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ASSESSMENT OF ACCUMULATED CARBON DIOXIDE EMISSION IN PORTLAND CEMENT CONCRETE

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Abstract: Escalating Carbon dioxide (CO_2) emission is an issue of major global concern. Portland cement and consequently concrete is known to have large contribution to such emission during its various stages of manufacturing, transportation, placement and curing. While many of the current codes of practices have guidelines on key characteristics such as strength, workability and durability, there is scarcity of information that quantifies carbon dioxide emission for the wide spectrum of concrete mixtures .
This study provides clear steps to assess CO_2 emission for commonly used concrete mixtures during the various stages of concrete manufacturing. Limited experimental work is conducted to provide feasible low-CO_2 mixtures as alternative for intensive CO_2 ones. An interactive formula is suggested to estimate the emission which is sensitive to transportation, equipment and other manufacturing techniques and considering variety of innovative concrete constituents.

1. Introduction

Climate change and global warming are considered as priority environmental and societal concerns. Unfortunately, CO_2 emission, a primary greenhouse gas responsible for global warming, has been steadily on the increase since the industrial age until the day (Intergovernmental Panel on Climate Change, 2007; McCaffrey, 2002; Davidovits, 1994). Many scientists associate the remarkable increase of CO_2 emission with the growing production of concrete (Green Buildings, 2010; Kumar, 2002). In 2007, Concrete production has reached 2 billion tons (Carbon Trust, 2008).

In response to above concerns, many studies have been conducted to address the viability of having sustainable construction and reduce the environmental impact of concrete industry worldwide (Taylor, 2006; Wimpenny, 2009; Assad, 2011). In some of these studies, the use of energy efficient methods in concrete production processes has been explored (Glavind et al., 2009). Other studies have investigated the mix design components in order to lower the CO_2 contributors, viewing this approach as a more viable tool (Boudaghpour et al., 2009; Kumar, 2002; Damtoft, 1998). However, many applicators in the construction industry view several practical barriers in the implementation of such approaches (Kumar, 2002). Examples are the lack of awareness, especially in developing countries, of green concrete and its viability for use (Shafik, 2009) while others claim that sustainable concrete exhibit less performance when compared to conventional concrete. In that sense, further work is needed to produce sustainable concrete with low carbon dioxide emission without sacrificing performance and quality aspects.

This work aims at investigating the viability of producing concrete mixtures with reduced CO_2 as alternatives to the conventional ones. The reduced CO2 herein is based on emission through the various stages of produced constituent materials, transportation as well as manufacturing. To meet this objective, both performances as well as environmental criteria were considered. Based on an experimental work supported by archived data, a formula is suggested to provide alternative mixtures possessing similar -if not enhanced- performance characteristics with less CO_2 emission.

2. Experimental Program:

The experimental program associated with this work was designed mainly to investigate properties of different Portland cement concrete (PCC) mixtures, including two low carbon ones. This includes tests of fresh concrete properties, mechanical and chemical properties such as: compressive strength, flexural strength and chemical durability tests. In this work, various sets of Portland cement concrete mix proportions with designated strength of 25, 35, 45 and 50 MPa were used (shown in Tables 1 and 2). Each comprises one control mix representing conventional PCC mixes and two "presumably" low-carbon mix alternatives with less cement percent composition.

2.1 Materials Properties:

Fine Aggregates: Natural siliceous river sand was used. The sand had absorption of 0.5%, S.S.D specific gravity of 2.57 and a fineness modulus of 2.82.
Coarse aggregates: Crushed dolomite with the following properties: Specific gravity of 2.44, percentage absorption of 1.75% and S.S.D specific gravity of 2.61.
Water: Ordinary municipal tap water was in all steps of the production and curing of concrete mixtures.
Ordinary Portland cements: Commercially available Ordinary Portland Cement (OPC). The cement had a density of 3.15 and Blaine fineness of 380 m^2/kg.
Water reducing Admixtures: Commercially-available water-reducing and high-range water-reducing admixture (super plasticizer & plasticizers) were used to produce mortar and concrete of high workability with lower water to cement ratios. The two types were complying with ASTM C 494 Types A and F respectively. The Type A was lignin based while the type F was naphthalene based. Both had a specific gravity in the range of 1.18.
***Supplementary cementitious materials*:** Silica fume was used as a supplementary cementitious material in some mixtures. The material had a SiO_2 content of 93% and average particle size of 0.15 µm.

