

DEVELOPING A SIMPLIFIED LCA/LCI MODEL OF FOUNDRY WASTE USED IN
CONCRETE

by

Rilwan Kayode Onimole, M.S.

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Committee Members:

Anthony Torres, Chair

Vedaraman Sriraman

Fred Aguayo

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ABSTRACT

This study presents a developed simplified LCA/LCI model of Portland Cement Concrete using foundry waste (slags and foundry spent sand) by investigating present LCA case studies with varying supplementary cementitious materials (SCM). Multiple concrete mixtures based on a 39 years' service life were investigated using the developed model which include a control mixture without any substitution of cementitious materials such as slags and the utilization of 100% virgin fine and coarse aggregate. Then concrete mixtures with 30% 40% 50% replacement of fine aggregate with Foundry spent sand and 20%, 25%, 30%, 35% of Portland Cement with slags were investigated. Different concrete mixtures with replacement of Portland Cement and fine aggregate with slag and Foundry spent sand at different replacement ratio level in the same mixture were also investigated and the GHG emission impact for all the mixtures were analyzed and it was discovered that the replacement of Portland Cement with slags and FSS shows a huge reduction in GHG emission impact as compared to control mixture. Emission impact of the service life of concrete from 1 to 39 years was also analyzed using this model and there was an observed decrease in the impact of emission as the service life increases.

1. INTRODUCTION

Background

In the construction industry, the use of concrete is paramount because it is one of the most durable building materials in the world. According to the U.S Geological survey of 2006, around 7.5 billion cubic meters of concrete are made every year. The service life of concrete is prescribed to be at least 50 years (Ferrer, alexandre, & Real, 2016). In order to meet the current demand of concrete, intense excavation and acquisition of raw materials are done which depletes the natural resources, because most raw materials exist as hitchhikers and requires high use of energy to process, which increases the environmental impact. Concrete industry today is one of the largest consumers of natural resources, such as water, sand, gravel, and crushed rock (Bjork, 1999). As a result of this high production cost of concrete in terms of raw materials depletion, high energy usage and environmental impact, several efforts have been incorporated to improve its production by substituting some of the constituents required in concrete production with some more abundant raw materials or recycled materials in order to optimize the production process and also increase its environmental sustainability. The production process of concrete is complex because it is a composite material made from coarse aggregate bonded together with fluid cement paste that solidifies over time, so adequate care need to be implemented during the production process in other to achieve the required properties and strength. As reported in a study by (SZYSZKO, CHMIEL, PIOTROWSKI, & CIEŚLIK, 2016) the production process of concrete involves mixing the right proportion of basic ingredients such as cement, aggregates (fine sand, gravel/crushed stone), water and improvers. There are different types of concrete available each varying with the type

of ingredient used some examples are: Portland cement concrete which is the most popular type of concrete, which uses Portland cement. asphalt concrete with bitumen as its cementing material, polymer concrete with polymers as its cementing ingredient etc. The quality of concrete mixtures is determined by the quality of applied components, their proportions and techniques as well as the technology of its production (SZYSZKO, CHMIEL, PIOTROWSKI, & CIEŚLIK, 2016). As the world is evolving into a more environmental sustainable practice, there have been several concerns in the production process of concrete. One of the major environmental concerns in concrete production is the emission of CO₂. In a study by (Flower & Sanjayan, 2007), it was reported that Portland cement was found to be the primary source of CO₂ emissions generated by typical commercially produced concrete mixes, which is responsible for 74% to 81% of total CO₂ emissions, followed by coarse aggregates, being responsible for 13% to 20% of total CO₂ emissions. The major contributor of CO₂ emissions in coarse aggregates production was found to be from electricity (Flower & Sanjayan, 2007).

In order to support the earlier claim, (Bjork, 1999) also asserted in his study “production of Portland cement is an extreme resource and energy intensive process where every tonne of cement requires about 1.5 tonnes of raw materials. In addition, each tonne of cement produced releases approximately one tonne of Carbon dioxide (CO₂) into the environment”, which clearly indicates that the production of Portland cement is a significant contributor to atmospheric pollution. Another concern in concrete production is the cost: which is the raw material acquisition and processing cost. The high cost of concrete is one of the major reasons for the high cost in construction industry. Many studies have been carried out on how to improve the cost of concrete

without hindering its strength and properties such as replacing some of the constituents or ingredients with recycled materials like: fly ash, foundry wastes, silica fumes etc. In this paper the focus is to investigate the environmental impact reduction and cost of improving concrete production by substituting some concrete ingredients with foundry waste.

A foundry can be called a factory that produces metal castings. In the foundry, metals can be casted into different shapes by melting them into liquid or molten forms and then pouring in a mold, and the casting or mold material is then removed after the metal is allowed to solidify as it cools. Aluminum and cast iron appears to be the most widely recognized metal been processed in a foundry. Although, other metals, such as bronze, brass, steel, magnesium, and zinc, are also used to produce castings in foundries. The input that goes into metal casting furnace are either received from virgin materials, which refers to commercially unadulterated types of the primary metal excavated as a raw material used to form a specific alloy (combination) or from reuse and recycle of metal scraps. The use of recycled metal scraps as an input in metal casting furnace is the most common in the recent years because is it very energy and cost efficient as compared to the cost of excavating and processing of virgin materials. According to (Singha & Siddique, 2011), the ferrous metal casts in foundry are cast iron and steel and non-ferrous metal are aluminum, copper, brass and bronze. Foundry industry requires a high input and out-put flow of materials and also produces large amount of by-product material during casting process, which are classified as desired output and foundry waste. There are different types of waste generated in a foundry such as: foundry spent sands, slag, refractory, baghouse dust, and pattern shop waste. In this study the focus is going to be

on Foundry spent sand and slags. Foundry spent sand is a silica sand with uniform physical attributes. It is a by-product of ferrous and nonferrous metal casting industries, where sand has been utilized for quite a long time as a molding material due to its thermal conductivity (Siddique, Schutter, & Noumowe, 2008). Foundry sands are classified into different type depending on the type of binder systems used in metal casting. The two types of foundry sands are categorized as: clay-bonded sand(greensand)and chemically bonded sand (Siddiquea, Gurdeep, & Anita, 2010). Sand cast system is the most widely recognized casting process utilized in the foundry industry. In a study by (Singha & Siddique, 2011), it was reported that over 70% of the total by-product material consists of sand because molds consist usually of molding sand, because it is easily available, inexpensive, resistance to heat damage and easily bonded with binder and other organic material in mold. Chemically bonded sands are used both in core making where high strengths are necessary to withstand the heat of molten metal, and in mold making and it is made of 93–99% silica and 1–3% chemical binder and it is lighter in color and texture compared to green sand (Siddique & Noumowe, 2008). However, (Siddiquea, Gurdeep, & Anita, 2010) asserted that all sand cast molds for ferrous castings are of the green sand type which made it the most commonly used molding sand in foundry. The clay-bonded (Green) sand is black in color due to the carbon content and it is made out of naturally occurring materials, which are mixed together such as: high-quality silica sand (85–95%), bentonite clay (4–10%) as a binder, a carbonaceous additive (2–10%) to enhance the casting surface finish and water (2–5%) for plasticity (Siddiquea, Gurdeep, & Anita, 2010). In a casting process, molding sand are recycled and reused for a long period of time, eventually the casting sands degrades to a

level that it can no longer be reused in the casting process it is then removed from the foundry and it is called spent sand. The physical and the chemical attributes of the foundry sand depends on the type of casting process and the type of industry by which it originates (Siddique & Noumowe, 2008). (Siddique, Schutter, & Noumowe, 2008) reported that in United States alone, the foundry Industry estimates that approximately 100 million tons of sand is used in production annually, of that 6–10 million tons are discarded annually and are available to be recycled into other products and are used in other industries. One of the industries that spent sand can be used is the concrete industry to replace some of the fine sand or used as SCM in concrete. The other type of foundry waste that is investigated in this study is slag.

Slag is the by-product or waste generated during the smelting of metals in a furnace or during separation of metals from its raw ore (smelting). Slags helps to remove dirt or unwanted materials in molten metal during metal smelting in the furnace before it is used to make solid metals. According to (Ilya et.al., 2016), slags generation during production of ferrous metals varies from 100 to 1000 kg per ton of steel resulting to high environmental load and waste of natural resources. The quantity of slags generated daily is very large and the disposal would have a negative impact on the environment.

Therefore, in order to help promote sustainable development in the protection of natural resources and reduce the environmental burden or impact during the disposal of slags, several efforts have been made to recycle slags into other products which are used as constituents in other industries. One industry where slag is being incorporated as a constituent is the concrete industry where slags are ground and granulated into a powder to become a supplementary cementitious material. In a study by (Qasrawi, 2014), it was

made very clear that steel slag has been utilized as coarse aggregate in concrete structures and several researches has proved that the use of steel slag in concrete as coarse aggregate improves the mechanical properties of hardened concrete leading to reduced permeability and better durability.

What is considered as waste and hazardous in foundry industry can be used as a constituent in the concrete industry to improve the mechanical properties of hardened concrete and help reduce the production cost as well as the environmental burdens of concrete. In this study a Life Cycle Inventory (LCI) and a Life Cycle Analysis (LCA) is completed on the use of spent foundry sand and slags in the production of concrete.

Problem Statement and Significance

Knowing the importance of concrete in the construction industry is a valid reason to find a viable way to improve and eliminate to negative effect or impact attached to its production, which is the CO₂ emission into environment. Many studies have emphasized the importance of partially or fully substituting some constituents in concrete production in order to make it more environmentally sustainable. Such potential constituent's substitutions are spent foundry sand and slags, which are currently a burden to the foundry industry because of the cost of disposal. Incorporating the foundry waste into concrete production would not only reduce the cost of concrete production but also reduce the environmental impact attached to it, while saving landfill space. To help assist with the decision, a study to measure and compare the LCI of various mixtures would be of immense importance. This paper concentrates on developing a simplified LCI model of cement concrete configurations by investigating present LCA case studies with varying supplemental cementitious materials (SCM). Developing a simplified LCI will

give the user the opportunity to easily compare a conventional Portland cement concrete mixture to possible sustainable alternatives (containing spent sand and slags).

Assumptions and Limitation

This study encompasses a research model that would be built based on accessibility of data from the current LCA research and case studies. An assumption that all the information for the regression coefficient taken from these studies are substantial and valid was made. It is also assumed that in the model there are no higher-order interaction effects between various levels of the model input. The model is assumed to have a linear relationship among input and output variables. Data extraordinary outliers amid data analysis would be excluded from the study. The LCA study of concrete and foundry waste would not cover any activity beyond concrete production factory (it is going to be a cradle to gate).

Delimitation

This research is aimed at developing a concrete model with high relevance and applicability for the construction industry but the environmental impacts associated with construction and in-service maintenance are not considered with the end goal of this study. The output model in this study is developed for the Green-House-Gas (GHG) emission in carbon dioxide mass equivalent(CO_{2e}) only.

Hypothesis:

- The LCA case studies on Portland cement concrete configurations can be used to develop an LCI working model.
- The resulting composition of (slags + spent sand) concrete pavement will reduce environmental impact in terms of GHG emission

- The cost of disposal of the wastes generated from the foundry industry would reduce drastically.
- The model would be very easy to apply among related industry.
- With this simplified model, estimation of environmental impact when dealing with concrete would be easy in related industries.

2. LITERATURE REVIEW

Considering the current land scarcity for disposal of solid waste and its environmental concerns, waste management has increasingly become a global concern, as a result several efforts have been made on how to recycle these wastes as an alternative to land filling and since foundry industries is one of the industries that generate large amount of solid wastes. Several studies have been carried out on how the by-product from foundry can be used to replace some constituents in concrete. In a study, by (Siddique, Schutter, & Noumowe, 2008) an extensive study was carried out to evaluate the mechanical properties of concrete mixtures in which fine aggregate (regular sand) was partially replaced with used-foundry sand. Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity were used to ascertain the effect of used foundry sand on the mechanical properties of concrete. In order to get optimum and unbiased result the author ensured the use of ordinary Portland cement that has been tested and satisfies the requirements of ASTM C150 for Type I cement and the used foundry sand that was used as partial replacement of fine aggregate was obtained locally. In the experiment, natural sand with a 4.75mm maximum size was used as a fine aggregate (regular sand) and it was tested as per Indian Standard IS 383-1970 and it fulfills the requirements of ASTM C33. The author also ensured that locally available coarse aggregates having the maximum size of 10mm and 20 mm were used in the experiment and testing of fine and coarse aggregates was done as per IS: 383-1970. Four concrete mixture proportions were made during the experiment and commercially available melamine-based superplasticizer was used in all the mixes. For contrast purpose, (Siddique, Schutter, & Noumowe, 2008) made a control mixture without the

