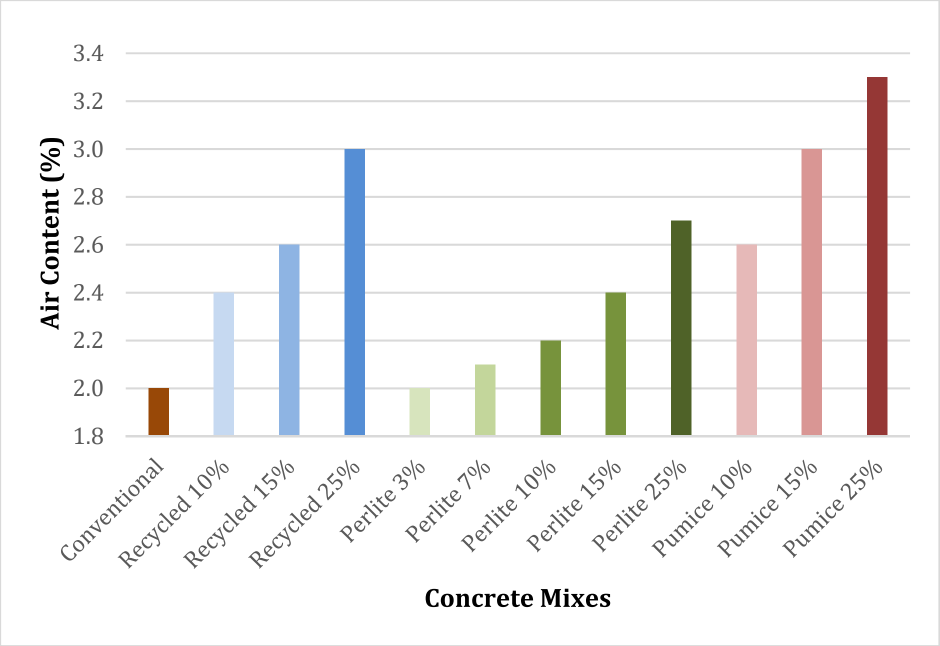

Figure 4: Air Content test results

4.3 Unit Weight

The results of fresh concrete unit weight are illustrated in Figure 5. While the results are somewhat close in values, there is a slight decrease in the unit weight upon incorporation of perlite, pumice and recycled aggregates. The decrease in unit weight seems to be proportional to the increase in perlite, pumice and recycled aggregate dosages. It has to be noted that the decrease is slight since both the perlite, pumice and recycled aggregate were saturated with water which makes such aggregates closer in its density to conventional aggregates. Pumice mixes showed the least unit weights, these happened due to the high porosity of the pumice aggregates in comparison to other aggregates used. It is worth noting that at lower dosages of perlite, unit weight was almost impacted, that goes back to the fact that replacement on volume basis, displaced small fraction of conventional dolomite aggregates. Unit weight decreased with higher dosages though. In summary, the incorporation of the perlite, pumice and recycled aggregates at the dosages associated with this work led to slight decrease in the unit weight.