2.2 Mix Design

In each set of mixtures, a control/conventional mix was prepared to act as a reference to the other proposed Low Carbon PCC mixes (A and B). Table 1 and 2 show the composition of the sets of proposed mixtures designated as 25, 35, 45 and 50 MPa. As seen, Alternative A and B had less cement composition than the control/conventional mixture which contributes directly to carbon emissions.

Table 1: Mix proportions of proposed batches (25 and 35 MPa)

	Targeted Strength 25 MPa			Targeted Strength 35 MPa		
Weight (kg)	Control	A	B	Control	A	B
OPC (Type I)	350	325	300	400	375	350
Water	120	135	140	180	169	157
Fine Aggregates	780	750	780	700	715	780
Coarse Aggregates	1410	1350	1410	1250	1290	1321
Type A admixture	-	2 L	-	-	2 L	-
Type F admixture	-	-	4 L	-	-	4 L
Silica fume	-	-	-	-	-	-
w/c	0.4	0.4	0.5	0.5	0.5	0.4

Table 2: Mix proportions of proposed batches (45 and 50 MPa)

	Designated strength 45 MPa			Designated strength 50 MPa		
Weight (kg)	Control	A	B	Control	A	B
OPC (Type I)	475	425	350	475	500	420
Water	190	149	149	166	150	150
Fine Aggregate	667	711	700	680	688	680
Coarse Aggregate	1201	1279	1250	1224	1238	1220
Type A admixture	-	-	-	-	-	-
Type F admixture	-	4.5 L	7 L	10 L	12 L	12 L
Silica fume	-	-	75	-	-	80
w/c	0.40	0.40	0.40	0.30	0.30	0.40

2.3 Test Procedure

The following tests were carried out to examine the properties of the fresh and hardened concrete mixtures:

Slump Test
Slump test was conducted according to ASTM C 1611.

Unit Weight
Unit weight test conducted according to ASTM C 138.

Air Content
Air Content test conducted according to ASTM C 231.

Compressive Strength
The compressive strength test was conducted was done according to BS 1048 and tested on 150x150x150 mm cubes after the 3, 7, and 28 days.

Flexural Strength
Flexural strength was conducted according to ASTM C 1609 on simple beam specimens of dimensions 750x150x150 mm after 28 days.

Chemical Durability
Chemical durability test was conducted according to ASTM C 722 on three cubes of dimensions 50x50x50 mm for each mixture. The test commenced at specimen's age of 28 days, test begun in cycles of 7 days till reaching the 28th day. Salt and acid attack was tested using Sodium Chloride and Sulphuric Acid.

3. Results and Discussion:

3.1 Slump Test Results

Figure 1 shows the results of slump test of the tested mixtures. As shown, the low-carbon alternatives (A and B) can represent substitutes to the conventional mixtures. In numerical terms, the margin of slump difference in each set is within 2 cm.

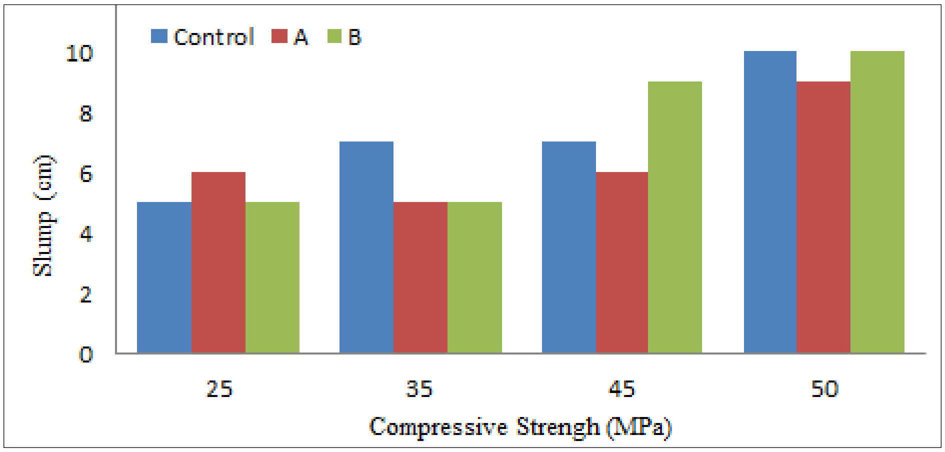

Figure 1: Slump test results

3.2 Unit Weight Results

Similar to Figure 1, Figure 2 shows the results of the unit weight. As shown from the figure, all the samples were within the expected range and almost of same behavior. This proves that low carbon PCC alternatives can present good dense alternatives of PCC.