used foundry waste and made the other three mixture with the used foundry waste. The proportions of fine aggregate replaced with used foundry sand were 10%, 20% and 30%. To ensure conformance to specification, (Siddique, Schutter, & Noumowe, 2008) made sure the control mixture without Used Foundry Sand (UFS) was proportioned based on the Indian Standard Specifications IS: 10262-1982 to have a 28-day cube compressive strength of 28.5 MPa. During the preparation and casting of test specimen, in the experiment by (Siddique, Schutter, & Noumowe, 2008), 150mm concrete cubes were cast for compressive strength, 150×300 mm cylinders for splitting-tensile strength and modulus of elasticity, and 101.4×101.4×508 mm beams for flexural strength were performed at the ages of 7, 28, 56, 91, and 365 days of curing in accordance with the provisions of the Indian Standard Specifications IS. 516-195. The result of the experiment as reported by (Siddique, Schutter, & Noumowe, 2008) shows that at day 28, control mixture M-1 with (0% UFS) achieved a compressive strength of 28.5 MPa, whereas mixtures M-2 with (10% UFS), M-3 with (20% UFS), M-4 with (30% UFS) achieved a compressive strength of 29.7, 30.0, and 31.3 Mpa. Additionally, the author also reported from the result of the experiment that compressive strength of concrete mixtures also increased with age. With age (from 56 to 365 days), percentage increase in compressive strength for control mixture (without UFS) was between 8% and 18%, between 11.4% and 18.8% for mixture M-2, between 12% and 20% for mixture M-3, and between 12.4% and 20% for mixture M-4 which indicates that there was a marginal increase in the compressive strength of concrete mixtures with the inclusion of used foundry sand as partial replacement of regular sand. Although, (Siddique & Noumowe, 2008) indicated that the increase in compressive strength with the inclusion of used foundry Sand could

probably be due to the fact that used foundry sand has finer quality than regular sand which resulted in the denser concrete matrix, also it may be due to the silica content present in the used foundry sand. To further verify the result (Siddique, Schutter, & Noumowe, 2008) conducted a splitting tensile strength and it was reported that at day 28, splitting-tensile strength of control mixture M-1 with (0% UFS) was 2.75 MPa, whereas mixtures M-2 with (10% UFS), M-3 with (20% UFS), and M-4 with (30% UFS) achieved strength of 2.85, 2.9, and 3.0 MPa, respectively. Splitting-tensile strength was also reported to increase with age, the results indicates that the splitting tensile strength of concrete mixtures increased with the increase in used foundry sand content. (Siddique, Schutter, & Noumowe, 2008) also, carried out flexural strength and modulus of elasticity in the experiment and the author reported that at day-28, flexural strength of control mixture M-1 with (0% UFS) was 3.41 MPa, whereas mixtures M-2 with (10% UFS), M-3 with (20% UFS), and M-4 with (30% UFS) achieved strength of 4.0, 4.1, and 4.18Mpa respectively, which is also a clear indication that flexural strength of concrete mixtures increased marginally with the increase in used foundry sand content. The last test carried out which is the modulus of elasticity as reported by the author shows that at day-28, control mixture M-1 with (0% UFS) achieved a modulus of elasticity of 25.1 GPa, whereas mixtures M2 with (10%UFS), M-3 with (20%UFS), and M-4 with (30% UFS) achieved a modulus of elasticity of 26.75, 27.60, and 28.4 GPa. which indicate that replacement of fine aggregate with used foundry sand marginally enhanced the modulus of elasticity of concrete mixtures. The result from all this test carried out, made (Siddique, Schutter, & Noumowe, 2008) to conclude that used-foundry sand could be conveniently used in making good quality concrete and construction materials.

In a similar study by (Singha & Siddique, 2011), a study was carried out to investigate the effect of waste foundry sand on the strength and durability properties of concrete mixtures where waste foundry sand was used as partial replacement of natural sand (fine aggregate). In this study several test such as compressive strength, splitting-tensile strength, modulus of elasticity, rapid chloride permeability test and ultrasonic pulse velocity test was carried out to determine the effect of partially replacing fine aggregate with waste foundry sand in concrete. A different type of cement which is Portland pozzolana (fly ash based) cement was used in this study and it was tested as per Indian standard specification for accuracy. The author ensured the use of natural coarse sand having 4.75mm maximum size particle and locally accessible crushed coarse aggregate having maximum size of 12.5 mm which was tested according to Indian standard and satisfied its ASTM C 33 requirement. Amid the experiment as reported by (Singha & Siddique, 2011), the Passing % from 12.5 mm sieve was (90–100%), Passing % from 10mm sieve was (40–80%) and passing % from 4.75 mm sieve was (0–10%). The waste foundry sand utilized as a partial substitution of fine aggregate in the study was obtained locally and the binders used were Bentonite clay and water. furthermore, the superplasticizer used to maintain the flow workability of plain concrete in form of slump was polycarboxylate which has a relative density of 1080 g/l at 30 degrees Celsius. To conduct the experiment and to comparison purpose, a control concrete mixture(M-1) without waste foundry sand was designed to have 28-days compressive strength of 40 MPa and four more concrete mixtures (M-2, M-3, M-4 and M-5) were made by replacement of fine aggregate with Waste foundry sand and the replacement% was 5%, 10%, 15% and 20%. Different sizes of cubes were cast and the five tests to be used to

determine the effect of waste foundry sand on concrete which are the compressive strength, splitting-tensile strength, modulus of elasticity, rapid chloride permeability test and ultrasonic pulse velocity test was then carried out on the cubes. The result of the compressive strength test carried out as reported by (Singha & Siddique, 2011), indicated that concrete mixtures made with waste foundry sand exhibited higher compressive strength than the control concrete mixture. From the results, it was found that at day-28 the compressive strength increased by 8.25%, 12.25%, 17% and 13.45% for mixtures M-2 with (5% WFS), M-3 with (10% WFS), M-4 with (15% WFS) and M-5 with (20% WFS) respectively than control mixture M-1 with (0% WFS). Additionally, at day-91, increase in strength was 7%, 14.25%, 16.25%, 19.5% and 15.5% for M-1, M-2, M-3, M-4 and M-5 mixture, respectively. However, the author noted that the increase in compressive strength of concrete with the increase in waste foundry sand content up to 15% as partial replacement of sand could be as a result of its dense matrix in light of the fact that waste foundry sand is a fine sand and its particle size fluctuates between 600 μ m to 150 μ m also the reduction in compressive strength with the inclusion of 20% waste foundry sand could most likely be due to increase in surface area of fine particles prompted to the reduction in the water cement gel matrix, thus; binding process of coarse and fine aggregate did not take place properly. From the result of the splitting tensile strength as reported by (Singha & Siddique, 2011), shows that splitting tensile strength of concrete mixtures increased with the increase in waste foundry sand content. The results show that splitting tensile strength of control mixture M-1 with (0% WFS) was 4.23MPa at day-28 and it was increased by 3.55%, 8.27%, 10.40% and 6.38% of M-2 with (5% WFS), M-3 with (10% WFS), M-4 with (15% WFS) and M-5 with (20% WFS) respectively.

Additionally, at day 91, it increased by 1.89%, 5.2%, 11.58%, 13.47% and 11.11% with M-1, M-2, M-3, M-4 and M-5 concrete mixtures respectively with an higher value of splitting tensile strength observed at 15% WFS. From the result of the modulus of elasticity carried out in the study as reported by (Singha & Siddique, 2011), It shows that, the inclusion of waste foundry sand in concrete mixtures resulted to increase in modulus of elasticity at all ages. according to the result at day-28, modulus of elasticity of control concrete mixture (M-1) without WFS was 29.9 GPa and there was an increase in modulus of elasticity by 1.67%, 5.01%, 6.35% and 4.35% of M-2 with (5% WFS), M-3 with (10% WFS), M-4 with (15% WFS) and M-5 with (20% WFS) concrete mixtures respectively than the control concrete mixture (M-1). Additionally, at day-91 concrete mixtures of M-1, M-2, M-3, M-4 and M-5 was reported to achieved an increase of modulus of elasticity of 6.02%, 8.69%, 10.03%, 12.37% and 11.37% respectively. At day-28 it was observed that, concrete mixture containing 15% WFS has higher modulus of elasticity (31.8 Gpa). The author also reported the result of the rapid chloride permeability test that was carried out on the five concrete mixtures to ascertain an experimental evaluation of electrical conductance of concrete to provide rapid indication of concrete resistance against chloride ion penetration since it known that chloride ion present in the concrete can have harmful effect on concrete as well as on the reinforcement (Singha & Siddique, 2011). Based on the results of the test it was reported that, at day-28, the charges passed were 1368, 1250, 1150, 1060 and 1190 coulombs at 0%, 5%, 10%, 15% and 20% of waste foundry sand (WFS). The coulomb value was reported to decreased with the increase in WFS content up to 15% WFS, which indicate that concrete became denser. However, the author also reported that at 20% WFS, there

was a little increase in coulomb value with references to 15% WFS and it was noted that all concrete mixtures have Low Permeability (coulombs between 1000 and 2000) as per ASTM C1202. Based on the results, (Singha & Siddique, 2011), postulated that rapid chloride permeability test values decreased with the increase in WFS% in concrete mixtures and the maximum reduction in rapid chloride permeability test value was observed at 15% replacement of natural sand with waste foundry sand which indicates that at 15% replacement, concrete exhibit more resistance to chloride ion penetrability than control mixture M-1 (0% WFS). Additionally, the author reported that at day-91, the coulombs charge passed were 1260, 1060, 990, 940, and 1040 at 0%, 5%, 10%, 15% and 20% of WFS which shows that the coulombs charges passed at 91 days were less than those of 28 days, these results indicates that concrete microstructure become denser. The final test carried out by (Singha & Siddique, 2011) in the study to diagnose the quality of concrete is the ultrasonic pulse velocity test which essentially involves the measurement of electronic wave velocity through concrete. According to the result of the USPV test that was performed at the age of 28 and 91 days on concrete containing 0%, 5%, 10%, 15% and 20% of waste foundry sand as reported by the author, it indicates that USPV value increased with the increased in waste foundry sand content in concrete mixtures and it also increased with age. The increase in USPV value with inclusion of WFS in concrete mixture, made the author to postulate that the quality of concrete in term of density, homogeneity and lack of imperfections is good and through this investigation, it has been established that up to 15% use of waste foundry sand results in better enhanced strength and more durable concrete. The results from the entire test carried out made (Singha & Siddique, 2011) to conclude that the inclusion of waste foundry sand as partial

replacement of fine aggregate in concrete leads to an increase in compressive strength, splitting tensile strength and modulus of elasticity, which increases the chloride ion penetrability and improves the quality of concrete in term of density, homogeneity.

In recent years, many researchers have shown the economic viability of the use of foundry wastes in the improvement of durability properties of concrete. (Yuksel, Bilir, & Ozkan, 2006) wrote a scholarly paper containing substantial findings from a study carried out to investigate how the usage of bottom ash (BA), granulated blast furnace slag (GBFS), and combination of both of these materials as fine aggregate in concrete affects the concrete durability. To access the durability characteristics of concrete and decide the ideal substitution proportion of the bottom ash and slags, several durability tests such as high temperature effect, freezing–thawing, drying-wetting, capillarity, and surface abrasion were conducted. In order to carry out the durability test a reference concrete group was produced with a certain mix proportions and three concrete series were produced replacing fine aggregate with granulated blast furnace slags (GBFS), bottom ash (BA) and the combination of granulated blast furnace slag and bottom ash as reported by the author. In the study by (Yuksel, Bilir, & Ozkan, 2006), five test groups were produced in each series by selecting the replacement ratios as 10%, 20%, 30%, 40% and 50% and durability tests such as: High temperature effect, freezing–thawing, drying–wetting, capillarity, surface abrasion and alkali–silica reactions were done on the series groups (which is 15) and the reference concrete, after which the durability properties of the concretes were compared in order to study the possible advantages of different replacement ratios. The author also reported the loss in volume of specimen due to surface abrasion, which was done per Turkish Standard TS 699 by using Bohme surface

abrasion test method, which is measured with volume loss of specimens for each group. From the results of the tests carried out it was reported by the author that in the high temperature effect test, compressive strength losses are around 75% for all series of concrete because of the deterioration of C–S–H in cement paste and there was an observed relative increase for 10–30% replacement ratios for all series in different rates but a slight decrease was observed in C series at 30% replacement ratio. The author also reported that residual strength is higher than the strength of reference concrete for replacement ratios up to 40% which indicates that replacement of GBFS and/or BA does have positive effects on resistance to high temperature. This result made the author to postulate that GBFS and BA can be used single or mutual to replace fine aggregate and this type of concrete shows similar performance against high temperature like the reference concrete. From the results of freeze–thaw test carried out it was reported that as the replacement ratio increases, the porosity of the concrete also increases in all series relatively, which proves that the new concrete produced by using GBFS and BA as partially fine aggregate is more durable to freezing–thawing than reference concrete. The author, also reported the results from the drying–wetting test carried out that demonstrates that drying–wetting impact quickens the compressive strength reductions for each of the three series of concrete. As the replacement ratio of the concrete with by-products increases, the structure of hardened concrete gets more porous which causes the compressive strength to diminish. The capillarity test as reported by the author presents a higher capillarity coefficient for all the substitution ratio when contrasted to the reference group asides from 10% substitution ratio which is based on pozzolanic reaction. As the substitution coefficient increases the amount of by-products also increases which makes

the structure of the concrete more porous resulting to increase in capillarity coefficient. It was also reported that replacement of GBFS and/or BA does not decrease the surface abrasion in all the concrete series because the surface abrasion has a resistance which is influenced by crushing strength of the aggregate, strength and porosity of concrete and the contact area of specimen's surface. During the micro-structure analysis as reported by the author, the observed SEM image shows that the reference concrete with only fine sand been used shows a dense structure with no porosity but as the bottom ash was added there was a slight difference in the structure but the porous structure became noticeable at the replacement ratio greater than 30%. This made the author to postulate that, the formation of discrete grains and porous area close to the aggregate surfaces might be the main cause in reduction of the compressive strength values with an increase in the percentage of bottom ash in the fine aggregate replacement. Based on the analyses of all the test result and the SEM images, the author was able to conclude that the granulated blast furnace slag and bottom ash have a positive effect on the durability of concrete when they are used to replace fine aggregate.