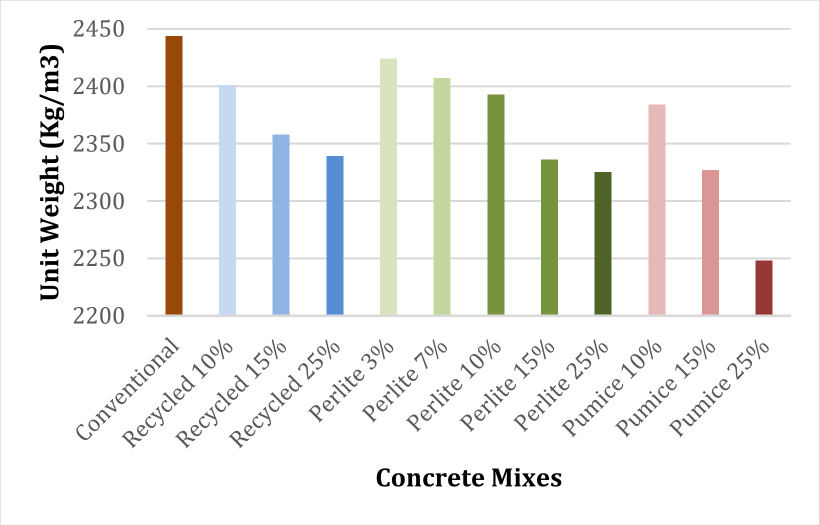

Figure 5: Unit weight test results

4.4 Shrinkage Assessment Test

The shrinkage test outcomes are outlined in Figure 6. At the start, one can see that the vast majority of the shrinkage occurred until 28 days and less increment in shrinkage was seen in the interim somewhere around 28 and 56 days. The outcomes demonstrate that uncured traditional concrete mixes had the most astounding shrinkage values. For instance, the ordinary concrete had a shrinkage cracking of 0.0369 mm while the mix with 25% recycled aggregates had almost half of that value (0.0162 mm). All internal curing mixtures of perlite, pumice and the reused concrete had critical impact in decreasing shrinkage cracking. Such reduction in shrinkage qualities was higher after expanding the perlite, pumice and reused aggregates dosages. The recycled aggregates and pumice, in any case, demonstrated the most reduced shrinkage of all mixes notwithstanding when contrasted with perlite blends.

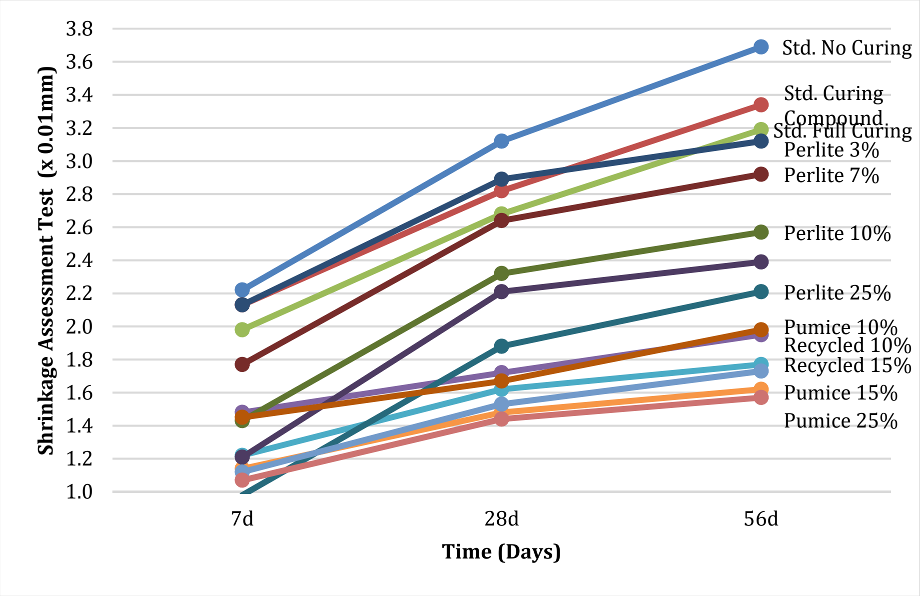

Figure 6: Shrinkage test results

4.5 Rapid Chloride Permeability Test (RCPT)

The RCPT outcomes are recorded in outlined in Figure 7. Chloride penetrability showed, on average, least results for the conventional concrete mixes. This can be explained mainly because of the high unit weight/density of the conventional specimens in comparison to the internally cured ones because of their decrease densities due to the aggregate replacement. Another factor is the amount of cracking inside the concrete section itself. Results of RCPT strongly assures on the issue of curing. All cured specimens, whether internally or externally cured have shown decreasing penetrability through the 28 and 56 days testing. Only the no curing specimen showed an increased penetrability as it passed 1588 charges in 56 days increasing by 24 units than the 28 days results. Conventional mixes' passing charges, on average, decreased by 29 charges from 28 to 56 days. Perlite mixes had the most decreased passing charges with 63 less passing charges from 56 to 28 days. Pumice showed the worst performance, this can be explained because of the high porosity of this kind of aggregate. It is concluded that unit weight, curing, interlocking (voids percentage), and aggregate porosity are the main factors that affect the penetrability of the concrete section.