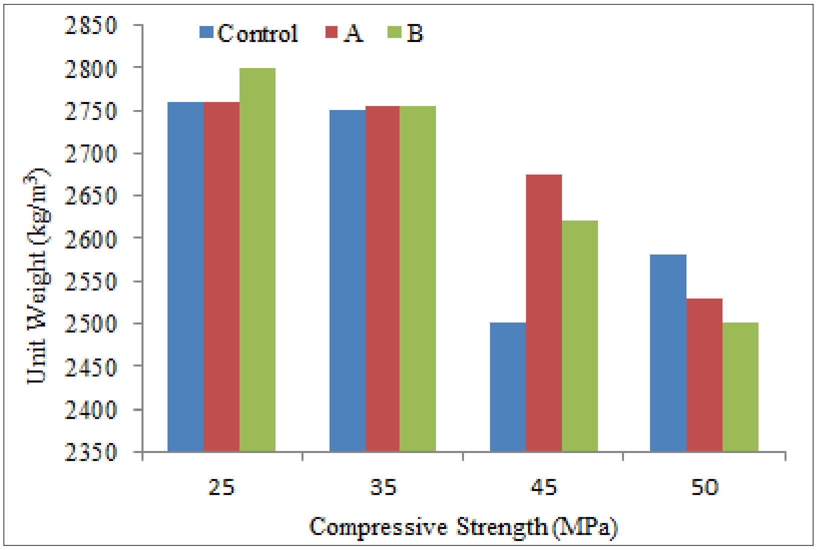

Figure 2: Unit weight results

3.3 Air Content Results

Figure 3 shows the results of the air content of all mixtures. Again, the performance results shows that low carbon mixtures yielded similar air content to the conventional mixtures. All of these mixtures had air content in the range of 2 to 3%.

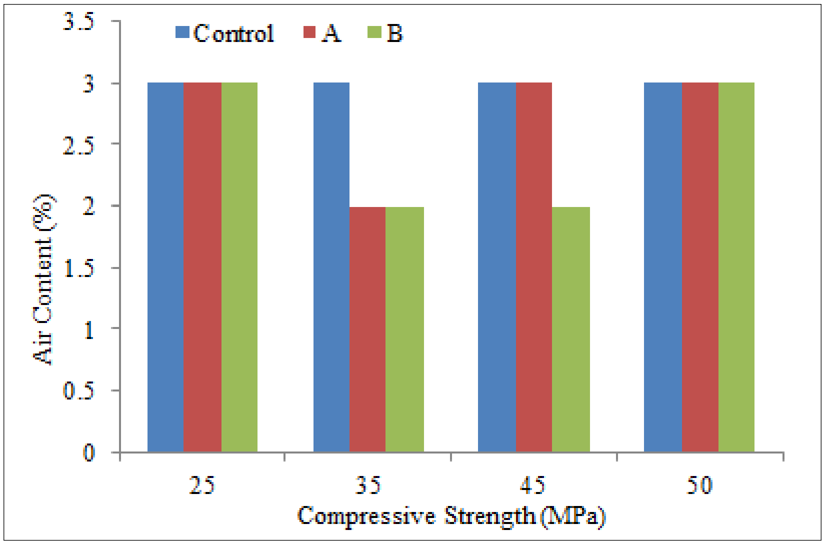

Figure 3: Percent air content test results

3.4 Compressive Strength Results

Figure 4 shows results of several sets of mixtures with one conventional and two low-carbon mixtures in each. The Figure demonstrates that the nominal strength in alternatives A and B was realized. This demonstrates that low carbon concrete alternatives do not sacrifice key performance criteria as in strength and durability.