As described above, many researchers have reported the importance the use of slags in construction industry and specifically the use in concrete (Kim, Koh, & Pyo, 2016). (Kim, Koh, & Pyo, 2016) also, wrote a scholarly paper from extensive research carried out to report the importance of slags in enhancing the flowability and sustainability of Ultra-High Performance Concrete (UHPC) because UHPC is one of the most advanced cement-based materials having prevalent mechanical properties and it requires high amount of energy intensive materials including cement, which could bring about environmental effects compared to normal concrete. According to the author,

different endeavors have been made to enhance flowability of concrete by adding supplementary chemical components or partially substituting constituents of concrete to bring down inter-particle friction but no attempt has previously been made to develop an eco-friendly UHPC with industrial slags by replacing cement and natural aggregates concurrently. To achieve this, the author first carried out particle packing analysis to successfully substitute cement and natural aggregates in UHPC after which flowability and compressive strength at different ages were then investigated to evaluate the effect of industrial slags and limestone powder in UHPC and finally, quantification of sustainability of the developed eco-friendly UHPC was ascertained. To actualize the intended goal, some carefully selected materials were used in this study as reported by the author such as: un-densified silica fume containing about 95% of SiO₂, ordinary Portland cement, two types of Limestone powder with various particle sizes, ground granulated blast-furnace slag (GGBFS), silica powder with median diameter of 3.15µm, and poly-carboxylate-based superplasticizer with 25% solid substance by weight. It was also reported that silica sands and rapid-cooling electric arc furnace (EAF) oxidizing slag with specific gravity of 3.40 were used as fine aggregate and brass coated smooth steel fibers each with length of 19.5 mm and a diameter of 0.2 mm having a base tensile strength of 2450 MPa were utilized as part of the mixes. The results from this experimental procedures as reported by (Kim, Koh, & Pyo, 2016), shows a substantial effect of limestone powder(LP) in UHPC to such an extent that the higher the substitution level of cement with Limestone powder, the higher the flowability of UHPC despite the fact that the particle size distributions of (LP I) is practically the same as cement, higher flowability of UHPC can still be achieved by using (LP I). However, the downside of the

utilization of Limestone Powder in UHPC as reported by the author is clearly the strength loss since their chemical effect is extremely constrained compared with Portland cement. Therefore, 30% of substitution with LP would be desirable to design high flowable UHPC with compressive strength higher than 150 MPa since according to American Concrete Institute (ACI) Committee 239, compressive strength of UHPC ought to be higher than 150 Mpa at an age of 28-days. Furthermore, the author asserted that it is beneficial to note that 45% of cement replacement in total with 30% of GGBFS and 15% of LP additional flow can be achieved without scarifying compressive strength. The results from the experiments as reported by the author also indicated that the flow of UHPC is significantly enhanced by substituting cement with ground granulated blast-furnace slag (GGBFS) such that there is up to 34.4% enhancement in the flow at the substitution level of 50% with 10.9% loss in compressive strength. The author also noted that the compressive strength of UHPC containing GGBFS is higher than that of UHPC containing LP at the same cement replacement level this is because GGBFS would create additional hydration items in the mixtures by reacting with water. It is also found that strength development is slow as replacement level increases, which demonstrates slower hydration process when GGBFS is used for cement substitution. The results also detailed that natural fine aggregates can effectively be replaced with the industrial by-products rapid-cooling EAF oxidizing slag (REOS) in UHPC with the additional advantage in flowability. Also by replacing 100% of natural fine aggregates with industrial by-products, 22.5% increase in flow and 7.9% strength loss were assessed. It was also reported that REOS can carry external load more than 150 MPa, and the ball bearing effect of REOS is still effective in UHPC as found in normal concrete. The author also

made it known that it can be culminated that even though the material cost of REOS is like the quartz sands because of additional synthesizing process, the series of experimental results demonstrates that the usage of REOS gives additional improvement in flowability as well as environmental benefits. The author also evaluated life cycle assessment (LCA) of UHPC by evaluating the following five essential effect categories : renewable primary energy input (PEI), non-renewable PEI, global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) and it was noticed that substituting UHPC mixtures with less energy intensive constituents were able to effectively reduce ecological over-burden (i.e.: substituting 50% cement with GGBFS, demonstrates a significant reduction in environmental categories because cement has a very crucial influence on the ecological effects in concrete). From the evaluations of the mechanical tests and environmental investigation results, the author was able to conclude that the use of GGBFS, LP and REOS to successfully substitute cement and natural aggregates in UHPC brings about higher flowability without sacrificing compressive strength and clear ecological advantages was found by utilizing this less energy intensive constituents in UHPC.

In recent year, many efforts have been made to enumerate and access the environment impact of concrete based blast furnace slags and spent sand. In a recent study conducted by (Ondova & Vaclavik, 2016), the utilization of blast furnace slag in the production of plain concrete and the life cycle assessment as well as the comparison of environmental impact of selected plain concretes by the LCA method was reported. To achieve the goal of the study, the consistency of concrete mixture, density of fresh concrete mixture, cube and prism strengths, water tightness, frost resistance and static

modulus of elasticity were observed by the author in all the prepared experimental mixtures and the total environmental impacts were monitored in terms of threats to soil, water, air and human health in order to select the most suitable alternative. Amid the experimental procedure as reported by the author, finely ground granulated blast furnace slag with the weight of 10, 20, 30, 40, 50, 60, 80, 95 and 100 % was used as a substitute of Portland cement in ratio 1:1 of weight in plain concrete and the physical and mechanical properties were studied. The author also conducted several analyses on the blast furnace slag to get the right chemistry and properties such as: a scanning electron microscopic analysis which at an amplified image of 1000 and 1999 times shows slag characterized by a high content of intact pyramidal particles of various sizes, which is caused by the grinding of slag. The other analysis carried out on the blast furnace slags (BFS) was X-ray diffraction analysis which identified the Melilite phase ($\text{Ca}_2\text{Mg}_0,5\text{AlSi}_1,5\text{O}_7$). This analysis as reported by (Ondova & Vaclavik, 2016), demonstrates a conspicuous gap above the background in the central part of the diffraction pattern, which indicates the presence of amorphous (glass) phase. The results of the comparison of the chemical analysis made the author to postulate that the determined higher contents of Si, Ca, Mg are consistent with the identified melilite phase. The aggregate with a fine fraction of 0/4 mm from Bohumin and coarse aggregate with the fraction of 4/8 mm and 8/16 mm from Dolni Benesov were used as filler in concretes and Plasticizer Addiment BV1 based on sodium lignin sulphonate was used as an additive during the study. It was reported by the author based on the results of all the tests and analysis carried out in the study that the estimation of slump ranges approximately around 80 mm in case of the substitution of Portland cement with finely ground blast

furnace slag of up to 60% of weight, while maintaining the same water-cement ratio of $w = 0.59$. Additionally, it was also reported that the substance of finely ground slag in 95 and 100% of the weight of cement causes an expansion of the volume weight of fresh concrete which is due to the fact that the finely ground slag partially contributes as a substitute of small aggregate, which prompts to the filling of the concrete pores, thereby expanding the volume weight of concrete with a partial substitution of cement with slag in comparison with the concretes without slag, where the cement as a binder does not contribute to the substitution of fine aggregate fraction, yet goes about as a hydraulic component. The author further postulated based on the results of the experiments carried out that the plastic deformations in these concretes are smaller, which was affirmed by the very fragile deformation of the test specimens during the strength tests. Therefore, the substitution of cement with finely ground slag from 20 to 80 of weight leads to the decline of the pressurized water entrance value in concrete. The author also reported the LCA for the two-selected type of blast furnace slag concretes (reference plain concrete (RC) and plain concrete with 60% blast furnace slag: R60) that were selected. The Functional unit was one cubic meter (1-m^3) of finished concrete and the initial system boundaries is cradle to gate (i.e. assessment of production phase, which is the most imperative one in terms of evaluated raw materials, in view of the greatest potential threats and critical negative impacts on the environment amid production processes of cement). The scope was defined as the comparison of selected concrete to get the most reasonable alternative in terms of their environmental impact. The LCA results carried out as revealed by the author, the impact assessment of the subsequent systems of variant RC and variant R60 with respect of main categories of category mid-point level (Abiotic

depletion; Acidification Potential; Global Warming Potential and Human Toxicity) shows that the resulting qualities (R60) of the cement impact compared to the reference variant (RC) were reduced by 11.5% on average on 1-m³ and the largest cement decrease was basically recorded in the indicator region by AP (17%). The author also reported the visible changes seen mainly in: Depletion, Acidification Potential, Ozone layer Depletion Potential, and Photochemical Oxidation which reduced the Potential risk to human health compared to the production and use of cement (RC). However, the environmental impact of transport was slightly increased because utilizing 60% blast furnace slag as cement replacement prompted to increasing the request on transport, which subsequently caused a minor increase in emissions production. Contrasted with the variant RC, this increase (0.98 - 4.25%) was seen mainly in following indicator areas: Ozone layer Depletion Potential, Eutrophication Potential, and Fresh water aquatic Eco-toxicity. The results of the life cycle assessment within the boundaries of "cradle to gate" as reported by the author shows that the aggregate estimation of LCA impact according to LCA indicators for variant R60 were decreased by about half (58%) compared to the variant RC which made the author to infer that plain concrete prepared with a share of blast furnace slag shows positive outcome in view of technological and environmental assessment and appears to be promising way to sustainability and to diminishing of negative environmental impacts of the production and utilization of building materials.

Similarly, more studies have been carried out that focused not only on the environmental effect of the use of foundry wastes (blast furnace slags, spent sand) to modify and produce a more sustainable concrete but also the cost. A scholarly paper was written by (Tae Hyung, Chang U, Sung Ho, & Won Young, 2016) from a ground-

breaking research carried out which reported the assessment of environmental effects and cost of the Industrial Waste Addictive Blast Furnace Slag (W-BFS) using Life Cycle Assessment (LCA) and compared it to general Blast furnace slags (BFS). During the experiment procedure, waste additives were partially mixed as an activator aimed to induce the hydration reaction of BFS and for coarse aggregate used for a physical test. To guarantee satisfactory trial result, crushed aggregate (20 mm, specific gravity: 2.60, fineness modulus: 6.68) was used and for fine aggregate, sea sand (specific gravity: 2.58, fineness modulus: 2.34) was applied. The author additionally detailed the utilization of 100% Ordinary Portland Cement (OPC) chosen for the plain (Type1) mixture and for Type 2 mixture (OPC: BFS = 70:30%) and for Type 3 (OPC: W-BFS = 70:30%). Slump test (KS F 2402) and air content test (KS F 2421) were also conducted on fresh concrete to assess fluidity. After which a compressive strength by age was measured as per KS F2405. The author also reported the fabrication of a circular test specimen (100mm by 200mm) to evaluate the qualities of compressive strength and compression testing machine after standard curing (20 by 2°C) was used to quantify the concrete strength. In addition, slump, air content and concrete temperature were measured. The concrete slump test was aimed to satisfy “(5 150 +/- 25 mm)”. For this study, chemical admixture was used. Also, air content test was focused to meet “(4.5~1.5)%”. Based on all the tests and experiments carried out it was revealed by the author that there is an increase in slump because the Blast furnace slags has a smooth wave surface and as lubrication among concrete particles increases because of interface lubrication action created by the acidic membrane on the surface, the bearing impacts of aggregates also increase. The author also made it known from the result of the experiment that the

slump and air content of W-BFS-mixed concrete reveal the same measurement value with the general BFS-mixed concrete, which gives the idea that there is almost no change in the physical properties of concrete brought about by a waste additive. The result from the compressive strength as far as strength development rates as detailed by the author shows that Type 2 is lower than Type 1 until the 7th day. However, Type 3 was the same with Type 1 from the 1st day regarding compressive strength and at the 28th day, specifically, higher compressive strength was measured which gives the idea that this sort of result happened because early-organize hydration was accelerated after Sulphur IV oxide ion in the waste added substance was assimilated into Al_2O_3 in the BFS and precipitated in the pore along with the formation of ettringite. The author also revealed the results from the LCA conducted and the results were broken into two stages: The Environmental Impact Assessment of W-BFS and the Environmental Impact Assessment of Concrete Mixing W-BFS. The results from the first stage as reported by the author evaluated the environmental impact of W-BFS in accordance with the LCA method under the ISO Standards and the classification of environmental impact for the Life Cycle Impact Assessment (LCIA) was divided as follows: global warming, acidification, eutrophication, abiotic depletion, ozone depletion and creation of photochemical oxides. In addition, the product stage of W-BFS was classified into raw material, transportation and manufacture stages. Furthermore, the environmental impact of input and output materials in each stage on atmosphere and hydrosphere was assessed. The author also reported the matters produced amid the production of W-BFS affect atmosphere and hydrosphere, and the related environmental issues include Global warming potential (GWP), Ozone Depletion Potential (ODP), Photochemical Oxidant Creation Potential

