ACHIEVING A SUSTAINABLE CONCRETE DESIGN AND CONSTRUCTION

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ABSTRACT

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Concrete is one of the key materials in the construction industry. But today, the use of concrete and its production has become a matter of environmental concern throughout the world. This statement is true especially for the manufacturing process of cement. One of the major problems is emission of CO_2 gas into the atmosphere during the manufacturing of cement. Every ton of concrete produced leads to emission of one ton of carbon dioxide gas. Hence replacement of cement by alternative materials has been investigated by many researchers.

In the past, fly ash has been the most common replacement. This study, however, suggests replacing all the major components of concrete to the extent that would satisfy the standard strength requirements. This paper focuses on the development of a sustainable or green concrete and proposes a set of tools for a sustainable concrete design and construction. Many researchers have been trying to replace one component of concrete to make it more sustainable. Discussion in this paper will not only give a direction to produce more sustainable concrete but also eco-friendly concrete, thus addressing the two important issues of economy and environmental friendliness simultaneously.

Defining the idea of sustainability with respect to the concrete and construction industry and doing a literature search on similar grounds was the first step taken towards completion of this research. The findings in the literature search made a survey necessary. This survey was done to have an idea of sustainability from the experts in the construction and cement industry. The survey was done by sending a questionnaire to concrete experts,

engineers, designers and contractors to get their ideas for green concrete and its usage in the industry. The findings of the literature survey and inferences from the survey results made the generation of the proposed sets of tools possible.

The concrete and the construction industry can achieve an overall sustainability by complete utilization of tools proposed in the paper. Strict usage of these tools will not only ensure environmental sustainability but will also satisfy the ends of economic and social aspects of sustainability.

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DEDICATION

This paper is dedicated to my family and friends.

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1. INTRODUCTION

Concrete is one of the prime materials of the construction industry and has cement as its major component. Few structures today can be built without concrete. However, production of cement has many environmental issues associated with it. Carbon dioxide emitted in large quantities during the production of cement strongly contributes to the greenhouse effect and to global warming. Various reports released by the United Nations in relation to climate and its changes have indicated that global warming is already occurring at a pace which could have irreversible and devastating effect on the earth's atmosphere. Currently carbon dioxide (CO_2) alone contributes about 80-85% of greenhouse gases. According to "IPCC" (Intergovernmental Panel on Climate Change) the emissions of this carbon dioxide gas should be controlled and emission rates should be brought down to the level of 1990's or less in the next 20 years. Hence the governing agencies and cement manufacturers worldwide are making decisive measures to achieve a significant reduction in the global carbon dioxide emission rate by 2030 (P.K.Mehta, 2009).

In order to achieve this target by 2030, researchers plan to replace a portion of cement with some other pozzolanic material or materials having pozzolanic properties. One of the immerging and most popular concrete technologies for sustainable development is to use "green" materials in concrete. The "green" materials use fewer natural resources and energy and generate less CO_2. These green materials are durable, recyclable and require very less maintenance. Currently, flyash has been seen and used extensively as a possible replacement .But there are many other ashes which can be used. One such ash is "Pond /Lagoon Ash", which is basically a residual ash obtained after screening of flyash from the residual waste obtained from the thermal power plants. It has a high content of carbon and is very fine, and so it has to be dumped in artificial ponds or lagoons.

The second component of concrete are aggregates which are naturally occurring materials. River sand is used for fine aggregates and crushed stones or rocks are used for coarse aggregates. However, in order to limit the dependability on aggregates some replacements for them have been tested. The possible replacements for fine aggregates are foundry ash and crushed glass powder. Coarse aggregates can be replaced by the waste obtained from the ceramic industry, crushed bricks and demolished concrete. In the ceramic industry about 30% of production ends up as waste, which is not recycled at present (R.M.Senthamarai, P.Devdas Manoharan, 2005).

Current researches have been focusing on replacement of one component of concrete. At the same time these researches majorly target economic sustainability. This new study is necessary to look beyond these researches to attain the overall sustainability of concrete and construction industry. This paper proposes ways of achieving the overall sustainability of not only concrete but the concrete industry as a whole. The focus is on the disadvantages of cement production on the environment, future prospects of the concrete industry from an overall sustainability point of view. An attempt to study and propose the suitability of pond ash, ceramic industrial wastes, crushed glass powder and foundry sand as replacements for the various components of concrete has also been made.

2. METHODOLOGY

This paper aimed at attaining the overall sustainability of the concrete/cement industry. Sustainability being a very vast subject needed this paper to have a well defined framework to move along. Hence, some steps were determined to have a proper flow to this research. These steps are as follows:

- Defining sustainability and identifying issues related to sustainability of cement, concrete and construction industry.
- Gathering the maximum information on this topic through and extensive literature search.
- Based upon the information from the literature search, a survey was done to know about the current scenario about green materials and its use in the cement and construction industry.
- Compiling the data and then proposing a solution to ensure overall sustainability of construction industry.

The first step was to define sustainability and identify the sustainability issues related to cement, concrete and construction industry. This included studying sustainability issues related to every single component of concrete, i.e. cement, aggregates and water. Then a literature search was done to collect as much data as possible about the current trends of research in the concrete industry. An effort was made to understand the global effect of this industry. Research was conducted to study the previous attempts that have been made to achieve sustainability, and the contribution of those attempts towards attaining overall sustainability (including environmental, economical and social) was evaluated. However, from the collected data it was observed that researchers discussed replacing either cement or aggregate in concrete, but each of these replacements was proposed individually. So the idea originated to develop a concrete with all of its components replaced to some extent with waste or substitute material. This shifted the original direction of data collection and analysis. Data was collected with reference to every component of concrete. Then after having done the literature survey, the next step was to compile the data. This obtained data was compiled accordingly and an effort was made to address the issues related to every component of concrete individually.

A survey was also conducted to address both the short and long term sustainability requirements of the concrete industry. A questionnaire was sent out to experts in the concrete industry including professionals related to production of cement, aggregates and the concrete as a whole. The ideas of the engineers and designers using the conventional concrete were also taken into consideration. The responses obtained helped in knowing the future of green concrete and the approach to be adopted to promote its use. The proposed solution or process addresses all three major components of sustainability (environmental, economic and social).

3. LITERATURE

Researchers have been successful in defining sustainability and have also been in a long debate of how to attain it without compromising the pace and technology of development. Economic sustainability was more important than environmental and social factors, and so researchers focused their interest on and tried to attain that sustainability. Later after the declaration of the Kyoto protocol which was set for binding targets on various industrialized countries to cut down the emission level of their green house gases, environmentalists and the United Nations started to warn the world about the irreversible climatic changes occurring. Researchers then shifted their area of focus towards environmental sustainability. At the same time less has been done for social sustainability, which is the final key component to achieve overall sustainability.

3.1. Environmental Issues Related to Concrete Industry

The production of cement and the related carbon dioxide emission is a major concern for the environment worldwide. A total amount of carbon dioxide emitted into the atmosphere worldwide in 2002 was about 21 billion tons (Malhotra, 2004). The major contributors in 2002 were:

Table 1: Major carbon dioxide emitting countries in the year 2002 (Malhotra, 2004)

Country	**Percent Emission**
United States of America	25
European Union	20
Russia	17
China	>15
Japan	8
India	>10

Each ton of Portland cement production leads to the emission of approximately one ton of CO_2. Cements which are lately used in the construction process contain almost 85% of Portland clinker. Production of one metric ton of clinker emits 0.9 metric tons of carbon dioxide into the air. The contribution of carbon emission by the concrete industry can be signified by the fact that in 2007, nearly 2.77 billion tons of concrete consumption was recorded by the concrete industry. It is expected that the demands for Portland cement in the world will double in about 25 years. (P.K. Mehta, 2002).