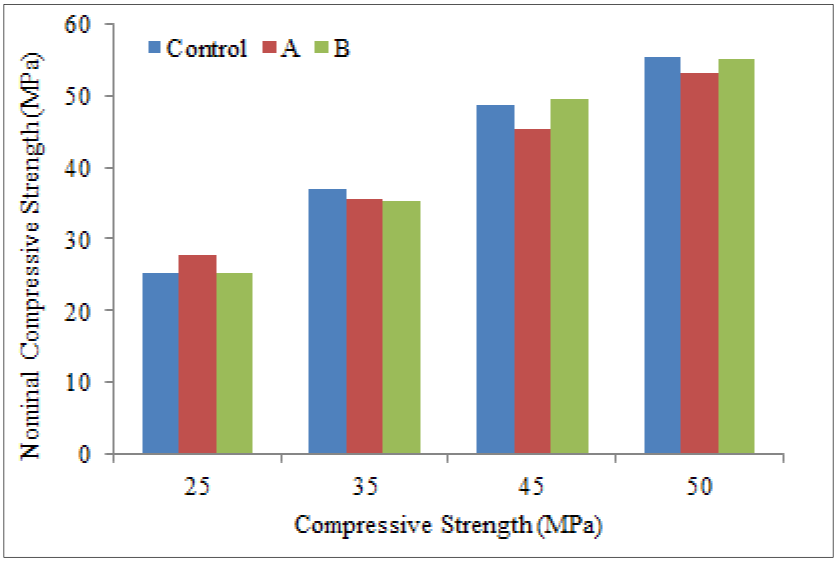

Figure 4: Compressive strength test results

3.5 Flexural Strength Results

Figure 5 further shows low carbon alternatives have exhibited good flexural resistance. Both low-carbon alternatives were within the same range to that of conventional mixtures.

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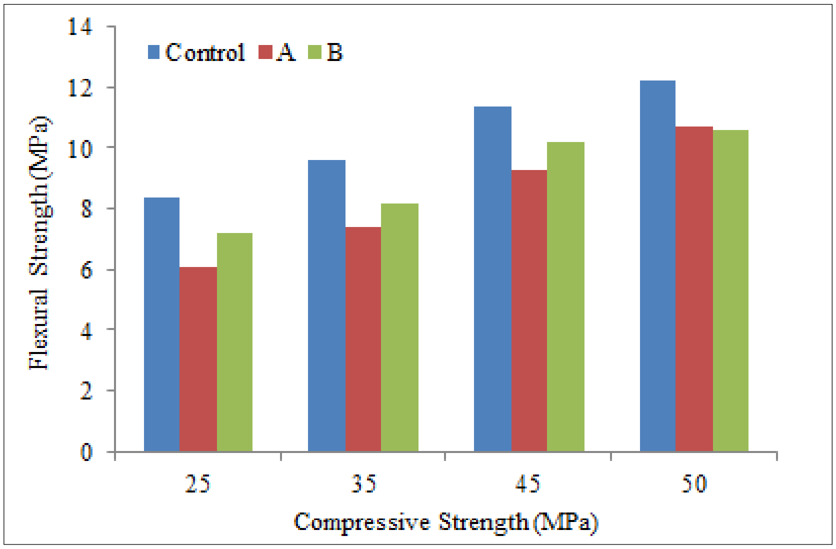


Figure 5: Flexural strength test results

3.6 Chemical Durability Results

Chemical endurance of all mixtures was tested using both salt and acid. Figure 6 shows the effect of using acid and salt attack on compressive strength performance. The trend of the graph shows that alternative A and B have exhibited -on the whole- better resistance to chemicals than the control mix at all designated strength.