(POCP), Abiotic Depletion Potential, Eutrophication Potential (EP) and Acidification potential (AP). It was also reported that most of the environmental issues were caused by LNG, which was used in calcination equipment at the production of waste admixture (W) because of the direct and indirect emission of CO₂, CH₄, SO₂ and H₂S which influence GWP and AP while using LNG. The author also made it known that in EP, POCP and ADP, raw material stage accounted for a great portion of the environmental impact as a result of “W” among input materials. It was confirmed that nitrogen oxides (NO_x), ammonia (NH₃), crude oil, natural gas, carbon monoxide (CO) produced amid the production and transportation of the components of ‘W’ (titanium gypsum, sludge and limestone) were influential. It was also discovered that in ODP, the oil that was used in transporting BFS to the W-BFS manufacturing factory was more influential also Trichloro-fluoro-methane (CFC-11), Hydro-chloro-fluoro-carbons (HCFC-22) and Halon-1301 produced after the use of diesel oil have been determined as major substances. The author made it clear that the environmental impact caused by the electricity, LNG and industrial water used in the manufacturing facilities of W-BFS was very minor. The second stage of the LCA conducted which is the environmental impact of the mixed concrete (W-BFS or general BFS) as reported by the author was classified into five cases depending on the mixing ratio (%) i.e. Case 1 is a basic mixture, which refers to OPC without any BFS or A-BFS while Cases 2 and 3 refer to mixed concrete having 10% “general BFS or W-BFS” also, Cases 4 and 5 represent concrete mixture with 20% “general BFS or W-BFS”. The author revealed the results of the mixed concrete (W-BFS or general BFS) compared to plain concrete (Case 1) as far as environmental impact (GWP and POCP) and it was discovered that the mixed concrete

was lower than Case 1 by 10%–25% as the mixing ratio (W-BFS + BFS) increased by 10% (Cases 2 and 4) and 30% (Cases 3 and 5). It was made known that the outcome originates from the little production of the significant impact substances of GWP and POCP (CO₂, CH₄, N₂O, CO, Ethane (C₂H₆), Sulfur (S)) amid the production of W-BFS and BFS in the mixed concrete. Moreover, it was additionally reported that, the mixed concrete was lower than Case 1 by 3%–11% as the mixing ratio (W-BFS + BFS) increased by 10% (Cases 2 and 4) and 30% (Cases 3 and 5) which resulted to the diminishment in the consumption of common cement comprised of natural resources such as limestone, clay, iron ore and silica with the mixture of industrial byproducts “W-BFS” and “BFS”. With decrease in the consumption of ordinary cement, the emission of the ADP-causing substances such as iron (Fe), natural-gas, hard-coal, lead (Pb) and uranium (U) decreased. Considering the findings discovered from the experiment and the LCA carried out, the author was able to conclude that the compressive strength of W-BFS-mixed (30%) cement was equal or more prominent than Ordinary Portland Cement (OPC). Since the 3-day compressive strength was 19.8 MPa, specifically it can remove the structures early, and if it is applied to RC structure, in this manner, it is expected to shorten construction period and reduce construction cost as well as to lower environmental impacts.

Considering the large amount of progress that has been recorded in the construction industry to improve the environmental impact of concrete, but it is imperative to know that it is unrealistic to gauge or assess environmental impact of concrete without considering the constituents or input of the concrete composition. After thorough consideration of the constituents or input of the concrete composition,

development opportunities may then be visible. This approach was followed in a study by (Sharma et al, 2016) where a simplified LCI model for concrete was developed which shows the practicality of a simplified LCI model by comparing the life cycle impact of different concrete compositions that contain Fly Ash (FA) and Recycled Concrete Aggregate (RCA). The principle goal of this study was to develop a model intended to breakdown the impact of any added concrete constituent at any combination or mixture, which can be used in the concrete industry to evaluate the effect of concrete mixtures. The study also shows the environmental impact of Fly Ash (FA) and Recycled Concrete Aggregate (RCA). The model input in the study were Portland cement, fly ash, fine aggregate, coarse aggregate and recycled concrete aggregate, transportation impact of aggregate to the concrete plant through road was included in the study. The functional unit in the study includes: one paved highway mile with a width of 7.315m (24-ft) and thickness of 0.2286m (9-in), which is equivalent to approximately 2691m³ (88704 ft³) in total and the service life or use period included in the functional unit is 39 years. Several assumptions were also made in the study such as: a concrete density $\rho = 2400\text{kg/m}^3$ (150 lb/ft³), the model functional unit weighs 6.458E6 kg (6458 tons), in all cases a constant per-weight concrete mix ratio consisting of 1 part-320 kg/m³ (19.977 lb/ft³) cementitious material, 2 parts- 640 kg/ m³ (19.977 lb/ft³) dry fine aggregate, 3 parts- 960 kg/ m³ (19.977 lb/ft³) dry coarse aggregate, and ½ part water and all this mix design when mixed with 100 percent Portland cement and virgin rocks aggregate produces a compressive strength of about 40MPa. The author established a baseline for comparison in the study and estimated the impact of a conventional Portland cement concrete mixture (Control) without any substitutions of cementitious material (R-Portland = 1, RFA = 0) and 100

percent virgin aggregate to represent a traditional concrete mixture. Additionally, the author also modified the conventional mixture, by substituting the Portland cement with 35%, 30%, 25% and 20% of FA and 50% and 40% of coarse aggregate with RCA within the same mixture. The result of the study carried out as reported by the author, demonstrated that supplanting the cement content with fly ash brings down the GHG effect when contrasted with a conventional mixture. Though supplanting coarse aggregate with RCA has an irrelevant decline in GHG effect because of the excess processing expected to prepare RCA for reuse in new concrete. The outcomes additionally revealed that the concrete service life is a basic element for deciding the general LCI of cement. This revelation made the author to presume that an increase in the service life of concrete reduces the environmental effect, since it will diminish the production and utilization of concrete and conserve natural resources.

The research that would be carried out in this study would be similar to the study of (Sharma et al, 2016) but the major difference would be changes in the design input. The design input of this study would be: Portland cement, foundry spent sand, slags, fine aggregate, Coarse aggregate, transportation impact of the aggregate to the concrete plant via road and ship.

3. EXPERIMENTAL METHOD AND LCA ANALYSIS

To achieve the goal of this study, the method would be divided into 3 main sections:

- A LCA of foundry waste (spent sand and slags) used in concrete production would be developed based on past LCA cases.
- A simplified LCI input and output model based on the findings would be developed.
- A comparison and analysis of the ideal substitution proportion of both spent sand and slags in the model developed.

Methodology for LCA

In order to achieve an in-depth and accurate analysis of the LCA of spent sand and slags used in concrete, the manufacture and environmental concerns of each major constituents needs to be assessed because each constituent are manufactured separately and assembled at the construction site or the batching plant. Therefore, a brief background on the entire LCI stages would be necessary.

Portland cement is considered one of the most important and mostly used binding materials in concrete production and it accounts for about 74% to 81% of the total CO₂ emission during concrete production. This is because of pyro-processing in the rotary kiln during cement production where calcium carbonate reacts with silica-bearing materials at high temperature of 1480^o C (2700^o F) in a calcination process (Sharma et al, 2016).

Foundry spent sand is a silica sand with uniform physical attributes and it is bonded to form molds. It is a by-product of ferrous (iron and steel) and non-ferrous

(copper, aluminum, brass) metal casting industries, where sand has been utilized for a long time as a molding material due to its thermal conductivity. There are two types of foundry sand such as clay-bonded sand (green sand) and chemically bonded sand. The major concern is the presence of heavy metals and phenols that are absorbed by the sand during the molding process and casting operations.

Slags is a by-product or waste generated during the smelting of metals in a furnace. It helps to remove dirt or unwanted materials in molten metal during smelting in the furnace before it is used to make solid metals. In order to increase sustainability, slag is being incorporated as a constituent in the concrete industry where slags are ground and granulated into a powder to become a supplementary cementitious material and several researches has proved that the use of steel slag in concrete as coarse aggregate improves the mechanical properties of hardened concrete leading to reduced permeability and better durability.

Aggregates are inert granular materials such as sand, gravel or crushed stone that can be derived from variety of natural stone sources such as stone quarries and riverbed gravel. The total volume of concrete comprises of 60 to 70% of aggregates and this aggregate can be divided into two types such as: coarse aggregate and fine aggregates. Fine aggregates consist of natural sand or crushed stones with most particles passing through 3/8 inches sieve while coarse aggregate are mostly crushed to an appropriate diameter usually within the range of 3/8 and 1.5 inches in diameter.

Concrete recycling is an increasing common method of utilizing the debris from the demolition of structures built with concrete. Recycling of concrete has helped to reduce the amount of spent concrete which are trucked to landfills for disposal.

Demolished concrete collected from demolition sites that are properly cleaned from all metals and organic compounds can be crushed and re-used as aggregates in fresh concrete. Crushing the recycled aggregate at the construction sites can help reduce cost and pollution generated from transporting the materials to and from a quarry. However, the process of demolishing, crushing and cleaning of the RCA requires high energy, which can also contribute to GHG emission.

Life Cycle Inventory

A life cycle inventory is a part of LCA that quantifies the energy, material inputs and emission during the product's life cycle. LCI process involves collection of available data of environmental impact and quantifying the input and outputs of the system. To achieve the aim of this study, a wide range of published reports and databases were reviewed in order to get an accurate quantification of the energy and emission data for each process. For the scope of this study, GHG emission in carbon dioxide CO_{2e} is considered and a thorough analysis of LCA with traditional concrete with sustainable alternatives (slags and spent sand) has been completed.

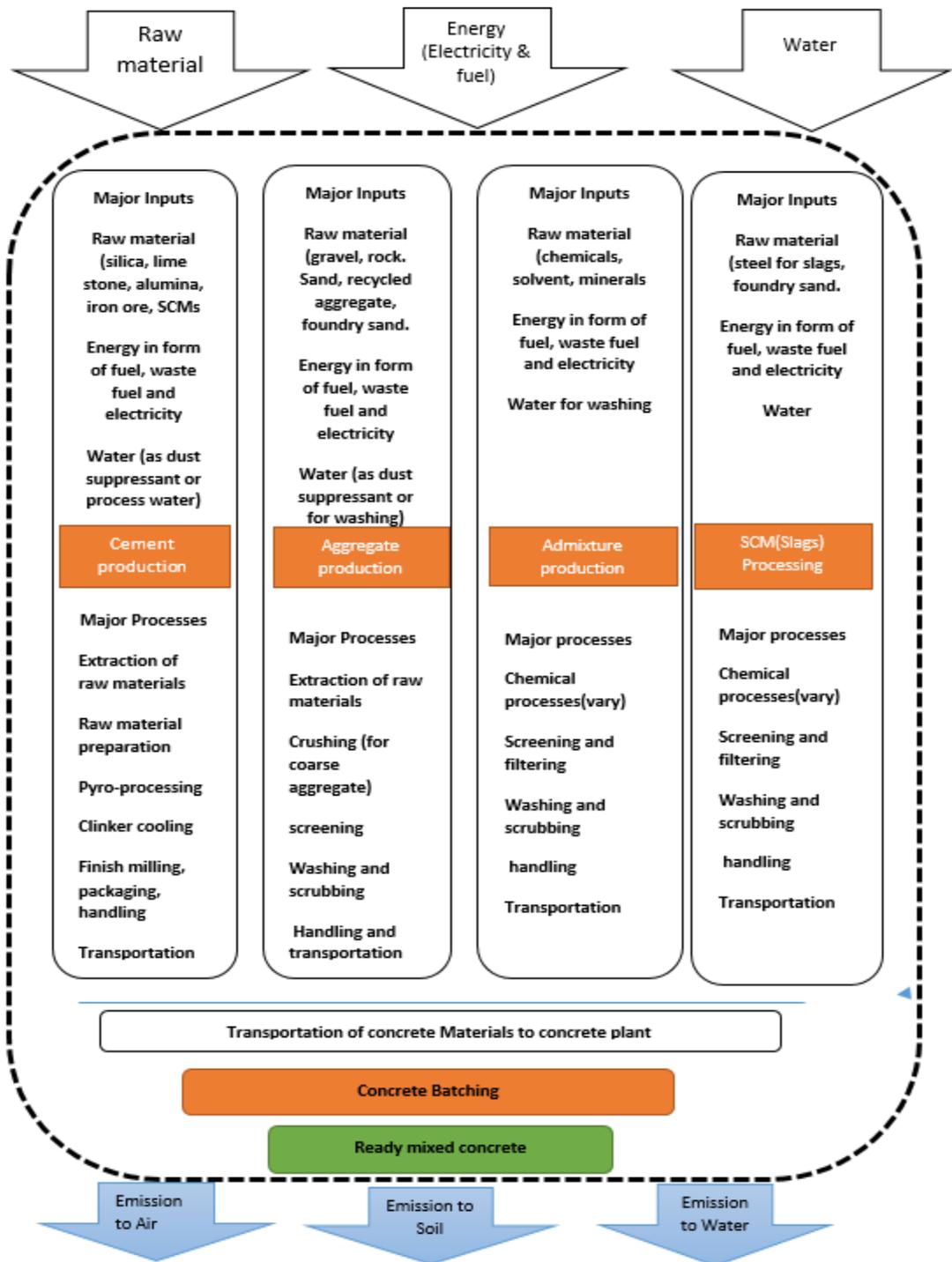


Figure 1. Life Cycle of Concrete Structures (Peter et al., 2014)

Figure 1 shows the cradle to gate system boundary, including the primary components of the life cycle stages, the processes within these stages and the emissions associated with each of the processes within the cradle to gate system. In this study, our major concern is the GHG emission in carbon dioxide CO_{2e} during the manufacture of concrete (with slags and spent sand). Although several researchers have quantified the environmental impact of CO₂ emission per ton of cement produced with fly ash and GGBFS used in concrete production but the main goal of this study is to develop a simplified model to estimate the environmental impact when dealing with concrete so an assessment of the CO₂ emission is necessary. Figure 3 clearly shows that the CO₂ emission from most of the activities involved in concrete production and placement is a result of the energy consumed to accomplish them making it exceptionally evident that examination of energy utilization is a vital component to analyzing the CO₂ emission.