Environmental problems generated due to the CO_2 emissions during the production of ordinary Portland cement, depletion of raw materials and their sources, high energy demand of nearly 6 million BTU for per ton production, and economical issues because high cost of manufacturing plants calls for replacing and substituting materials like flyash or pond ash. Every ton of Portland cement clinker production, leads to emit about 1.4 to 9 kg of NO_x (nitrogen oxide) into the atmosphere. In 2000, the worldwide cement clinker production was approximately 1.6 billion tons (Malhotra 2004).

Considering the above concerns use of substitute materials and more efficient and environmental technologies should to be developed.

3.2. Economical and Social Issues with Concrete Industry

Economical and social issues are also important aspects from a sustainability point of view. But in recently economical issue has been more concentrated upon while environmental and social issues are neglected. For example, limestone is the major component for cement manufacturing and its deposits all over the world are depleting so their availability will be an issue in years to come. Some parts of the world have already started suffering this problem. The production of Portland cement will not be possible without sufficient limestone deposits and then the immediate problem will be the employment of the people associated with the cement production industry. The seriousness of this issue can be well understood with the fact that in the USA alone, concrete construction provided for about 2 million jobs in 2002 (H.R. 394 2004). At the same time the concrete production worldwide was 2.7 billion m^3 which is almost 0.4 m^3 of concrete produced per person annually (Tarun R. Naik, 2008).

Other raw materials required for cement and eventually concrete are also naturally occurring which will eventually get depleted. For every ton of cement production , 1.6 tons of raw materials is consumed (Wu 2009). Therefore to manufacture the current worldwide production of 2.5 billion tons of cement annually, almost 4 billion tons of raw materials will be required. This issue is very important and requires immediate attention. Therefore use of environmental friendly materials becomes more urgent.

3.3. Sustainability

Sustainability means the ability to support and it aims at sustaining life for the continued growth of a society and human development. World Commission on Environment and Development of the United Nations has defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (UNFCCC COP9 Rep.2004). Environment, economy, and society are the three major components of sustainability and to attain overall sustainability, these three components remain balanced. Currently, environment being the concern, for engineers worldwide the term sustainability means having no adverse or negative impact construction materials. These are the issues needed to be seriously considered by the engineers and architects while planning and building a structure, and these are the issues the paper addresses in here.

3.4. Sustainability of Concrete

Concrete is a product obtained from the mixture of fine and coarse aggregates, cement, water and some chemical admixture and it often contains a mineral admixture replacing some portion of the cement. A concrete mix majorly consists of large portions of aggregates (both coarse and fine), a medium amount of cement and water, and some contribution of admixture. Almost all of these materials are either naturally occurring (mined from the quarries), manufactured or an end product of any manufacturing process. Hence, to study the sustainability of concrete, sustainability of each of its component materials should be studied individually.

3.4.1. Portland cement

Ordinary Portland cement is the most common and basic material used in the production of concrete. Engineers must reduce its use in concrete (Malhotra, 2004), and must use more blended cements, especially with chemical admixtures. This is because Portland cement is made by using limestone i.e. limestone→ crusher → grinder → cement (Worrell and Galtisky, 2004). The problem here is that, some regions in the world are reported to be running out of limestone deposits.

Manufacturing of Portland cement is done by heating a mixture of limestone and shale to a temperature of 1870° C (3400 ° F), then grinding the obtained red hot marble-sized substance (commonly known as clinker) with gypsum to form a fine powder once the clinker is cooled. The reaction between limestone and shale to produce clinker produces CO_2. Noticeable amount of gaseous waste majorly of CO_2 and CO are produced due to the combustion of fuel used in the kiln. These gases contribute to global warming. Amongst the carbon dioxide emitted worldwide, the cement production accounts for nearly 5-8%. Looking at the current rate of increase in cement production (USGS 2006, 2007), the expected increase will be from about 2.5 billion ton in 2006 to about 5 billion ton by 2020. This indicates that the increase in the cement production will be nearly doubled, thus doubling the CO_2 emissions. For every ton of Portland cement clinker produced, 1.5 to 10 kg of NO_x is released into the atmosphere. In the USA alone, the clinker production was about 85 million t in 2005 (PCA, 2006); and therefore about 125 to 850 thousand t of NO_x were generated in the production of Portland cement. As per Malhotra, 2004, the following process in the manufacturing of Portland cement contributes the relative percent of carbon dioxide and other greenhouse gases:

- From Calcinations of limestone = 50-55%
- From fuel combustion = 40-50%
- From use of electric power = 0-10%

3.4.2. Aggregates

Apart from cement, aggregate and water are also important components of concrete. "Assuming an average of 0.6 water cement-ratio and 75% aggregate content by mass, nearly one billion tonne (1 trillion liters) of drinking water and 8 billion tonnes of sand and gravel or crushed rock are being consumed worldwide for concreting every year" (T. R. Naik and G. Moriconi, 2005). The aggregates are obtained by mining from the quarries or dredging from the river bed or banks. Aggregate such as recycled concrete that occur as a by-product of other process are also used. Aggregates are crushed, and may be washed or dried depending upon their use and where they are obtained. They are usually sieved so as to classify them into various required sizes. Every of these processes consume a good amount of energy and the waste generated from these processes are mostly water and dust. Water can be recycled or reused for operations. Dust is a matter of concern as most of the times it is just washed away by wind or water as it is very fine and light, thus giving rise to environmental hazards.

Obtaining and using these coarse and fine aggregates has many issues from the environmental sustainability point of view. These materials are non-renewable and extensive use of these materials will lead to their depletion. Economy and sustainability issues can be addressed if these materials are available locally. But on the other hand if they have been carried from a distant location, many environmental and economical sustainability issues are generated. Some parts of the world have abundant sources of rocks and stones which ensure easy availability of aggregates for them. But at the same time some places have to import these sources from distant locations to meet their needs. As per the environmental sustainability report of HIS published in 2009, the state of California has already reported of importing aggregate materials from other countries, such as Canada and Mexico, to meet its demand for crushed stone. The energy spent by the vehicles in carrying these materials from one place to another is enormous and at the same time the emissions from these vehicles lead to green house gases emissions. Also, transporting of aggregates is not sustainable from economical standpoint as it promotes burning of a valuable non renewable source of energy. Dredging of sand from the rivers is affecting the river water level. Countries like India where sand is mostly obtained from river dredging are already facing problems with the lowering of river beds, which in some way is affecting the flora and fauna of the water bodies. The water used for washing of aggregates is leading to water pollution.

To overcome all these issues it is important to promote the use of aggregates (natural, artificial or substitutes) that are available locally. Even today design and construction codes have been specifying the use of a specific type of aggregates for construction. This practice needs to be changed, and use of locally available materials, recycled concrete aggregate or other substitutes should be encouraged. Anyhow the practice of taking trials of concrete before finalizing its design is still prevalent in the industry. Hence design of concrete with locally available materials should be encouraged and the same concrete should be tested before putting it into use in order to be on the safer side. This will limit the dependency on the naturally occurring aggregates, which are associated with large environmental and economical costs of their exploitation and transport. Also the issue related to the landfills of waste materials can be addressed by recycling these waste materials and reclaiming the land for other uses.