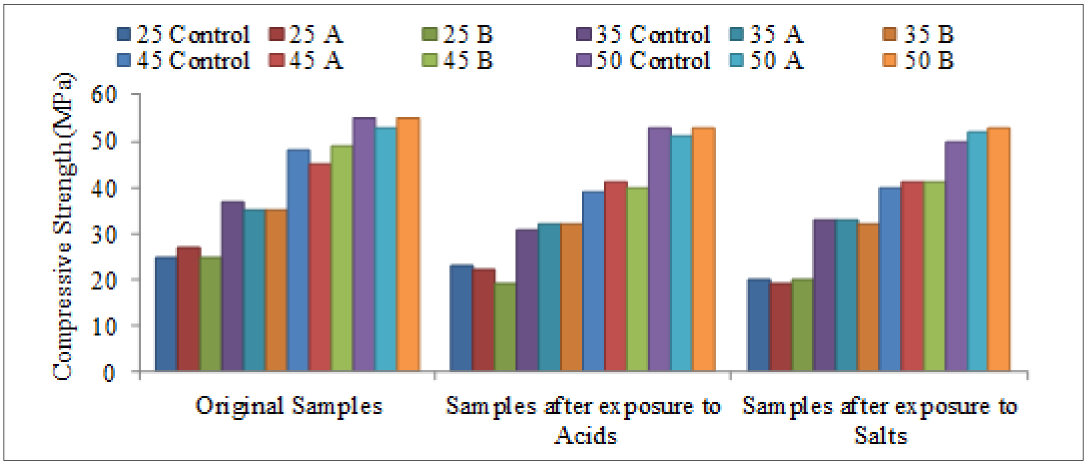


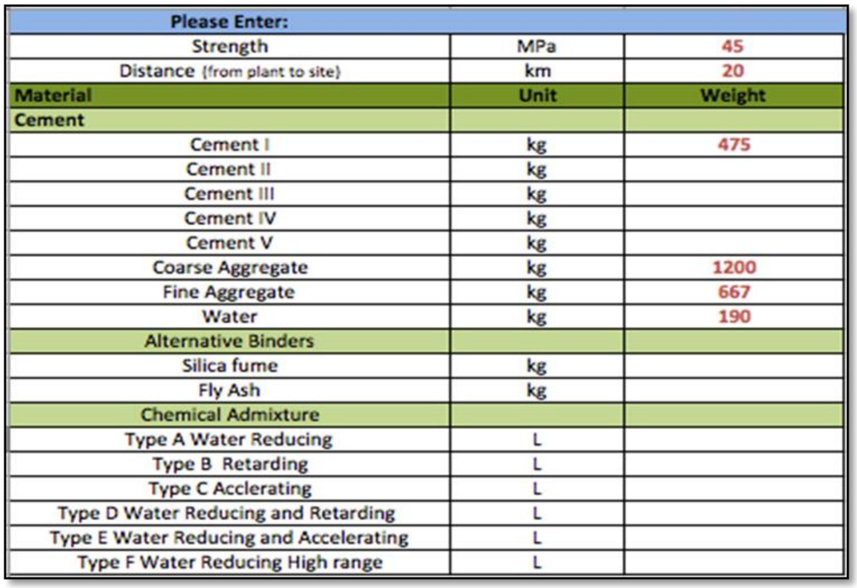
Figure 6: Acid and salt effect on strength for the control and alternate mixtures

4. Proposed Model & Potential Application:

A proposed model entitled "*Low Carbon Concrete Model* (LCCM)" is presented to act as a platform for assessing concrete mix designs in terms of its: (1) carbon footprint, (2) mechanical properties and (3) cost estimates. This model quantify carbon dioxide emission per one cubic meter of concrete, providing alternative of low carbon concrete mix designs, calculating rough cost estimate as well as calculating the percentage of carbon dioxide saving. The model was implemented using commercially-available spreadsheet and consists of various worksheets whereby each worksheet represents a function as follows:

4.1 User Interface:

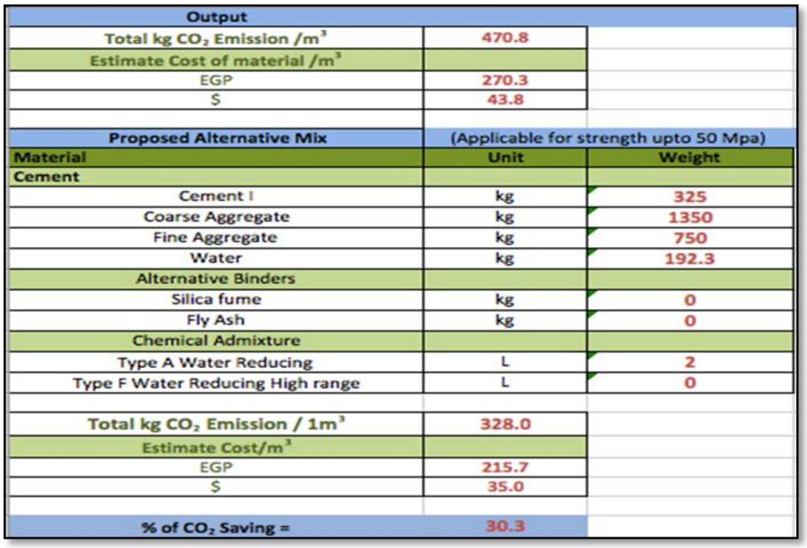
The model gives room for users to insert customized concrete design including the following: targeted strength, distance from plant to site, the mix proportions in (Kg) including 5 alternative commercial types of cement and any alternative binder or admixtures as shown in screen shot in Figure 7.