The functional unit studied is:

- One paved highway mile which is equal to approximately 2769m³ (97786 ft³) in total.
- A concrete density of 2400kg/m³ (150lb/ft³) was assumed.
- The model functional unit weighs 6.458E⁶kg (6458 tons)

During the adjustment of the replacement level of alternative cementitious and aggregate materials in the model, assumptions are:

- In all cases a constant per-weight concrete mix ratio consisting of 320kg/m³ (19.977 lb/ft³) cementitious material, 640kg/m³(39.954lb/ft³) dry fine aggregate, 960kg/m³(59.9308lb/ft³) dry coarse aggregate, and ½ part water was made.

In this analysis, the following were investigated: Ground Granulated Blast Furnace Slags (GGBFS) as an alternative Supplemental Cementitious Material (SCM) in addition to Portland cement and Foundry Spent Sand as a substitute to fine aggregate in addition to fine sand. The functional unit of the LCA of concrete is:

- 1 ton of concrete produced
- Source of transportation of aggregate studied were trucks, freight car and ship.
- Time scale 1 year

Inventory data collection

To achieve the aim of the study, a wide range of published reports and databases were reviewed to quantify the energy and emissions for the each of the process activity defined as part of the system. The inventory data for emission during the cradle to gate of the production of concrete with foundry waste (slags and spent sand) was collected from a study report of (Kawai, Sugiyama, Kobayashi, & Sano, 2005) and the Figure 3,4 and 5 represents the inventory loading. The emission inventory data were collected for the energy, transportation and the material phase as per the system boundary of the study. Figure 3 provides emission inventory data for CO₂, SO_x, NO_x for various types of energy such as electric power, LPG for fuel, LNG, light oil, gasoline, heavy oil, kerosene and acetylene gas during the cradle to gate production process of concrete production. Figure 4 provides emission data for the transportation during the production of concrete as per the system boundary. The data provided in figure 5 are emission data from the production of Portland cement, blast furnace slags, coarse and fine aggregate production (mining and processing) and spent sand. Only necessary (useful data for this study) data was collected from the entire information provided in the figures 3, 4, and 5. The results of the

inventory analysis is a summary of all inflow and outflow related to the functional unit. The emission data provided is for 1 ton of concrete produced. The characterization factor of CO₂ and SO₂ is 1 and the result of each impact category is the total of all individual inventory loading data. Emission inventory data for Portland cement and blast furnace slags in this study are the sum of inventory data as of 2003 reported by Japan cement association and the corresponding emission data derived from the transportation of raw materials and the use of purchase power. It is necessary to note some assumptions made in the calculations in the energy phase. It was assumed that to produce 1 ton of concrete 10.38KWh of electricity is required (source).

Table 1. Emission inventory data for energy used during concrete production (Kawai et al. 2005)

	Unit	Calorific value (MJ/*)	CO2 emission (Kg-CO ₂ PER ton)	SO2 emission (kg-SO _x per ton)	NOx emission (kg-NO _x per ton)	Particulate matter emission (kg-PM)
Electricity	KWh	9.00	0.407	0.13×10 ⁻³	0.16 ×10 ⁻³	0.03 × 10 ⁻³
LPG for Fuel	Kg	50.2	3.03	#	#	#
LNG (imported)	Kg	54.5	2.79	-	-	-
Light Oil	L	38.2	2.64	2.04 ×10 ⁻³	19.77 ×10 ⁻³	1.66 × 10 ⁻³
Gasoline	L	34.6	2.31	0.59 ×10 ⁻³	39.61 ×10 ⁻³	2.01 × 10 ⁻³
Heavy Oil	L	41.7	2.77	13.00 ×10 ⁻³	2.38 ×10 ⁻³	# 3.00 × 10 ⁻³
Kerosene	L	M36.7	2.50	-	-	
Acetylene gas	M3	50	3.38	-	-	-

Table 2. Inventory data for transportation during concrete production (Kawai et al. 2005)

		Unit	Input Energy (GJ)	Oil Conversion(Kg)	Purchase Power(KWh)	CO ₂ Emission kgCO _{2e} per ton	SO _x kgSO _{2e} per ton	NO _x Emission KgNO _{2e} per ton	Particulate matter emission kg-PM
TRUCK S	Gasoline(2t)	Km.t	0.00300	0.0770	-	0.200	0.0000600	0.000250	0.00050
	Diesel(2t)	Km.t	0.00337	0.0756	-	0.233	0.000179	0.000146	0.000146
	Diesel(4t)	Km.t	0.00222	0.0497	-	0.153	0.000118	0.0000964	0.0000096
	Diesel(10t)	Km.t	0.00177	0.0396	-	0.122	0.0000941	0.0000768	0.0000076
	Diesel(20t)	Km. m3	0.00103	0.0231	-	0.0714	0.0000549	0.0000448	0.0000448
Dump truck	Diesel(10t)	Km. m3	0.00169	0.0379	-	0.117	0.0000901	0.0000735	0.0000073
Agitator truck	0.8-0.9m ³	Km. m3	0.00566	0.127	-	0.392	0.000302	0.000298	0.000298
	1.6-0.9m ³	Km. m3	0.00639	0.143	-	0.442	0.000340	0.000336	0.000336
	3.0-3.2m ³	Km. m ³	0.00399	0.0896	-	0.276	0.000213	0.000210	0.000210
	4.4-4.5m ³	Km. m3	0.00366	0.0820	-	0.253	0.000195	0.000192	0.000192
Freight car		Km.t	0.000507	-	0.0553	0.0219	0.00693	0.00140	0.00140
Ship	500t class	Km.t	0.00277	0.0553	-	0.162	0.00280	0.0000721	0.000721
	1000t class	Km.t	0.00170	0.0340	-	0.0999	0.00172	0.0000444	0.0000444
	2000t class	Km.t	0.00105	0.0209	-	0.0615	0.00106	0.0000273	0.0000273
	5000t class	Km.t	0.000552	0.0110	-	0.0324	0.000559	0.0000144	0.0000144
	10000t class	Km.t	0.000340	0.00679	-	0.0199	0.000344	0.00000886	0.0000088

		Unit (*)	Type of energy *1 (main use)	Input energy *2 (GJ/*)	Oil conversion (kg)	Coal conversion (kg)	Purchased power (kWh)	Non-metal mineral (kg)	Iron resource (kg)	Material recycling (wet-kg)	Waste emission (wet-kg)	CO ₂ emission (kg-CO ₂ /*)	SO _x emission (kg-SO _x /*)	NO _x emission (kg-NO _x /*)	Particulate matter emission (kg-PM ₁₀ /*)
Cement	Normal portland cement	t	C, Oc, Hc, E	3.40	16.24	93.84	31.2	1 236	-	148	-	766.6	0.122	1.55	0.0358
	Blast furnace slag cement (Type B)	t	C, Oc, Hc, E	2.28	13.13	56.80	30.1	715	-	85	-	458.7	0.0809	0.919	0.0218
	Fly ash cement (Type B)	t	C, Oc, Hc, E	3.02	18.25	75.71	34.0	998	-	120	-	624.0	0.0984	1.25	0.0289
	Normal eco-cement	t	Ha, E	6.40	108.67	-	250.9	829	-	765	-	784.0	0.152	0.319	0.00652
Aggregate	Coarse aggregate (Natural, crashed)	t	L, E	0.05	0.37	-	4.3	1 000	-	0	-	2.9	0.00607	0.00415	0.00141
	Fine aggregate (Natural, crashed)	t	L, E	0.07	0.37	-	6.2	1 000	-	0	-	3.7	0.00860	0.00586	0.00199
	Limestone aggregate	t	L, E	0.05	0.37	-	4.3	1 000	-	0	-	2.9	0.00607	0.00415	0.00141
	Waste aggregate (Melted using fuel)	t	K, E	29.71	721.86	-	240.0	-	-	1 238	141	2 293.6	0.0309	0.0376	0.00624
	Waste aggregate (Melted electronically)	t	E	9.13	13.09	-	959.3	-	-	1 238	141	430.3	0.123	0.150	0.0249
	Recycled aggregate (Type III)	t	E	0.06	0.21	-	5.9	-	-	1 000	No data	3.1	0.00127	0.0108	0.000655
	Recycled aggregate (Type I)	t	E	0.38	0.49	-	39.8	-	-	1 000	No data	17.7	0.00628	0.0289	0.00218
Mineral admixture	Blast furnace slag	t	E	0.58	-	-	65.0	-	-	0	No data	26.5	0.00836	0.0102	0.00169
	Fly ash	t	E	0.43	-	-	48.2	-	-	0	No data	19.6	0.00620	0.00754	0.00125
	Limestone powder	t	L, E	0.35	0.37	-	36.8	1 000	-	0	No data	16.1	0.0112	0.0103	0.00244
	Coal ash	t	-	-	-	-	-	-	-	1 000	-	-	-	-	-
Steel	Electric furnace steel	t	E	4.24	3.60	71.79	337.7	33	93	No data	7	767.4	0.134	0.124	0.0101
	Basic oxygen furnace steel (Shapes)	t	Cc, C, E	18.54	7.29	728.45	260.5	65	1028	No data	7	1 256.0	1.18	1.80	0.00781
	Basic oxygen furnace steel (Bars)	t	Cc, C, E	18.40	7.29	728.45	253.2	65	1028	No data	7	1 213.0	1.18	1.80	0.00759
	Basic oxygen furnace steel (Wire rods)	t	Cc, C, E	18.98	7.29	728.45	299.4	65	1028	No data	7	1 321.8	1.18	1.81	0.00898

Table 3. Emission inventory data (Material) (Kawai et al. 2005)

Calculation of Emission inventory to impact category

Table 4. Calculation of global warming for energy use phase

	Electricity	LPG for Fuel	LNG (imported)	Light Oil	Gasoline	Heavy Oil	Kerosene	Acetylene gas	Total
Emission									
kgCO ₂ per ton	0.407	3.03	2.79	2.64	2.31	2.77	2.50	3.38	23.2278
									4

Table 5. Calculation of global warming for material use phase

		kgCO _{2e} per ton
Cement	Port-land cement	766.6
	Blast furnace slags	458.7
Aggregate	Coarse-aggregate (natural, crashed)	2.9
	Fine-aggregate (natural, crashed)	3.7
	Recycled aggregate (spent sand)	17.7
Mineral admixture	Blast furnace slags	26.5
	Lime stone powder	2.9
Total per ton		1279

Table 6. Calculation of global warming for transportation phase

	Emission	kgCO_{2e} per ton
TRUCKS	Gasoline(2t)	0.200
	Diesel(2t)	0.233
	Diesel(4t)	0.153
	Diesel(10t)	0.122
	Diesel(20t)	0.0714
Dump truck	Diesel(10t)	0.117
Agitator truck	0.8-0.9m³	0.392
	1.6-0.9m³	0.442
	3.0-3.2m³	0.276
	4.4-4.5m³	0.253
Freight car		0.0219
Ship	500t class	0.162
	1000t class	0.0999
	2000t class	0.0615
	5000t class	0.0324
	10000t class	0.0199
Total per ton		2.657

Table 7. Calculation of Acidification for energy use phase

	Electricity	LPG for Fuel	LNG (imported)	Light Oil	Gasoline	Heavy Oil	Kerosene	Acetylene gas	Total
Emission									
kgSO₂	0.13×10⁻³	-	-	2.04× 10⁻³	0.59×10⁻³	13.0×10⁻³	-	-	0.0170
KgNO₂	0.16×10⁻³	-	-	19.77×10⁻³	39.61×10⁻³	-	-	2.38×10⁻³	0.0634
Total per ton									0.0804

Table 8. Calculation of Acidification for material use phase

		kgSO _{2e}	kgNO _{2e}	Total per ton
Cement	Port-land cement	0.122	1.55	
	Blast furnace slags	0.0809	0.919	
Aggregate	Coarse-aggregate (natural, crashed)	0.00607	0.00415	
	Fine-aggregate (natural, crashed)	0.00860	0.00586	
	Recycled-aggregate (spent sand)	0.00628	0.0289	
Mineral admixture	Blast furnace slags	0.00836	0.0102	
Total per ton		0.23221	2.5181	2.7503

Table 9. Calculation of Acidification for transportation phase

	Emission	kgSO_{2e} per ton	KgNO_{2e} per ton
TRUCKS	Gasoline(2t)	0.0000600	0.000250
	Diesel(2t)	0.000179	0.000146
	Diesel(4t)	0.000118	0.0000964
	Diesel(10t)	0.0000941	0.0000768
	Diesel(20t)	0.0000549	0.0000448
Dump truck	Diesel(10t)	0.0000901	0.0000735
	0.8-0.9m³	0.000302	0.000298
	1.6-0.9m³	0.000340	0.000336
	3.0-3.2m³	0.000213	0.000210
	4.4-4.5m³	0.000195	0.000192
Freight car		0.00693	0.00140
	500t class	0.00280	0.0000721
	1000t class	0.00172	0.0000444
	2000t class	0.00106	0.0000273
	5000t class	0.000559	0.0000144
	10000t class	0.000344	0.00000886
Total per ton		0.0150591	0.00329056

Impact results and tables

Table 10. Impact results from life cycle inventory for energy use

Impact category	Unit of characterization factor	Total per ton
Global warming	Kg CO₂equiv	23.2784
Acidification	KgSO₂equiv	0.0804

Table 11. Impact results from life cycle inventory for Transportation

Impact category	Unit of characterization factor	Total per ton
Global warming	Kg CO₂equiv	2.675
Acidification	KgSO₂equiv	0.01835

Table 12. Impact results from life cycle inventory for material phase

Impact category	Unit of characterization factor	Total per ton
Global warming	Kg CO₂equiv	1279
Acidification	KgSO₂equiv	2.7503

Interpretation of results

Based on the impact assessment calculation from the emission inventory data, it was discovered the material phase produced the highest CO₂ emission during the entire (cradle to gate) production of concrete with foundry waste (slags and spent sand). The highest CO₂ emission during the material phase was from the production of Portland cement this is as a result of the chemical reaction (calcination) in the kiln during the heating of limestone (CaCO₃) to produce lime (CaO), $\text{CaCO}_3 + \text{heat} = \text{CaO} + \text{CO}_2$ (Mohammadi & Warren, 2017). The production of blast furnace slag also produced a significant amount of CO₂ due to smelting of metals in the furnace or raw ores. The CO₂ produced during the transportation and energy phase are very little compared to material

phase. In transportation phase, the CO₂ produced is due to transportation materials since most concrete materials are produced separately and transported to the concrete plant or construction site. The CO₂ generated during the energy phase is because of the electricity, LPG for fuel, heavy oil etc. used to generate energy to the process and produce concrete constituents. Figure 2 below shows the amount of kgCO₂-equiv per ton of concrete produced for each phase (energy, material and transportation) contributing to Global warming.