3.4.3. Water

Water is also extensively used in concrete industry. It is used for mixing of dry concrete and is also used for washing of aggregates in ready mix concrete. As per the studies of T R Naik, 2008, even if 0.6 water-cement ratio is considered, almost one trillion liters of drinking water is being consumed in a year. This makes it a matter of concern for the parts of the world facing water scarcity. Ordinary tap water is generally used in concrete. This tap water is obviously fresh water. Fresh water resources in the world are abundant for now, but already some parts of the world have started facing the problem of water scarcity

(Hawken et al., 1999). Out of the total 70% of water resource on the planet, just 3% is fresh water, most of which is concentrated in the Polar Regions in the form of the ice glaciers and as groundwater, deep below the earth's surface.

Water in the construction industry has a wide variety of usage. It's the key component for production of concrete. Use of potable water in the production of concrete has been recommended by the construction practice codes (P.K.Mehta, 2001). Water pollution is another environmental pollution issue related to the concrete industry. This adds to the list of environmental sustainability issues of the concrete industry as a whole. This pollution comes in the form of washout water used for production of ready mix concrete. Another major contributor is the curing procedure and the practice of washing the concrete trucks and related equipment. This washout water is reported to have a high amount of pH value, even as high as 12. This water when drained into the rivers can prove to be harmful for aquatic life and plants. The use of water in the concrete industry can be estimated from the fact that about 100 L/ m^3 of wash water are consumed by the ready mix concrete trucks (P.K. Mehta, 2001). Environment Canada estimates that the water use at batching plants is at about 500 gallons per truck. Total water used by the British concrete industry alone is over 12 million cubic meters (excluding the water used in admixture production). As per P.K. Mehta, 2001, yearly consumption of water in the concrete industry for mixing is around 1 trillion liters.

Water is a precious resource and therefore has to be used wisely. Being one of the major consumers of water, the concrete industry has to search for alternatives for water or devise plans for less and smarter use of water. Reduction in water use can be achieved by proper aggregate gradation and use of water reducing admixtures. As per UK cement admixture association, if even 10% of water reduction is achieved, it can save about 600,000 cubic meters of water used by the concrete industry every year. The world consumption of water can be reduced to half, if the use of water reducing agents, mineral admixtures and super plasticizer is encouraged. Industrial waste water can be used to produce concrete, unless proven otherwise. Similarly, water for the processes like curing and washing can obviously be recycled and used or rather waste water can be used for such applications. The concrete industry worldwide has now been trying to promote the use of composites with dual properties of water absorption and impermeability. One such composite is the textile composite, which has water absorbent fabric on the interior and impermeable membrane on the exterior and which can be used for curing and thus reducing water consumption (P.K. Mehta, 2001).

4. ALTERNATIVE MATERIALS

Alternative materials are referred to as the materials that can be used as the replacement for the conventional materials in concrete. These materials can be used for replacing any component of concrete including cement and aggregate. Cement is replaced by fly ash or pond ash, whereas the possible replacement for aggregates can be the waste from ceramic industries and debris generated from demolition of the concrete structures.

4.1. Possible Replacements for Cement in Concrete

Cement is the component of concrete that is being targeted today for the environmental nuisance caused during its production. Many researches recently have studied the behavior of concrete with the use of supplementary materials such as the flyash and the ground granulated blast furnace slag. The cement consisting of a combination of regular ordinary Portland cement (OPC) and supplementary pozzolanic/cementatious material is known as blended cement. Advantages of using blended cements in concrete are:

- The performance of concrete with at least one supplementary pozzolanic material is better than the OPC in the long term.
- The concrete with use of blended cement has a better workability.
- As concrete with blended cements have a longer setting time the risk of development of thermal cracks is minimized.
- Blended cement concretes obviously make a use of otherwise waste material and hence they cost less overall as compared to the OPC concrete.
- Though blended cement concretes have a long curing period and longer setting time they develop better durability and long term strength.

The use of blended cement surely is an added advantage for the concrete. These blended cements today majorly use the ashes obtained from the thermal power plants. Recent studies of Rajan Vempati and his group have indicated the possibility of using the ashes generated from the combustion of agricultural waste (Reily M., Discovery News, July 7, 2009). These ashes are studied in detail:

4.1.1. Fly ash

Fly ash, is also known as pulverized fuel ash. Even today the majority of power generation in the world comes from thermal power plants, using pulverized coal as fuel. The annual estimated production of coal ash is about 700 million metric ton, out of which 70% of ash is separated and used as flyash while the other 30% is still a waste which is dumped away in artificially created ponds. The finer fraction of ash, entrained in the flue gas, gets collected in the electrostatic precipitators (ESP) and is referred to as fly ash. The part of class F ash that usually contains 5% of analytical lime. This type of ash is produced from burning anthracite or bituminous coal. It is called low lime fly ash and is another part of class C that usually contains 15% to 35% analytical lime. Burning of the lignite or sub-bituminous coal results in the formation of fly ash. Part of ash that falls at the bottom of the boiler in the form of hot clinker is known as bottom ash. It is crushed before disposal. As a general practice in most countries, bottom ash is mixed with water and transported to the ash ponds/lagoons. The ash thus deposited in lagoons is called lagoon ash (LA) or pond ash. The thermal power plants use low quality mineral coal with average ash content of about 40%. Around 25%-35% of flyash generated and mostly collected in dry condition from ESPs, is presently utilized in the cement, concrete, brick manufacturing and geotechnical applications. The remaining flyash and bottom ash is disposed off in the open ponds/lagoons, creating huge land, water and air pollution. Any effort towards large scale utilization of this ash is welcome and will go a long way in the sustainable development of the thermal power generation industry. One of the effective ways to utilize this waste material, on a large scale, is by partially replacing this ash for cement in concrete in high volumes thereby contributing to the sustainable development of cement and the construction industry as well.

The high volume flyash concrete (HVFA) typically uses only FA. The HVFA concrete contains FA in high volumes, usually more than 50% as a replacement of cement by mass (Bapat, et.al 2006). The HVFA concrete was developed for mass concrete applications, requiring low heat generation. The main aspect of HVFA concrete is its low water/binder ratio of 0.19-0.46, where the binder is considered the sum of cement and FA (Bisaillon et. al.1994).

HVFA concrete has a tainted history because of its inability to perform satisfactorily and gain sufficient strength, drying shrinkage and durability; but this was the outcome of coarser particles and high content of carbon in the ash. This shortcoming was overcome by new and modern thermal power plants which generated the fine ash with low carbon content. The effect of this could be seen on the performance of HVFA concrete using ash from the modern power plants as this concrete required 20% less water content as compared to the conventional concrete thus solving the problem of sustainability of water used in concrete construction. There is still a scope of further reduction in water content by enhancing the grading of aggregates and using the proper super plasticizers. Table No. 2 shows the comparison of mix of conventional concrete and HVFA concrete.