Please Enter:		
Strength	MPa	45
Distance (from plant to site)	km	20
Material	**Unit**	**Weight**
Cement		
Cement I	kg	475
Cement II	kg	
Cement III	kg	
Cement IV	kg	
Cement V	kg	
Coarse Aggregate	kg	1200
Fine Aggregate	kg	667
Water	kg	190
Alternative Binders		
Silica fume	kg	
Fly Ash	kg	
Chemical Admixture		
Type A Water Reducing	L	
Type B Retarding	L	
Type C Acclerating	L	
Type D Water Reducing and Retarding	L	
Type E Water Reducing and Accelerating	L	
Type F Water Reducing High range	L	

Figure 7: Screen shot for input-user page in the model

Once the user inputs required data, an output window appears in the same user interface page showing the amount of CO_2 emissions/m^3 and a cost estimate of the PCC mix. Clearly, this cost estimate is a regional one pending prevailing prices. Furthermore, a proposed low carbon alternative mix design of same preferred strength and customized user preferences will be suggested with its calculated CO_2 emission and corresponding cost estimate for comparison and analysis. An extract of results from user interface page is shown in Figure 8.



Output		
Total kg CO_2 Emission /m^3	470.8	
Estimate Cost of material /m^3		
EGP	270.3	
$	43.8	
Proposed Alternative Mix	(Applicable for strength upto 50 Mpa)	
Material	**Unit**	**Weight**
Cement		
Cement I	kg	325
Coarse Aggregate	kg	1350
Fine Aggregate	kg	750
Water	kg	192.3
Alternative Binders		
Silica fume	kg	0
Fly Ash	kg	0
Chemical Admixture		
Type A Water Reducing	L	2
Type F Water Reducing High range	L	0
Total kg CO_2 Emission / 1m^3	328.0	
Estimate Cost/m^3		
EGP	215.7	
$	35.0	
% of CO_2 Saving =	30.3	

Figure 8: Screen shot for output page in the model

4.2 Database, Mix designs, Assessment, Cost estimate.

The user output mainly depends on a data base that is established in the same model and includes different PCC mix proportions and their expected properties on the short and long terms. Carbon assessment (expected CO_2 emissions) is calculated through the use of factors such as: fuel emission, the machines used in mixing and placement of concrete and the fuel used for the vehicles transporting the ready mix. On the other hand, an estimated cost of the PCC mix based on materials used is calculated. Costs are mainly obtained from suppliers. The total cost of the materials per m^3 of concrete is calculated in both EGP and US $ for both the user defined mix and the proposed mix by the model. In this work, the conversion rate was 1 US $ as equivalent of 6.2 Egyptian pounds. Moreover, mechanical properties as strength of different PCC mixes tested in the experimental part are listed in the Mix design sheet. The proposed alternative mix is chosen by selecting the PCC mix of minimum amount of CO_2 emitted of same required strength.

Furthermore, the model can be used to conduct a cost/carbon analysis study. Figure 9 shows a cost comparison for each of the tested concrete mixtures. By comparing the costs, it can be indicated that low carbon mixes costs did not vary drastically than the conventional mix. On the other hand, Figure 10 shows CO_2 emission percentage savings comparison between the control mix and the low carbon mixes. The figure shows the amount of CO_2 savings that could be reached if adopting low carbon alternatives. Based on Figures 9 and 10, CO_2 emission in PCC alternatives can be decreased with no significant increase in cost.