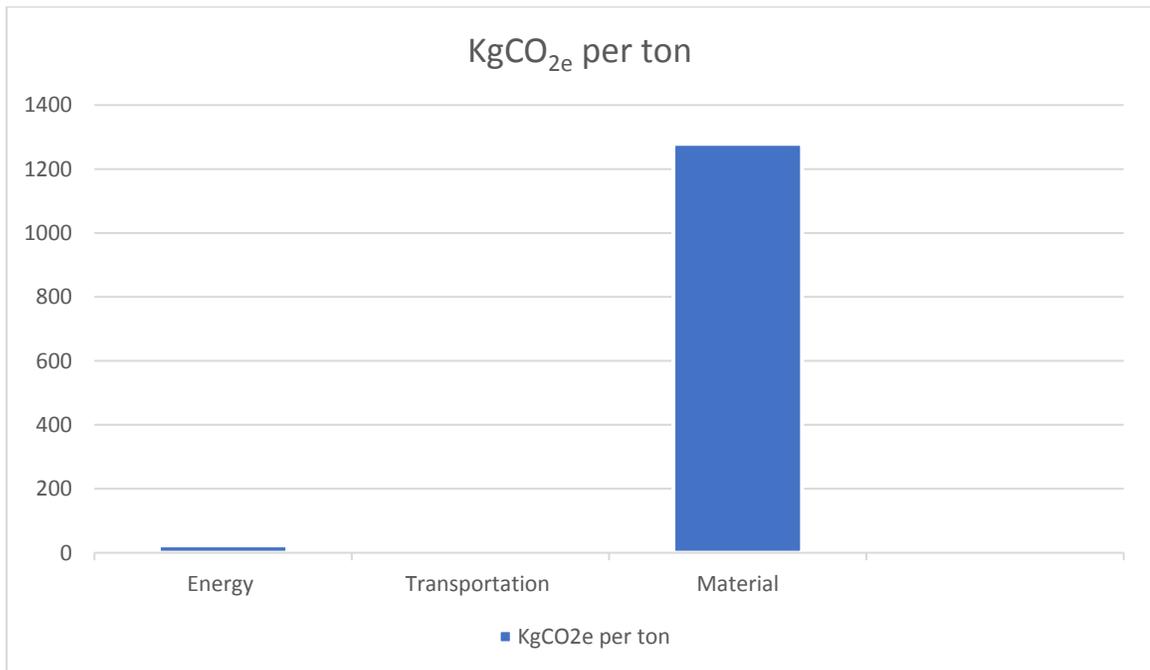


Figure 2. Concrete Phase Contribution to Global Warming

Figure 3 below shows the amount of SO₂ and NO₂ produced during the production of concrete contributing to acidification. The highest SO₂ and NO₂ produced was during the material phase due to the production and processing of concrete materials. The

emission release during the transportation and energy phase are very little. Overall, the Concrete production has very little contribution to acidification.

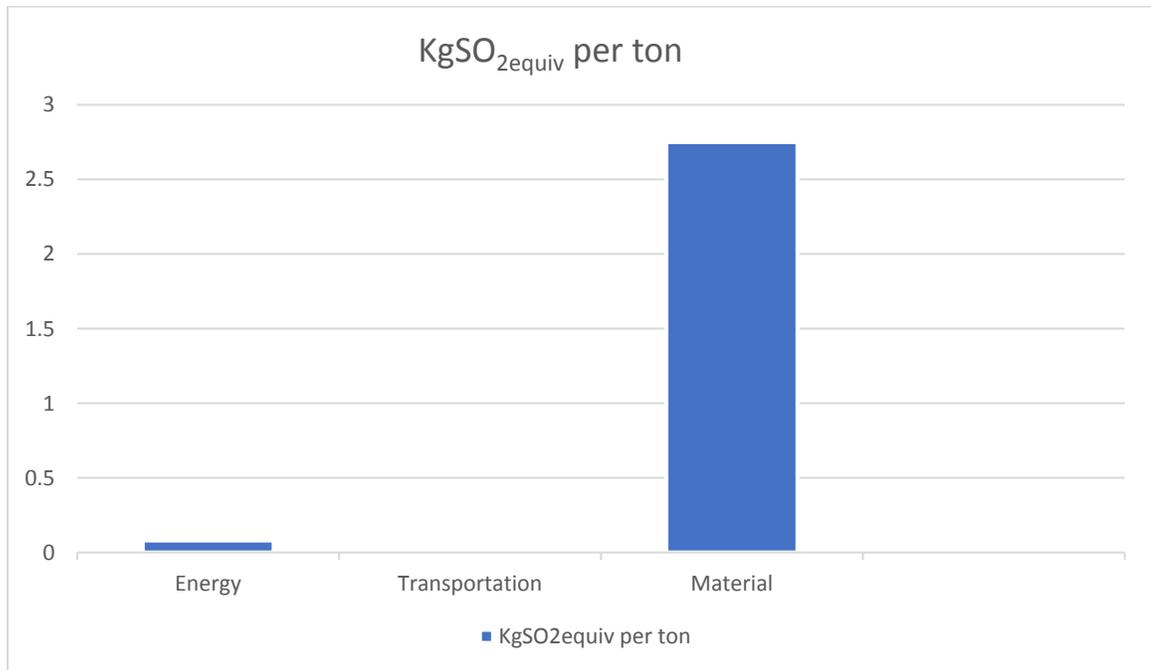


Figure 3. Concrete Phase Contribution to Acidification

Figure 4. below represent, the overall environmental burdens of concrete production (with foundry waste) based on the LCA carried out. From the impact analysis, it was clear that the major impact of concrete production is global warming due to the material phase (processing and production). There is also little contribution to acidification and eutrophication but the values are very insignificant. Based on this study, concrete production using spent sand and slags has no additional environmental impact apart from the global warming and very little acidification and eutrophication impact based on the SO₂ and NO₂ generation.

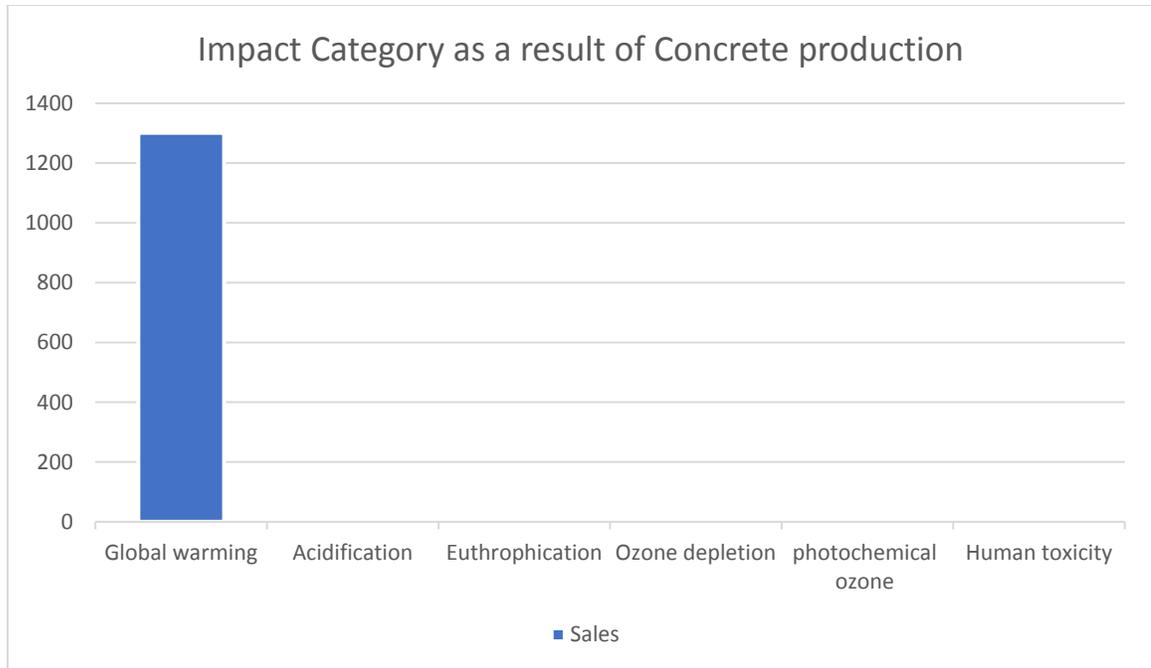


Figure 4. Environmental Burdens from Concrete Production

The above LCA of concrete with foundry waste (slags and spent sand) was developed to establish the basics of this study. The end goal of this study is to develop a simplified model of cement concrete configuration that can be used in construction industries to reduce the negative impact and cost of concrete production through CO₂ emission but that cannot be done without first establishing the environmental impact associated with concrete production.

4. MODEL DESIGN AND CALCULATIONS

Model Design

Developing a simplified approach in which the LCI for a functional unit of concrete is paramount for this study and it can be represented as:

Impact = (Cementitious material production impact + Aggregate production impact + Transportation impact) / Service life

The model can be represented as:

$$I = \frac{C}{SL} \quad \text{Eq. 1}$$

Where I represent the life cycle impact of the concrete structure (CO₂e emission), C is the summation of the constituent material and transportation and SL is the viable service life of the concrete. Service life is known to be the design esteem that influences the total impact of GHG emissions, in spite of the fact that the longer the service life the more durable and proficient the concrete is perceived to be. This value is variable from state to state and from mixture to mixture. The service life also changes with the use of recycled materials since the use of recycled materials like foundry waste and recycled concrete helps to improve the concrete structure by increasing the service life while reducing the amount of GHG emission in form of CO₂e.

It was reported in a study by (Sharma et al, 2016) that numerous U.S. highway agencies have started to design pavement of low-maintenance service life of 40 years or more and a study was cited where the service life is taken from a historical study done by various U.S. state transportation department in which they determined an average service

life of a traditional concrete mixture to be 39 years and an underlying model was developed. In line with the model, from Eq. 1 the constituent effect C can be additionally broken down to fit the coveted input of the model.

$$C = \sum_{i=1}^n \alpha_i m_i + \sum_{j=1}^n \beta_j m_j + \gamma m_k + T_r \quad \text{Eq.2}$$

Where m_i is the mass of each binder material such as Portland cement and slag, and m_j represents the mass of natural coarse aggregate and m_k represents fine aggregate and foundry spent sand, per functional unit in the concrete mixture and α_i, β_j , are linear regression coefficients. All these represent the GHG per-weight impact derived from the data accessible, which came from the production of binder materials, coarse aggregate and fine aggregate, respectively as shown in Table 13. The values in the Table 13, are averaged from the different data reported in the studies of (Sharma et al, 2016), (Kawai et al, 2005), (Mohammadi & South, 2017), (Knut, Maria, & Asa, 2005), (Van den & De Belie, 2012), (Leeuwen, Kim, & Sriraman, 2016), and (Nisbet, Marceau, & VanGeem, 2002), (Kim, Jang, Kang, Ahn, & Yun, 2015) and (Yang & Choi, 2016) most of the data were in $\text{kgCO}_2\text{e}/\text{m}^3$ and $\text{kgCO}_2\text{e}/\text{t}$ and were converted to $\text{kgCO}_2\text{e}/\text{Kg}$. Table. 13, provides the rundown of model coefficients for Eq. 3 below. T_r represents the impact from the transportation of the aggregate and finished concrete mix and the values were also averaged from the different data of the sources stated above. It is observed in this model that the cement and aggregate types each contribute autonomously to the total environmental impact. While this strategy is less complex and more user-friendly, it does not account for the possibility of interaction effects between the different impact factors. When used appropriately, this model can yield an estimate of the LCI of concrete given the mass of each cementitious material and aggregate type. It should be noted that, the

exact mass of each input material is not generally accessible for utilization by potential end-user of the model. A consistent concrete density and the steady proportion of binder, aggregate, and water is assumed as a part of the functional unit, the representation of the material input can be effectively changed from individual mass to fractions of the total concrete mass, which is more use-able at the input level. Altered along these lines, the impact for cement aggregate production is further broken down as follows:

$$C = \sum_{i=1}^n \alpha_i u_i R_i + \sum_{j=1}^n \beta_j v_j v R_j + \gamma \delta + T_r \quad \text{Eq. 3}$$

Where R_{ij} represents the ratio of each cement and aggregate type such that $\sum_{i=1}^n R_i = 1$ and $\sum_{j=1}^m R_j = 1$. The coefficient u_{ij} , v_{ij} , & δ are the ratio-to-mass conversion constant for binder, coarse aggregate, and fine aggregate based on the overall density of concrete and the weight ratios between binder, aggregate, and water determined in the pavement functional unit. The values of ratio to mass conversion constants are given in Table 14 and the values were derived from the stated functional units.