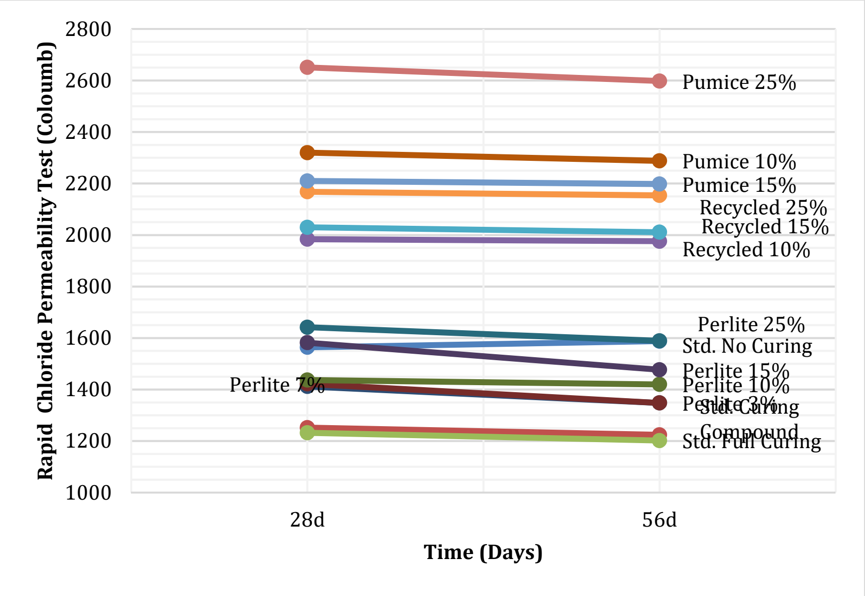

Figure 7: Rapid Chloride Permeability Test results

4.6 Abrasion Test

Conventional concrete specimens have demonstrated the best abrasion performance as it lost only 1.6 mm on average, which is the least amount, followed by perlite specimens with 2.36 mm, then recycled concrete specimens with 2.83mm. Pumice was at the worst at abrasion resistance, averaging almost 3mm of lost thickness. This behaviour is explained through the abrasion resistance of the aggregates themselves. Dispersion plays an important role here. Perlite demonstrated similar behaviour to the conventional specimens because of the well dispersion of perlite throughout the section, in contrast with both the Recycled concrete aggregates and the pumice specimens. Aging may also be a reason for the poor abrasion performance of specimens with recycled concrete aggregates. This recycled concrete dates back to the 60's, which is the time of construction of the famous AUC science building. Results are show below in figure 8.

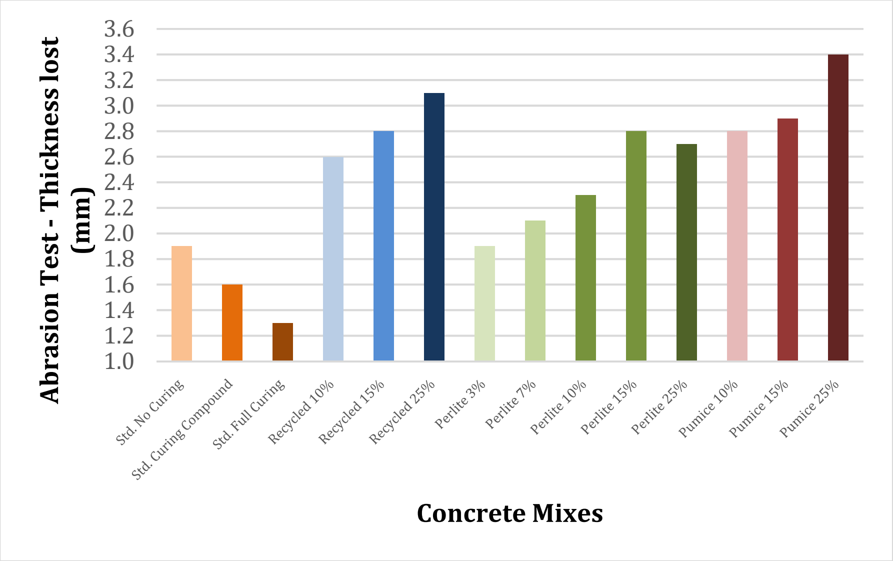

Figure 8: Abrasion test results

5 FEASIBILITY ANALYSIS

The unit cost of HPC was evaluated to be 13% higher than that of ordinary C-40 concrete basically because of the increased amount of cement in the mix. The unit cost of HPCIC was set to that of HPC in addition to a 35% expansion to represent the cost contrast connected with the procurement and transportation of the lightweight aggregate used to substitute a small amount of the ordinary aggregates.