Table 2: Comparison of mixture proportions for 25MPa concrete (P.K. Mehta, 2002)

	Conventional	**Concrete**	**HVFA**	**Concrete**
	By mass **lb/yd^3 (kg/m^3)**	**By Volume** **ft^3 (m^3)**	**By mass** **lb/yd^3(kg/m^3)**	**By Volume** **ft^3 (m^3)**
Cement	517 (307)	2.65 (0.075)	260 (154)	1.33 (0.037)
Fly ash	----	----	260 (154)	1.73 (0.049)
Water	300(178)	4.81 (0.136)	200 (120)	3.21 (0.091)
Entrapped Air (2%)	----	0.54 (0.015)	----	0.54 (0.015)
Coarse Aggregate	1750 (1040)	10.40 (0.294)	2030 (1210)	12.10 (0.343)
Fine Aggregate	1390 (825)	8.60 (0.244)	1300 (775)	8.00 (0.228)
Total	3957 (2350)	27.00 (0.764)	4050 (2413)	27.00 (0.760)
w/c	0.58	----	0.38	----
Paste Volume percent	----	8.00 (0.226) 29.6%	----	6.81 (0.192) 25.0%

HVFA concrete has less water cement ratio therefore, the quantity of cement paste is also less; eventually leading to reduction of cement content in this concrete by 40%-50%. The heat generated during the hydration process is lesser, so thermal cracking even in structures having mass concreting is greatly reduced.

Generally the strength of concrete is measured in terms of compressive strength. The table no. 3 shows the strength gain comparison of OPC concrete and HVFA concrete.

Table 3: Average compressive strength development in HVFA concrete (Bapat, et.al, 2006)

Type of Concrete	**1- day**	**3-day**	**7-day**	**28-day**	**91- day**	**365- day**
Portland Cement	40-50	65-70	75-80	100	110	120
HVFA	20-25	43-48	55-65	100	130-140	150-165

**Average compressive strength as a percentage of 28 day strength

The table shows that the strength gain of HVFA concrete increases gradually after 7 days and the strength gain at 365 days is almost 150-165% over 28 days strength. Hence this justifies the point that this type of concrete cannot be used at places which require early strength. However, after laying this concrete, it is necessary to maintain adequate humidity and temperature regimes to prevent surface drying and resultant plastic shrinkage which can be accomplished by providing windbreaks, fog sprays, evaporation readers, and covering the freshly laid concrete with impervious sheeting. (Bapat, et.al, 2006)

4.1.2. GGBS concrete

GGBS concrete is similar to Portland cement concrete in terms of constituents except for some differences. The best part of this cement is that the ground granulated blast furnace slag can replace the actual cement content by almost 80-85%. This replacement is possible when one uses this slag in ready mix concrete. As per Peter Seymour (Business Development Manager with Ecocem Ireland Ltd), industries in Ireland have come up with the concept of using "Ground Granulated Blast furnace Slag (GGBS)" cement. This GGBS is a molten slag comprised of silicates obtained from the molten iron in the blast furnace. This molten slag is a waste and is not of any use the in steel manufacturing process, hence this slag when cooled is finely ground to form a fine powder used for making GGBS cement. This cement is used extensively in Europe, for example the continental Europe consumes almost 17.7 million tonnes of GBBS cement annually (Construct Ireland article, visited 08/31/2009). This cement has the potential of reducing the CO_2, NO_x and SO_2 emissions by almost 50% as compared to conventional cement. As it replaces the Portland cement, it is also effective in reducing the embodied heat in the concrete by large percentages, thus contributing to a significant increase in the life of concrete therefore meeting the needs of sustainable development. Generally all over Europe, this slag is used to replace cement on a one-to-one basis by weight. This replacement can be anywhere between 30-85% but usually the industries use 40-50% replacement.

The concrete made using this ash has many advantages to conventional ordinary concrete. As per the Construct Ireland article for sustainable future (reference no. 7), the advantages rendered by GGBS cement concrete are:

- Generates higher strength as compared to conventional concrete, but this strength gain is gradual.
- Imparts a smooth finish to the surfaces casted using this concrete and the chances of its staining due to efflorescence is reduced drastically, thus giving an architectural edge over conventional concrete.
- 50% replacement of Portland cement with GGBS slag enhances the concrete resistance against sulphate and chloride attacks, thus not only increasing the life of concrete but also ensuring a good insulation of reinforcement embedded in it.
- Environmental sustainability is achieved by the fact that GGBS is a waste material with pozzolanic properties and is being successfully reused. Replacing cement in concrete leads to the use of less cement, thus indirectly controlling the carbon dioxide emissions that will otherwise occur during cement production.
- GBBS cement production requires very little energy for its production. It uses about 307 MJ (85 kW.hrs) compared to 4000MJ (1100 kW.hrs) used by conventional concrete production. This leads to a total energy saving of almost 3693 MJ (1015

kW.hrs) per tonne. Also, the GGBS cement has only 6-9% of embodied energy as compared to ordinary Portland cement.

From the discussion and advantages above it can be seen that this cement contributes to the overall sustainability requirements of the cement industry. GGBS cement ensures strong and durable structures, thus reducing the dependability on naturally occurring raw materials like limestone for Portland cement manufacturing. The durable structures to be constructed by this cement will ensure enhancement of the structural life span. This will reduce the chances of demolition of the structure due to a shorter life span. This will also reduce the use of aggregates (6 tonnes per tonne of cement) that would have to be used otherwise to reconstruct the structure after demolition.

4.1.3. Rice husk ash

This ash has been attracting researchers worldwide recently, especially in developing countries like China and India, where the consumption of cement and production of rice is increasing. This ash has been studied recently by many researchers.

The annual world rice production for 2007 was 649.7 million tons, out of which the husk constitutes almost 20% (United Nations FAO, 2008). The rice husk is a case that is naturally formed around the kernels of rice. This ash is reported to have high content of silicon dioxide (SiO_2) which is an integral ingredient of concrete. Previously unsuccessful combustion of this rice husk was tried but it was observed that the residual produced had a high content of carbon in it. Hence it could not be used as replacement for cement.

Recently, a group of researchers led by Rajan Vempati of ChK Group, Inc. in Plano, Texas figured out a solution to this problem (Reilly, M., Discovery News, 2009). They suggested that if the husk is heated to 800 degrees Celsius then nearly carbon free rice husk ash is produced.RHA has not been utilized yet in the construction industry, except for some repairing works in the US where it was used in a dry-mix shotcrete to repair the Bowman Dam in northern California's Sierra Nevada Mountains, with positive results (Talend, D., 1997). Mixing rice husk in concrete makes it stronger and corrosion resistant, but there are still many things to be studied in regards to this ash. It has tremendous potential of providing a substitute for cement in concrete because of its pozzolanic properties, but detailed tests and requirements of this ash are yet to be established. This is because the natural composition of rice husk in different parts of the world will be different and hence some common frame of testing and establishing its suitability is required.

4.1.4. Calcium Sulfo Aluminate cement

China has developed cement known as calcium sulfo aluminate (CSA) (Reference no. 8). Unlike blended cement this is rapid hardening cement and can be used for structures like bridge decks, runways, and roadway patching because of its rapid hardening properties. CSA may not be popular, but attention should be given to it as it provides a great deal of advantages over ordinary Portland cement.