Calculation

To validate the importance of the simplified model for the LCA, CO_{2e} emission (kg) per functional unit were modelled, using the impact factor constants determined from LCA case studies as reported in Tables above. The weighted model for one highway mile (6458 tons) of concrete is as follows: (note: k_f is a constant for the conversion to the function unit: $k_f = 6.458 \times 10^6$ kg/highway mile).

$$I_{CO_2e} = \frac{k_f C}{SL} \quad \text{Eq. 4}$$

Where I_{CO_2e} is, the impact based on the CO₂ emission, K_r is a constant, and C is the summation of the constituent material and transportation and SL is the viable service life of the concrete. It was reported in the study of (Sharma et al, 2016) that the European Commission figures estimate that the carbon emissions from different aggregate minerals transport options are approximately: 0.00016kg CO₂e (3.527 E⁻⁴ lb CO₂e) / kg / km for road, 4.1E⁻⁴ kg CO₂ (9.04 E⁻⁴ lb CO₂e) / kg/ km for rail and 2.5 E⁻⁵ kg CO₂ (5.5 E⁻⁵ lb CO₂e) / kg/ km for water (inland or coastal). The average transport for aggregates by road delivery is 50 km (31.0686 mi), rail delivery is 150 km (93.2057 mi), and barge delivery 90 km (55.9234 mi). In this model, the emission factor due to the transportation of aggregates from the quarry to the batching plant and transportation of concrete to the site is considered.

Table 13. Impact Model Coefficients

Coefficient	Impact Factor	Per-Weight Impact (Kg CO₂e/Kg)
α_1	Portland Cement	0.5190
α_2	Slag	0.0265
γ_1	Coarse Aggregate	0.0037
β_1	Fine Aggregate	0.0025
β_2	Foundry spent sand	0.00125
T_r	Transportation	0.0019

Table 14. Ratio to Mass Conversion Constant

Coefficient	Value/ Explanation	Source
U_i	0.1538m ³ /kg binder material	Calculated from functional unit: $\rho = 2400\text{kg/m}^3$ concrete, 13.33% binder in mix
δ	0.4615m ³ / kg coarse aggregate material	Calculated from functional unit: $\rho = 2400\text{kg/m}^3$ concrete, 40% coarse aggregate in mix
V_i	0.3077m ³ / kg fine aggregate material	Calculated from functional unit: $\rho = 2400\text{kg/m}^3$, concrete, 26.67% in mix
R_i	Volume ratio of i binder and j aggregates in mix design s.t $\sum R_i, \sum R_j = 1$	Input variable - determined by user of model
k_f	6.458 kg/ functional unit	FU conversion constant

Table 15. Traditional mixture and Concrete with different ratios of FSS and Slag

Mix	Description	$R_{PCement}$	R_{slag}	R_{NCA}	R_{NFagg}	R_{FSS}
Controlled	Traditional mix	1	-	1	1	-
FSS30	FSS 30 % replacement	1	-	1	0.7	0.3
FSS40	FSS 40 % replacement	1	-	1	0.6	0.4
FSS50	FSS 50 % replacement	1	-	1	0.5	0.5
Slag20	Slag 20% replacement	0.8	0.20	1	1	-
Slag25	Slag 25% replacement	0.75	0.25	1	1	-
Slag30	Slag 30% replacement	0.7	0.30	1	1	-
Slag35	Slag 35% replacement	0.65	0.35	1	1	-

$R_{PCement}$ - Ratio of Portland cement, R_{FSS} - Ratio of foundry spent sand, R_{NCA} - Ratio of natural coarse aggregate, R_{NFA} - Ratio of natural fine aggregate, R_{slag} -Ratio of slags

The Table.15 above shows the impact of substituting one constituent of the traditional mixture at one substitution percentage in different mixtures. Keeping in mind the end goal to set up a standard for correlation, estimating the impact of a traditional Portland cement concrete mixture which is called the control without any substitutions of cementitious material such as slags ($R_{\text{portland}}=1$, $R_{\text{slag}}=0$) and the utilization of 100 percent virgin fine and coarse aggregate to represent concrete mixture was made. After which, the estimation of impacts of the mixture at different replacement level such as replacing the fine aggregate with FFS at a replacement level of: 30%, 40%, 50% and replacing the traditional Portland cement with slags as a cementitious material at a replacement level of 20%, 25%, 30% and 35% respectively was made and the impact for each replacement level was recorded. The impact calculated in Table. 15 above was based on a 39 years' service life of one highway mile as reported in the study of (Sharma et al, 2016), that various U.S state transportation departments determined an average service life of this kind of pavement to be 39 years.

The information in Table.16 below, demonstrates concrete mixtures with the replacement of Portland cement and coarse aggregate with FSS and slag respectively at different percentage in the same mixture. The mixture was modified to test the model and ascertain the impact of replacing fine aggregate and traditional Portland cement with Foundry spent sand and slags in the same concrete mixture. In the modified concrete mixture, Portland cement was replaced with slags at a replacement level of 20%, 25%, 30%, 35% and 50% respectively and the natural fine aggregate was replaced with Foundry spent sand at a replacement level of 40% and 50%. In addition, the impact calculated in Table. 16 below, was based on a 39 years' service life of one highway mile

as reported in the study of (Sharma et al, 2016), that various U.S state transportation departments determined an average service life of this kind of pavement to be 39 years.

Table 16. Concrete mix with different ratios of both FSS and Slags

Mix	Description	RPtCement	RSlag	RNCA	RNFagg	RFSS
A	Traditional mix	1	-	1	1	-
M_{20/40}	Slag 20% + FSS 40 % replacement	0.8	0.20	1	0.6	0.4
M_{20/50}	Slag 20% + FSS 50 % replacement	0.8	0.20	1	0.5	0.5
M_{25/40}	Slag 25% + FSS 40 % replacement	0.75	0.25	1	0.6	0.4
M_{25/50}	Slag 25% + FSS 50 % replacement	0.75	0.25	1	0.5	0.5
M_{30/40}	Slag 30% + FSS 40 % replacement	0.7	0.30	1	0.6	0.4
M_{30/50}	Slag 30% + FSS 50 % replacement	0.7	0.30	1	0.5	0.5
M_{35/40}	Slag 35% + FSS 40 % replacement	0.65	0.35	1	0.6	0.4
M_{35/50}	Slag 35% + FSS 50 % replacement	0.65	0.35	1	0.5	0.5
M_{50/50}	Slag 50% + FSS 50% replacement	0.50	0.50	1	0.5	0.5

5. RESULTS AND DISCUSSION

Life Cycle Impact Assessment

In Tables 15 and 16 above, the impact of each mixture was calculated by substituting the values of the mixture ratios and GHG per-weight coefficients determined into Equation 4 and the values of each mixture was analyzed individually. In the Figure 5. below, the results from analyzing the impact recorded from the calculation made in Table. 15 which contains the traditional mixture(control) with three mixtures containing different replacement of fine aggregate with foundry spent sand at different replacement level of (30, 40, AND 50%) and four separate mixtures containing Portland cement being replaced with slags at a replacement level of (20, 25, 30 and 35%) was reported.

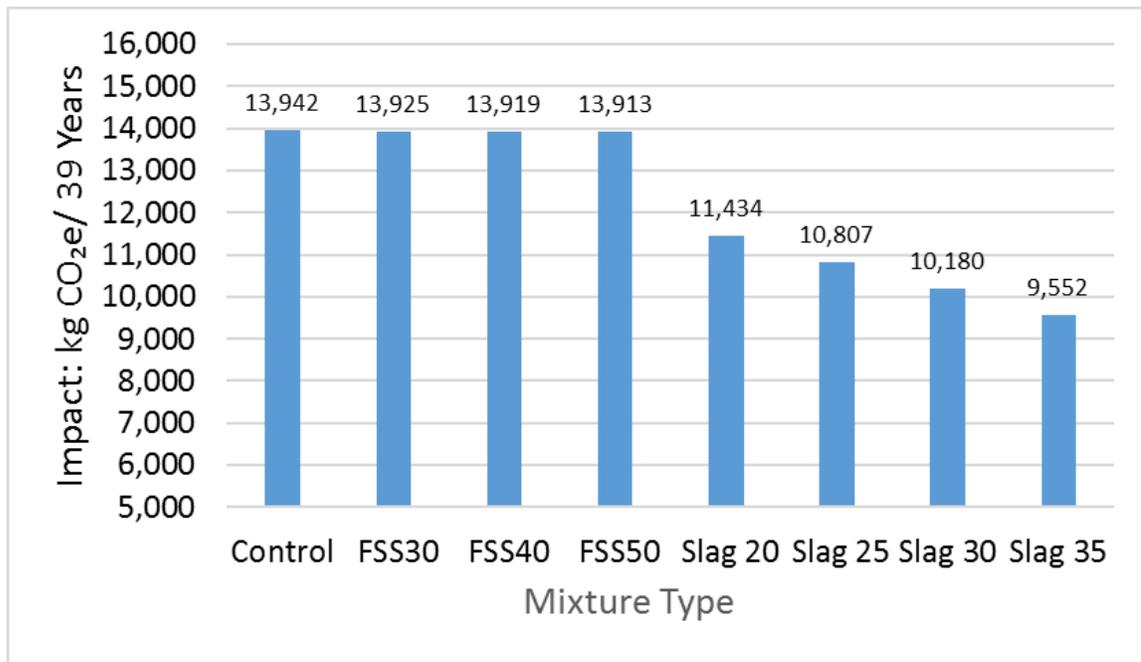


Figure 5. Impact of Concrete mix with FSS and Slag

In the figure.5 above, various replacement level of fine sand with foundry spent sand and different level of replacing Portland cement with slags was reported and it shows that replacing fine-sand with foundry sand is very efficient but the CO₂e reduction

is very little and almost insignificant. The mixtures with the foundry sand shows almost the same CO_{2e} impact as the control mixture with 100% fine sand. Even if there are no significant amount of GHG emission impact reduction with the use of foundry sand, the cost of producing and processing natural fine aggregate would be minimal and the use of foundry sand can help preserve natural resources and avoid waste disposal because used foundry sand is considered a waste in the foundry industry and re-using it in concrete helps to also promote recycling which in turn would save but the concrete and the foundry industry time and money. Although, many studies have reported the use of foundry sand as a supplementary cementitious material (SCM) for concrete to replace Portland cement alongside slags and fly-ash but for the scope of this study our focus is on replacing foundry sand with fine aggregate in concrete. Looking through the other part of figure. 5 where Portland cement was replaced with different percentage level of slags, it shows that the higher the replacement level of Portland cement with slags in a mixture, the lower the GHG emission impact. This correlates with the proven fact as reported in a study of (Leeuwen, Kim, & Sriraman, 2016) that Portland cement accounts for 91% of CO_{2e} in concrete due to the high emission produced in the kiln because of the calcination process in cement production. Although the production of slags also generates GHG emission, but the impact is very minimal as compared to Portland cement. Utilization of slags to partially replace Portland cement does not only help reduce the environmental impact (GHG emission impact) but it also helps promote recycling and cost reduction.

The Figure 6. below show, the results of the analysis of mixtures containing both Portland cement replacement with slags and fine aggregate replacement with foundry spent sand in the same mixture as reported in Table16. above. It is obvious from the

results that there is a reduction of GHG because of the combined substitute materials in the same mixture.