For this situation consider, an arrangement of different maintenance exercises were expected to occur over the life cycles. For normal concrete (NC) for example, destructive (NDT) assessment and protection exercises were planned to happen at regular intervals, while patch repairs were scheduled when 10% and 25% of the concrete surface would be spalled. In this study, replacement was esteemed vital when half of the concrete surface would be spalled. After replacement, it was expected that the concrete would be reconstructed with a similar initial construction cost considering inflation rate. Concrete thickness was assumed at 200mm to represent figures in m^2.

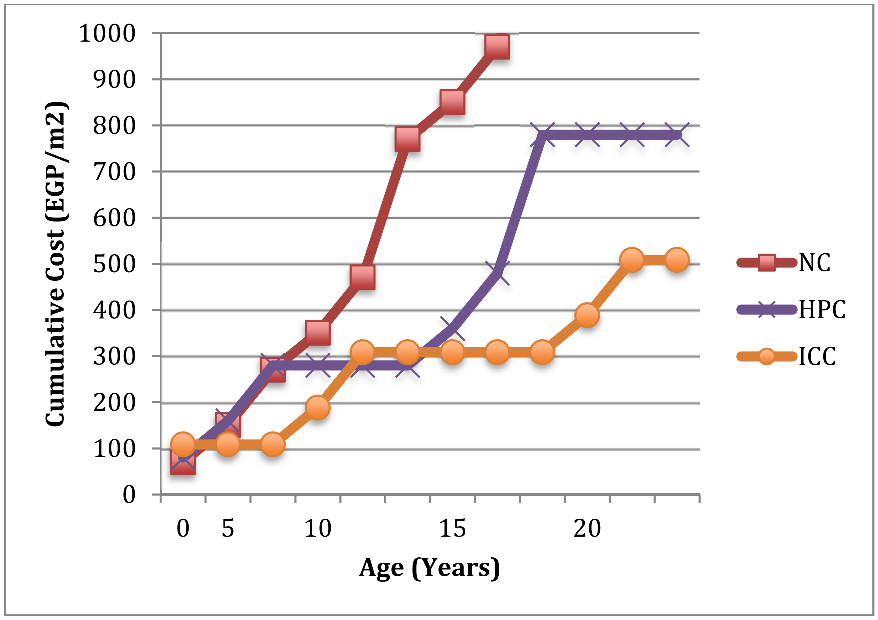

Figure 9: Cumulative Costs of different concrete mixes over time in years

It's obvious that the ICC has less frequent check, protection, maintenance and replacement times than the HPC and NC respectively. Costs of maintenance activities were estimated from average market prices. Over a 60-year examination period, the cumulative costs for the normal concrete deck is the most noteworthy, which is basically because of the shorter service life and the more incessant maintenance and replacement exercises. The HPC deck (no internal curing) diminished this cost by 35%, predominantly because of the more extended service life. The ICC deck further lessened the cumulative costs to be 42% less costly than the NC deck, or 11% less costly than the HPC deck because of the utilization of internal curing.

6 CONCLUSIONS AND RECOMMENDATIONS

In the light of scope, types and dosages of materials investigated as well as other experimental parameters and variability associated with this work, the following key conclusions can be warranted:

1. The concrete mixtures incorporating saturated lightweight and recycled concrete aggregates demonstrate increase in slump values and air content percentage and slight decrease in unit weight compared to conventional mixes
2. Internally cured concrete mixtures had critical impact in decreasing shrinkage and shrinkage cracking. Such reduction was higher after increasing the replacement doses of lightweight and recycled concrete aggregates.
3. Internally cured concrete yielded slightly decreased permeability performance compared to conventional concrete. However, Internally cured mixtures yielded significantly better improvement from 56-28 days.
4. Abrasion resistance of internally cured concrete is similar to that of conventional concrete. This was the case for mixtures made with lightweight and recycled concrete aggregates.
5. With water scarcity in Egypt and elsewhere, internally cured concrete will contribute to efforts exerted in minimizing water consumption.

6. A simple Life-Cycle Cost Analysis reveals that internally cured concrete saves almost 42% of cost throughout its service life. The higher initial investment of internally cured concrete can be counterbalanced in just 5 years because of the lower maintenance costs associated.

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