Questions have been asked about the urgency of construction and hence constructors justify the use of rapid hardening cement. In OPC the component that is responsible for early strength is calcium trisilicate (C_3S). OPC comprises almost 60% of this component. For every 1000 kg of tricalcium silicate produced almost 580 kg of CO_2 is released. On the other hand, the production of 1000kg of CSA releases 220 kg of carbon dioxide which means almost 350 kg of carbon dioxide emission per 1000 kg of cement is reduced. The savings in emissions is greater than those achieved after replacing cement with substitutes like flyash or ground granulated blast furnace slag. This cement is posing a challenge to the other classes of cements which include Sorel cements (magnesia cement), calcium aluminate cement and cement made using water glass (sodium meta silicate) when compared to carbon dioxide emissions. This type of cement has low alkalinity, low shrinkage and shorter curing time.

However, this cement is twice as costly as to OPC and still much has to be revealed about it which does not make it economically sustainable.. It has restrictions when it comes to placing in hot weather conditions and appropriate quantity and type of retarders are needed to control the setting of this cement. Hence much experienced and highly organized workforce is needed. The CSA cement has to be used under strict supervision and needs a flawless planning and execution when it comes to mixing and placing operations.

4.2. Possible Replacements for Coarse Aggregates

4.2.1. Debris from concrete demolition

Aggregates are generally quarried from the mines. Fine aggregates or sand are obtained by river dredging or from crushing coarse aggregates. But these resources though considered renewable, are scarcely obtained now a days. Some parts of the world are already facing this problem. The renewability is a long term process and hence measures are required to come up with a replacement or substitute for these aggregates. Recycling concrete or the waste generated from demolition of the concrete structures is the possible option.

The concrete structures when demolished generate the broken concrete pieces which in turn can be crushed to the required sizes. These types of aggregates are called recycled aggregates. These sizes can be the same as that of coarse aggregates required in the concrete mixes. Studies have revealed that the compressive strength of concrete using crushed concrete aggregate is sufficient as required by the relative codes. This practice will not only help the environment by solving the problem of disposal but will also reduce the dependability on natural aggregates.

At more than 450 million tons per year, the construction and demolition waste (C&DW) stream constitutes the largest waste stream in quantitative terms within the European Union, apart from mining and farm wastes (European Commission 2000). Besides having tremendous reusing and recycling properties, majority of this waste is dumped into the landfills. Therefore this waste can be used in number of ways in the concrete and construction industry. Several authors have studied the possibility of preparing structural concrete using recycled aggregates. A Technical Committee (CEN/TC 154) have recently designed an European Standard (EN 12620 – "Aggregates for concrete including those for use in roads and pavements") in which artificial or recycled aggregates are considered beside natural aggregates for use in concrete (Naik and Moriconi, 2005). A research was conducted in order to verify the possibility of using C&D debris as substitute for natural aggregate in structural concrete production (Sani et al. 2005). The results of this study revealed that this waste substitution in concrete enhances both structural and leaching behavior. Hence recycled aggregate can prove to be more environmentally sustainable.

4.2.2. Ceramic and crushed brick waste

In the ceramic industry today almost 30% of production goes to waste (Senthamarai and Manoharan, 2005). This waste is not recycled but just dumped out on the fields. Several researchers have viewed this material as a possible replacement of coarse aggregates in concrete. Ceramic waste has good durability and resistivity to chemical, physical and biological degradation processes. As these waste piles up every day, the ceramic industries owners are facing tremendous pressure for its disposal. Experiments have been conducted to determine the compressive, tensile and flexural strengths and the modulus of elasticity of concrete made up of his waste with those of conventional concrete made up with natural aggrgates. The properties of the aggregates were also compared. Test results indicate that the workability of ceramic waste coarse aggregate concrete is good and the strength characteristics are comparable to those of the conventional concrete (Senthamarai and Manoharan, 2005).

Akhtaruzamman and Hasnat, in 1983, studied the use of crushed brick as a 100% replacement of coarse natural aggregate in concrete. It was observed that the crushed brick particles had the unit weight, bulk specific gravity and water absorption value of 953 kg/m^{3,} 1.93% and 11.2% respectively. The resulting concrete had the unit weight between 2000 kg/m^3 to 2080 kg/m^3 and compressive strength between 13.8 MPa and 34.5 MPa. At the same time this concrete was successful in achieving 11% greater tensile strength than normal concrete.

4.3. Possible Replacements for Fine Aggregates

Fine aggregates face the same availability and renewability problem. Therefore replacements for these aggregates should also be found. The most common replacement was the crushed sand obtained from the process of demolished concrete, crushing rocks and stones. These types of aggregates have a good effect on both, mechanical properties and durability of concrete. This option is viable, but technology and environment has made it mandatory to think of more than these options. Hence foundry sand and post consumer glass powder are viewed as possible replacements.

4.3.1. Foundry sand

Foundry sand can replace regular sand up to 45% by weight; to meet various requirements of structural-grade concrete (Naik & Kraus 1999). However, some amount of loss in strength of concrete may occur by using this type of sand. The possible reason for this problem is increase in water demand of concrete, but if properly proportioned, this problem could be addressed.

This type of sand can be obtained from the plants or foundries preparing copper, ferrous, aluminum and others. More than 7 million t of foundry by-products are produced in the United States alone. Nearly 1.1 million t of foundry by-products including foundry sand are produced by Wisconsin alone (Naik 2008). But most of this waste is land filled, which is adding to the nuisance of environmental issues. The following table no. 4 shows the properties of foundry sand along with the standard testing method number applied to test these properties.

Table 4: The physical properties of used foundry sand (T.R. Naik, 2008)

Property	**Value**	**Test method**
Specific gravity	2.39	ASTM D 854
Unit weight	2590 kg/m^3	ASTM C 48
SSD absorption	0.45%	ASTM C 128
Coefficient of permeability	10^{-3}	ASTM D 2434

The table above conforms that this sand has already been tested as per the ASTM standards. However complete replacement of fine aggregate with this type of sand is not possible. Extensive studies and tests have to be carried out to make this possible.

4.3.2. Post consumer glass powder

Recycling of glass waste is a major problem for the municipal corporations worldwide. This is because of the variety of glass colors associated with paper and plastic waste. This extensive waste has been posing a major problem from a disposal point of view and the extent of this waste could be imagined by the fact that New York City alone collects more than 100,000 tons of mixed color waste annually (Weihua et.al, 2000). Many studies have been conducted in the 1960's to try and use crushed waste glasses as aggregates for concrete. Meyer and Baxter, in 1998, conducted very extensive laboratory studies on the use of crushed glass as aggregates and found that a concrete mixture can be produced by using 100% crushed glass as aggregates, 80% ASTM type III Portland cement and 20% metakaolin as cementatious materials and a proper amount of super plasticizer (S.C.Kou & C.S.Poon, 2009). Crushed glass is highly reactive with cement (alkali-silica reaction). ASR (alkali silica reaction) of crushed glass is of a major concern as it has long term negative impacts on the concrete leading to its deterioration. This effect results from the reaction of glass with the natural aggregates in concrete. But if fly ash is used as to replace cement by more than 45% by mass, then controlling alkali-silica reaction would be possible. Another alternative to nullify this alkali-silica reaction would be using, ground waste glass as aggregate for mortars with particle sizes up to 100 μm. Using lithium compounds also can serve to be good ASR mitigating measure in concrete and promoting pozzolanic reactivity (L.M Federico & S.E. Chidiac, 2009). The addition of mixed colored glass increases the impermeability of concrete as its age increases and can be used for partial replacement of sand in other cement-based materials also (S.C.Kou & C.S.Poon, 2009) experimented and studied the properties of self compacting concrete prepared using recycled glass aggregate and found that it was feasible to produce SCC with the use of recycled glass cullet. They also found that the alkali silica reaction expansion in concrete can be reduced significantly by using flyash in concrete. In spite of its potential reactivity in an alkaline environment, there are many properties of glass that make it a potential material as aggregate in concrete and concrete products. The properties that make glass powder a possible aggregate replacement is:

- It has zero water absorption capacity.
- Being one of the most durable materials it can contribute to durability and performance of concrete.
- The glass has extremely good hardness, which in turn enhances the abrasion resistant properties of concrete.
- Glass aggregate enables attaining higher strength in concrete without the use of superplasticizers as they improve the flow properties of fresh concrete.
- Glass has pozzolanic properties too and therefore can serve both as partial cement replacement and filler.