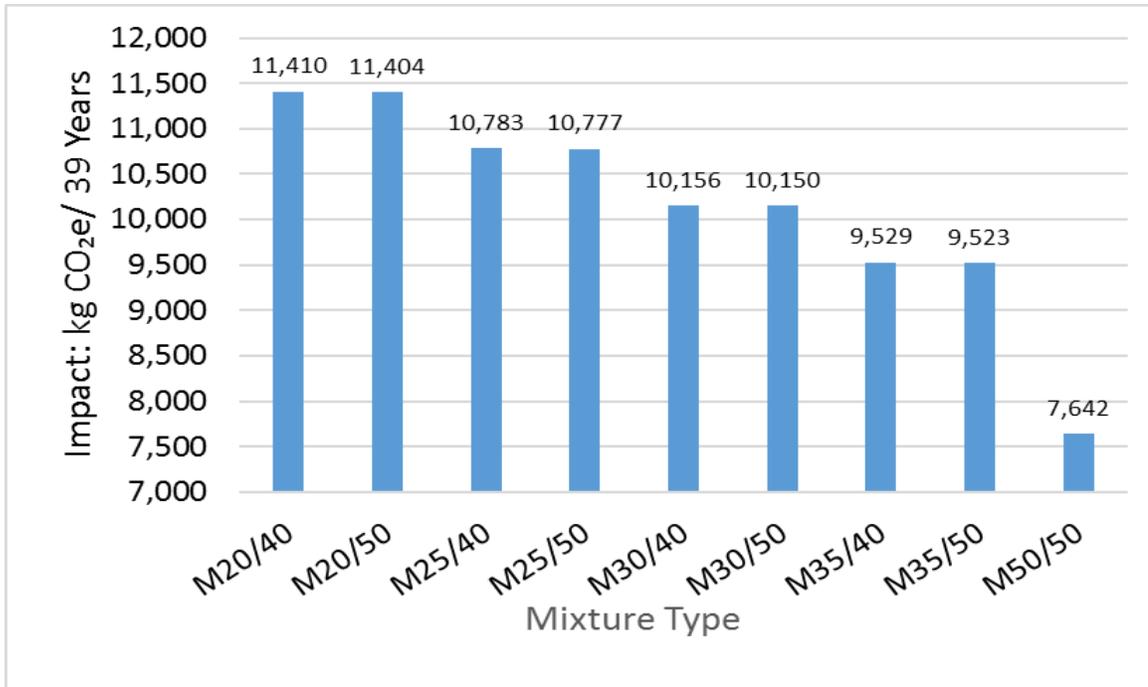


Figure 6. Impact of Concrete mix containing variable ratio of Slags and FSS in the same mixture.

The figure 6. above, shows a steady downward trend with the increase in both the substitute materials (slags and foundry sand). There is a distinct reduction in CO₂ emission in the replacement level of M_{50/50} with 50% replacement of slags and 50% replacement of foundry sand as compared to the control mixture. In addition, there is a noticeable reduction in the CO₂ emission in the mixture M_{35/40} and M_{35/50} with replacement of 35% replacement of slags and 40% and 50% replacement of foundry sand as compared to the control mixture. It was noticed in the results as reported in figure 6. that at a constant replacement level of slags and variable replacement levels of foundry sand, there is a very little difference in the GHG emission impact. This is due to the fact that most of the CO_{2e} in concrete is from cement therefore getting the right replacement

level for cement with slags in concrete is paramount. In order to further demonstrate the little noticeable difference in the GHG emission impact of the replacement of fine sand with foundry sand, an additional analysis was completed on the traditional mixture with 20% Portland cement replacement with Slags and 0 - 100% fine aggregate replacement with foundry sand in 10% augmentation as shown in Figure 7.

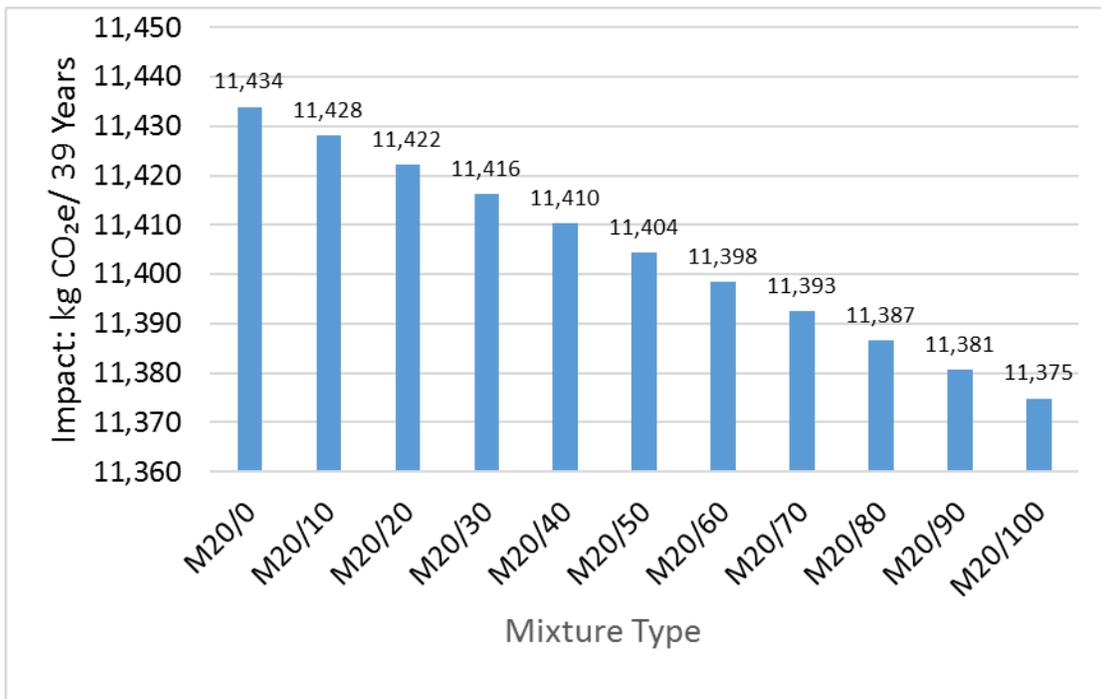


Figure 7. Impact of Concrete mixture with 20% slag and 0-100% FSS replacement

In the Figure 7 above, there is a steady decrease in the GHG emission impact as the replacement level of fine aggregate with foundry sand increases at an increment level of 10% and a 20% constant replacement level of Portland cement with slag in the same mixture but the rate of decrease in the GHG emission impact is very little. This little impact difference provides a supporting evidence that cement plays a huge role in GHG emission impact in concrete. Although there is a reduction in the GHG emission impact because of replacement of fine aggregate with foundry sand but the difference is not large

compared to the variable replacement of Portland cement with slags. Therefore, while considering the life cycle impact of concrete, the use of SCM materials to partially replace the high emission impact materials is very necessary

In this study, our focus was a service life of 39 years, but analyzing the effect of variable service life on the impact of concrete mixtures would give a better view of the dependency. To analyze the effect, service life of concrete from 1 to 39 years at a constant C value of the traditional mixture was investigated and the effect was reported in the Figure 8 below.

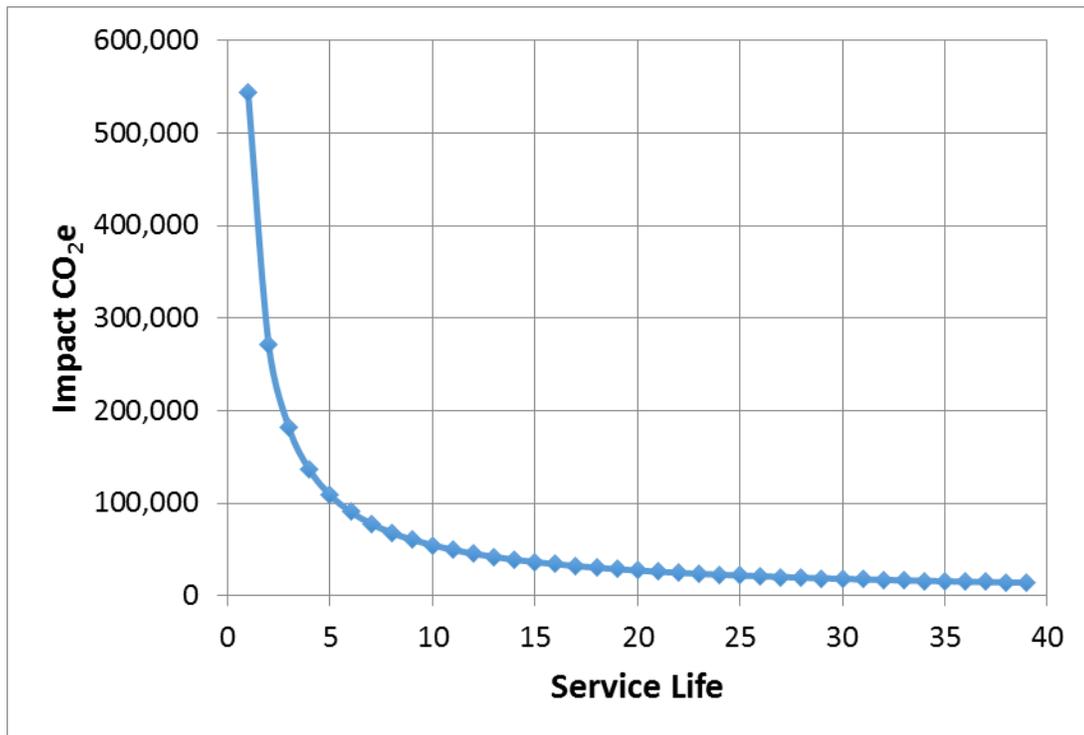


Figure 8. Traditional mixture impact of a service life from 1 to 39 years

The Figure 8 above was calculated using Eq. 4 at a constant, C of the traditional mixture value and variable service life (1-39 years) and as shown above, there is an observed decrease in the impact of emission as the service life increases. From a service

life of 1 to 2 years, there is a huge difference in emission impact and from the service life of 5 to 39 years there is a steady decrease. This gives an inversely proportional indication that as the service life of concrete increases, the emission impact decreases. Therefore, replacing the traditional concrete mixture with sustainable materials (slags and foundry sand) will show a further decrease in emission impact as the service life increases. With this analysis, it will be reasonable to conclude that an extended service life of concrete will help conserve resources by reducing maintenance and the need for consistent reconstruction as well as environmental impact.

Sensitivity Analysis

In this study, our independent variables are the inputs (Portland cement, fine and coarse aggregate) and the service life and the dependent variable is the GHG impact emission. It was observed that the variable adjustment or manipulations of the inputs (Portland cement, fine aggregate) and the service life of a traditional concrete has an effect in the GHG emission impact of the concrete. The higher the replacement ratio of Portland cement and fine aggregate with slag and foundry sand in concrete, the lower the GHG emission impact. It was also revealed that the longer the service life of concrete, the lower the environmental impact, since it will reduce the need for production and utilization of cement.

6. CONCLUSION AND RECOMMENDATION

Conclusion

Going through the entire investigation and analysis in this study, it might be logical to conclude that reduction in the environmental impact of the concrete production through the substitution of some its constituents with more sustainable materials can easily reduce the industrial impact globally. The replacement of Portland cement and natural fine aggregate with slags and foundry sand in concrete allows various environmental advantages including the reduction of embodied GHG emissions and depletion of natural resources. The use of foundry spent sand and slags in concrete helps promote recycling and reduction in cost of production. The simplified model discussed in this paper is an example of a potentially useful tool for rough LCA impact estimation when contrasting the evaluating impacts of different ratios of slags and foundry sand as concrete inputs that are promptly accessible to end users. The data from result of this study clearly demonstrates that replacing the cement content with slags ultimately brings down the GHG impact when compared to a traditional mixture. However, it also shows that the difference in GHG impact reduction because of replacing natural fine aggregate with foundry sand is very insignificant as compared to the traditional mixture. The results from the investigation of the mixture with both slags and foundry sand in the same mixture provides proves that GHG impact emission is achievable with the use of these sustainable materials although when the replacement of Portland cement was kept constant at 20% and the slags replacement varied from 10-100% the difference in the emission impact was very negligible because of the known fact that majority of the emission impact in concrete comes from the use of cement. The result from this study

also reveals that the increase in service life of concrete leads to a decline in the environmental impact, since it will reduce the need for production and utilization of cement which will in turn help conserve natural resources by reducing maintenance and the need for reconstruction. These analyses, provides evidence to postulate that concrete service life is particularly a critical factor in determining the overall LCI of concrete. The use of this simplified model will permit viable and reasonable impact studies to be produced, which will aid in an enhanced sustainable design and construction. The model discussed in this study was used to demonstrate the impact of just a few alternative concrete constituents but it can also be used to develop a model to evaluate the impact of other SCM binders, which can be used throughout the industry.

Valuation and Recommendation

Considering the result from this study as well as several similar studies, it is of no doubt that, the use of slags in concrete mixtures can help reduce the global GHG emission. The current increase in use of slags in concrete bolsters sustainable construction and promotes recycling because slags is considered a waste in the foundry industry. It should also be noted that partially replacing Portland cement with slags in concrete does not reduce the durability or strength of the concrete as long as a certain proportion is maintained with the type of concrete being produced. The use of foundry sand in concrete also helps promote sustainable construction and recycling as well as reducing the GHG emission impact even though the difference as compared to fine aggregate GHG impact emission is not large. The continuous use of foundry sand would help reduce the cost of production of fine aggregate since it can be replaced with foundry sand without hindering the concrete quality. For the scope of this study, foundry sand was

used as a partial replacement of fine aggregate but there have been several reports that foundry sand can also be used as SCM to replace Portland cement, further investigation about the use of foundry sand, as SCM would be recommendation for future study.

Additionally, our focus in this study was on GHG emission in CO_{2e}, but there have been several arguments by scholars regarding the intake of atmospheric CO₂ by concrete. In a study by (Pade, 2007) an intrinsic property of Portland cement based concrete was reported which shows that about 50% of the CO₂ released during concrete production is reabsorbed upon exposure to air during its life cycle and the process is termed carbonation. The author further reported that the carbonation will occur during the service life of a concrete structure, as well as after demolition. A lot of published studies on the carbonation of concrete have focused mainly on durability issues, only a few studies have focused on the balance between CO₂ emissions and CO₂ uptake in the life cycle of concrete. For future studies, an expanded simplified model of concrete that will include the emission and absorption CO₂ should be investigated.

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