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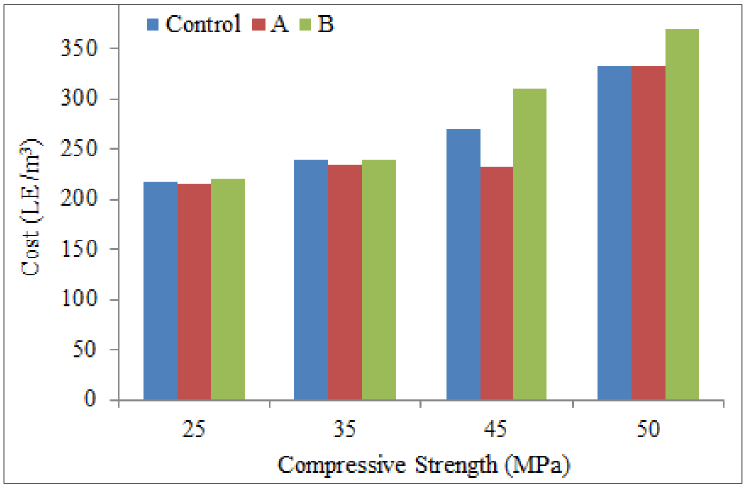

Figure 9: Cost comparison between control and alternate mixtures

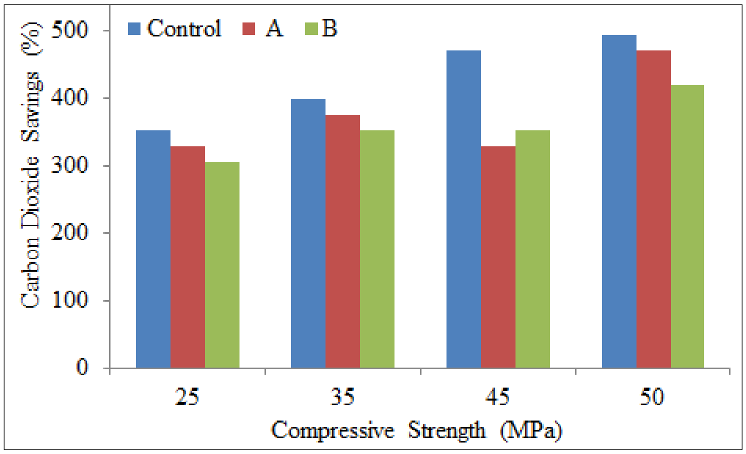

Figure 10: Carbon dioxide percentage saving

4.3 Model Assumptions:

There are several reasonable assumptions and constraints that were utilized in the model. These assumptions can be adjusted/modified if this model is to be applied under different conditions. These assumptions are as follows:

1. Using diesel fuel with efficiency for loaded truck of 71.2 % and the capacity of the truck is 8 m^3.
2. Average fuel efficiency per trip, assuming that the travel and return distances are the same is 2.66 kg of CO_2 per liter of diesel.
3. The proposed alternatives are applicable for strength up to 50 MPa in non-air entrained concrete. This covers most of day-today concrete applications in various parts of the world.
4. The estimated cost is calculated for taking into consideration the direct costs with the assumption –based on demonstrated results- that such mixtures will have similar performance criteria.

Yet, it is to be emphasized that the model is a flexible one that allows further adjustments and inputs such as other innovative materials, different assumptions and monetary rates.

5. Concluding Remarks:

Based on the materials used, the experimental method followed as well as all other parameters associated with this work, the following conclusions can be warranted:

1. The low-carbon concrete alternatives can acquire similar fresh concrete properties compared to conventional mixtures in terms of slump, unit weight and air content.
2. Low-carbon PCC mixes can be produced and used as an alternative to conventional PCC mixes with similar mechanical and long-term properties such as compressive strength, flexural strength and chemical resistance.
3. Low carbon concrete alternatives could be attained within the same cost range of conventional mixes.
4. Substantial savings in CO_2 emission can occur in the concrete industry, without sacrificing strength, chemical resistance or cost, reaching up to 30 % in some alternatives.
5. A proposed model to assess carbon emission and cost in PCC mixes and estimate can serve as a platform for providing lower carbon concrete alternatives in the industry.

6. Recommendations:

In light of the relatively limited scope of this investigation within its time frame, the following recommended are presented:

1. To further expand the experimental work herein through extended testing on other mechanical properties and long term performance.
2. To introduce a larger set of potential low-carbon concrete alternatives by using other materials and techniques to provide a range of choices for end-users.
3. To develop the model into a commercial software program to serve the industry. It is preferable to change the language to C++ or java with frequent update of materials and costs.
4. To create a Life cycle cost certification as a way to show literary acknowledgement to organizations taking part.
5. To encourage concrete practitioners and building community to include low carbon as a clear criteria in the codes of practice with guidelines as provision for alternatives.

Acknowledgement

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