All the alternative materials discussed above provide great deal of advantage over conventional material. These alternatives which are otherwise known as wastes have tremendous potential to substitute the conventional raw materials of concrete. If used they not only can reduce the pressure of demand for conventional material but can also lead to green construction. Use of these alternatives will not only solve the problem of their disposal which is of great concern from environment point of view but will also contribute towards making economic and quality concrete and construction.

5. SURVEY RESULTS AND RECOMMENDATION

Certain questions related to concrete sustainability were drafted and attempts were made to get the answers for these questions. These questions were answered by the design firms, contracting firms, concrete specialists and experts from companies producing ready mix concrete. These questions were specifically aimed at the North Dakota construction industry. The experts interviewed placed their point of view from the experiences they had working in the state of North Dakota; but they also mentioned that the overall scenario nationwide does not have large variations compared to their views.

5.1. The Surveying Process

To start the survey a set of questionnaire was drafted. The question majorly were related to the current use and the future of green concrete, advantages and hurdles in use and promoting green concrete. The draft of questionnaire was then emailed to concrete experts and professionals in the various part of the country. Some experts in the city of Fargo were interviewed personally.

The questionnaire was emailed to 52 experts and 3 professionals were interviewed personally. Out of 52 professionals, 2 could send back their responses successfully and in time. The summary of data obtained from this survey has been discussed in the next part of the paper.

5.2. Summary of Views from the Industry

After having the data generated from the responses from the experts, it was clear that there were some common factors that play a major role in establishing a sustainable product or procedure. It is a fact that, not always the green product or process will be cheaper than the conventional product or process. But this not means that they cannot be made cheaper. Now here is where a common response was obtained from the experts. They felt that it is majorly the federal agencies that are responsible for promoting a new product or process. Only once they take initiative then the state governing authorities and then the engineering design firms will come into action.

When asked about the sustainability of concrete, all of the responses indicated towards a positive answer. Everyone felt that concrete is the most sustainable product because of its service life. It is a durable material with a long life span which brings down the maintenance to negligible. When asked about the carbon dioxide emissions related to cement/concrete industry, they did not feel it as an important factor because of the life span of the product. The manufacturers and designers argued that the amount of emissions can be neglected if the quantity of emissions is divided over the life span of the concrete. But they could not answer the fact that the life of concrete is much more than what it is actually used for.

The designers were reluctant to use the new product or the greener material just on the basis of the laboratory tests. They strongly believed that performance of the product varies greatly when it is actually put in to use on the field. They said that governing agencies are not excited to invest in trials which make it hard for a new product to establish itself. In response to the question of the priority between economic and environmental sustainability, all the responses indicated that economic sustainability is still the key factor. Environment is a concern but then still no one seemed to achieve it as the cost of economy.

Almost every of the respondent promotes the use of green concrete in his firm, but somewhere or the other they believe that this use is restricted. This is because the engineers and the contractors feel the lack of trained personnel to handle and use these green materials and processes. Skilled labor is necessary for this kind of work and not many people are trained to make use of them. On the other hand the designers and manufacturers feel the lack of in depth specifications and codes towards manufacturing and use of green materials or processes. All of them feel that it's the job of federal agencies to initiate the process by drafting the required codes and specifications. Flyash, silica fumes and recycled concrete the main substitutes used today, with flyash being substituted in maximum percentage in Fargo (22%), moderately in Bismarck (5%) whereas the city if Minot does not allow any substitutes in concrete.

Every respondent felt that concrete has an upper hand when compared to other materials like wood and asphalt. One example of concrete as a superior material can be understood from the difference between asphalt and concrete roads. The designers claim that the fuel consumption of the vehicle reduces by roughly 6% when it travels on concrete roads as compared to its consumption on asphalt roads. At the same time the color of concrete roads being light reduces the heat absorption from the sun and hence reduces the risk of "island effect" in major cities with lots of traffic. These factors contribute towards the overall sustainability of the concrete industry.

At the end every respondent felt that the federal agencies play a key role promoting in the whole sustainability cycle. Because it will be only after their initiative and efforts that the other players in the system will come forward towards promoting green materials and boost the sustainability of cement/concrete and construction industry.

5.3. Inferences from the Responses

Considering the overall discussion from various experts, it is clear that economic sustainability of the product is still the governing factor in feasibility of the product. Even though the environment is a major issue with the threat of irreversible changes to it, the governing agencies are still not very serious about promoting environmentally sustainable material. Even the engineers or designers are skeptical about green concrete just because they do not have proper codes and specifications related to it in place. Similarly the state agencies would be reluctant to start promoting the use of green concrete unless and until it is certified by the federal agencies and they contribute to promotion and use of such materials. The industry feels that there is a need of green material but without compromising the cost. This may be because of the current economic scenario of the country. But they do agree that the use of locally available material should be promoted in order to compensate the ever fluctuating market of the primary components of concrete.

Experts from the industry are not eager to establish the worth of a new green product or design just on the basis of couple of laboratory tests. They have the opinion that test performed in the laboratories are carried out in controlled conditions which is exactly opposite to the practices on the field. Hence, the possibility of materials failing on the field is much greater than in the laboratories. This not only bothers them from economy stand point but also leads to wastage of resources and time on a large scale. The companies always face the heat of budget restrictions and hence are not at all enthusiastic to promote use of such materials. They demand that the use of these types of new materials should be promoted by the state and federal agencies. The experts believe that there should some sort of initiative on the part of state and federal agencies to test the materials and establish their worth in form of drafting specifications and codes for the use of that material. Similarly, the need of sufficient skilled manpower is something that bothers these experts. They believe that every new product brings with it the allied cost of skilled manpower to use it. Industry feels that it alone cannot train unskilled manpower, the state and federal agencies should also contribute in this cause. This can be done by including the information about the new materials in the academics of the students, setting up workshops and training schools etc.

6. WAYS TO ATTAIN SUSTAINABILITY FOR CONCRETE INDUSTRY

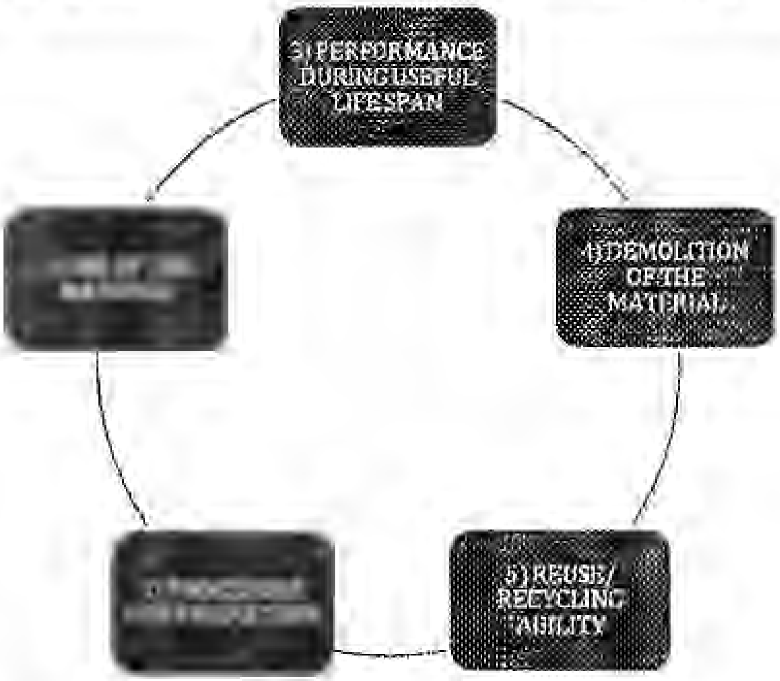
After all the discussion about sustainability it's important to learn of how that can be achieved. As previously said, sustainability is measured with respect to the environmental, economic and social impact of a material or process. And when it comes to the concrete industry environmental sustainability is of major concern. Environmental impact is basically measured or evaluated on the basis of all the factors and steps involved during the lifespan and after the useful lifespan of any construction material. This includes the procedure of production, use of the material, its performance throughout its useful life, the demolition of material and reuse or recycling ability after demolition.

6.1. Evaluation of Environmental Sustainability

The figure below works as a cycle where every step affects the other in some way. Among the above stages, the first and the fifth step are the most important, because production of material and its reuse capacity mainly depend on each other. It's a two way relationship where each step governs the performance of the other. Any construction material obtained results from the combination of prefixed raw materials and the procedures to mix the materials. This set of procedures consumes some sort of energy and at the same time there are end products generated which may or may not be useful. Then the material is used with certain specifications to serve for the predesigned performance period. After this period the material is demolished and then may or may not be used after demolition. If the material has some sort of reuse or recycling properties, it will have an impact on production. This impact can be in a form of quantity of production, quality of production, material used for the production or even the procedure adopted for the production. Hence the last two stages of this cyclic diagram are interdependent of each other. Therefore it would not be wrong to say that the environmental impact majorly depends on these two steps.

The impact of the product on the environment can be evaluated with respect to the cycle shown in figure no.1.

Figure 1: Cyclic diagram to evaluate environmental sustainability of a product



When evaluating any material for its environmental sustainability it is important to consider the use of the material. This mostly depends upon the procedure of its use, the governing codes and specifications, the energy consumed during its use and the waste generated during its use. All these procedures affect the environment in some way or another. The specifications adopted for the use of the materials in construction mostly focus on the service of the material in terms of strength and life, but environmental impacts have never been considered. For example the energy used for putting the construction material in to use and the waste generated have some sort of environmental impacts.

The performance of the material is one step that has a major impact on the environment, post production of material. If the material does not perform as it is required to, then it needs to be demolished. This requires more material to be placed in use or sometimes the manufacturer tends to renovate the production procedures or alter the quantity of raw materials. It is a common observance that anything that changes leads to some sort of effects which may be environmental, economic or social. Then it's not always necessary that this change would be accepted in the market by the users.

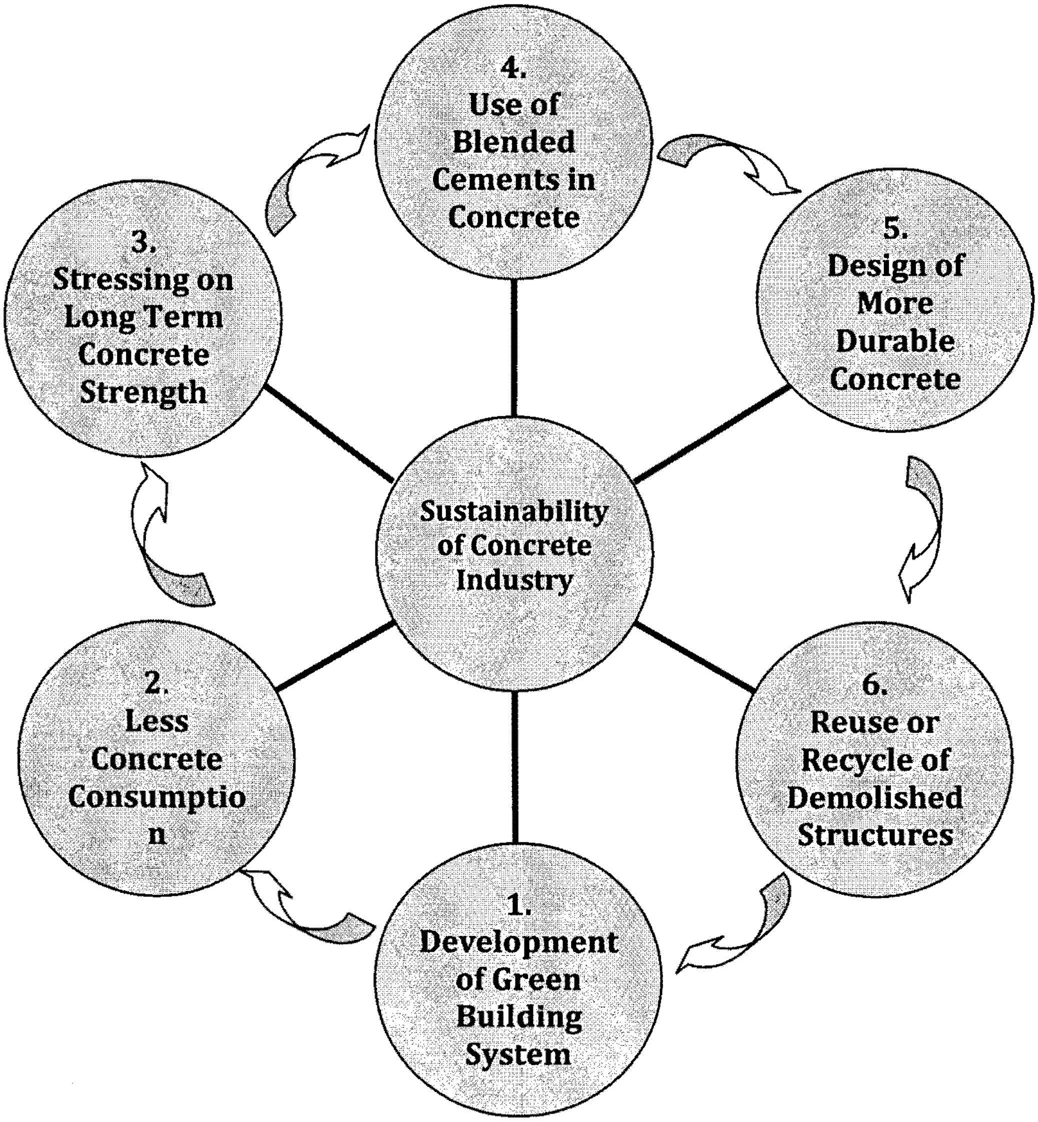
Demolition of the material may take place before or after the intended useful life of the structure. For example a structure has to be demolished; this procedure consumes a great deal of energy. At the same time the dust and the other waste produced after demolition is a matter of concern to the environment if they cannot be reused. This is the reason a large amount of demolition waste is produced. "As per the Construction and Demolition Debris (2003), USA produced 140 million t of construction and demolition debris (C&D debris), which is nearly 1.4 kg per person per day in 2002" (Tarun R. Naik, 2008). The majority of this waste is dumped in the landfills without recycling, thus having an impact on the environment.

In order to improve the environmental sustainability of the construction material it is very necessary to restudy and revise the above stages of material production, use, performance, demolition and reusing/recycling ability. Environmental sustainability can easily be achieved once the above-mentioned stages are targeted and optimization of these stages is achieved. On the other hand, economic sustainability can be achieved once the construction material produced completes it serviceable life and then can be reused even after it is demolished. Social sustainability can be automatically achieved once the measures to achieve environmental and economic sustainability are taken. This can be proven by the fact that once the material is recycled or reused there will be more jobs generated thus providing employment opportunities.

6.2. Measures to Achieve the Overall Sustainability

To achieve the overall sustainability of the concrete industry, it is necessary to devise long term sustainability plans with immediate enforcements. This paper completely agrees with the sustainability tools proposed by P. Kumar Mehta in his paper titled "Global Concrete Industry Sustainability" in 2009 for the overall sustainability of concrete industry Mehta has tried to explain these tools that can be beneficial towards analyzing and achieving the sustainability for concrete industry. But considering the literature survey done and views from the experts obtained in the survey, the need of some more sustainable tools are felt to achieve the complete sustainability of concrete industry and the construction industry as a whole. Hence an attempt has been made to put forth this idea in the form of the following diagram.

Figure 2: Suggested tools for overall sustainability of concrete and construction industry



These tools are discussed below:

Tool No. 1: Development and Use of Green Building Rating Systems

This is the most urgently needed tool or a measure for today because everything else will start from here. These rating systems can prove an effective tool for promoting, applying and maintaining sustainability. In fact many of these systems are already being designed. Countries like the USA and countries in the European Union have started strictly following these codes. The rating systems like the Leadership in Energy and Environmental Design (LEED) in the USA and Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom are the best examples of the environmental rating systems.

These systems were designed to set guidelines and to help the designers and the owners to minimize their effect on the environment. They also set up guidelines for the efficient and optimum usage of all the natural resources. Thus these systems aim at minimizing the adverse impact on the environment and the ecosystem. The International Organization for Standardization (ISO) has drafted and published the ISO 14000 series in order to address the environmental management system issues related to goods and services. But the concern for today is that these guidelines and rating systems are still being ignored by developing countries like India and China. The developing countries should understand the need for strict implementation of these rating systems. But they are more interested in achieving their economic interest than environmental sustainability.

Strict guidelines have to be established which can address the environmental and economic issues at the same time and which are in the social and economical interest of these countries. This will not only bring every country under strict scanning for negative impacts to the environment but will also encourage the countries to boost their research operations to achieve a new alternative material.

Tool No.2: Less Concrete Consumption for Construction of Structures

This tool will mainly rely on the engineering and designing skills that we have or will have in next the generations to come. New innovative methods and designs can ensure less consumption of concrete in the structures without compromising its engineering and aesthetic requirements. "A modern example of this is the Old de Young Museum complex in San Francisco, CA, that has reduced the building footprint by 37% while doubling the exhibition space." (P.K. Mehta, 2009). This was achieved by providing roof top gardening options in the newly constructed structures of the museum. Using more prefabricated members developed under controlled conditions can be a good way to ensure the necessary life span of structures. They can also be handy while placing them in position and also while displacing them minimizing the waste generation and energy consumption.

Tool No. 3: Stressing for Long-term Strength of Concrete

Concrete is evaluated depending upon its performance. The criteria for deciding the performance of concrete is its compressive strength. Currently specifying 28-days compressive strength of concrete is more in practice in the industry. If this practice can be modified and concrete could be evaluated for its 56 days or higher strength, this could lead to great savings in use of cement in concrete, indirectly lessening the green house gas emissions that would otherwise have been generated if more cement was produced and consumed. Calcium trisilicate is the compound in Portland cement that is responsible for its early strength. And this compound makes nearly 60% of the Portland cement composition. And for every ton of calcium trisilicate produced nearly 580 kg of carbon dioxide are emitted into the atmosphere. So if less cement is consumed there will be a good amount of reduction in emissions of green house gases. "A large volume of concrete is consumed for construction of foundations, columns, beams, and structural walls that are seldom subjected to significant structural loads before 2 to 3 months of age. From experience with 30-40 MPa concrete mixtures, it's known that specifying 56-day instead of 28-day strength can result in 15% cement savings". (P.K. Mehta, 2009). Any structure would not be subjected to substantial loading immediately after its construction. There is a good amount of time gap between placing of concrete, curing, stripping of forms and actually using the whole structure. Hence if low strength concrete is proposed, there will be a great amount of reduction in cement consumption as the overall mix proportion of the whole concrete with change and will be less as compared to the mix of higher strength specifications.

Less water in concrete mixes can be a good solution too. This will affect the cement content in concrete in the form of reduction of cement content. This can be achieved by promoting the use of more water reducing admixtures.

Tool No.4: Use of Blended Cements in Concrete

Promoting use of blended cements will provide a dual advantage. The materials identified up to now for blending cement, are the byproducts or the waste material generated by various industries. The problem of disposal is always associated with these waste materials. Land filling operations are no more economical as cost of land is increasing daily. On the other hand with the world population exploding at the present rate, no land could be afforded for land filling operations in time to come. Again there are numerous problems associated with disposal of these materials such as soil leaching, water pollution and air pollution. On the other hand more cement production is leading to the generation and emission of green house gases. So if blended cements are used this will not only address the issue of disposal of wastes but will also tackle the emission of green house gases. Blended cement will ensure less use of Portland cement, without compromising the strength of the concrete mix and also giving the advantage of low thermal and drying shrinkage for the mix. This will not only increase the resistivity of concrete towards cracking but will also increase its durability, thus giving a boost to the efforts of making sustainable concrete.

Tool No.5: Designing more Durable Concrete

This tool could be a great step ahead towards the more economic use of concrete. The concrete designers should aim at designing concrete with more durability and strength. This would not only make structures more durable but would also avoid the necessity for early demolition of structures. Structures like dams, tunnels, bridges, pre cast segments, pavements are the ones which involve mass concreting. Basically, structures today are designed with a life span of 100 years theoretically, but then they are demolished before the completion of their designed lifespan. This may be because the structure deteriorates or rather is replaced with a new structure. The latter condition can be understood, because there may be a need to replace structures with better design and area. But the first condition is what the designers should start working on. The concrete should be designed so that there should not be any need to demolish the structures before they complete their designed lifespan. Even concrete designed for the structures should be designed for longer life, more than what it is right now. This could be achieved by the proper mix of materials and expert combination of raw material selection for cement and other components of concrete.

Tool No.6: Reuse/Recycling of Demolished Concrete

As discussed above the concrete structures are demolished because of either deterioration or replacement with better deigns and size. But this raises the question of the disposal of demolished concrete. Land filling operations are no longer economical hence the new methods of disposal have to be thought of. We could also try to reuse the demolished concrete. This could be in the form of coarse aggregates. The demolished concrete could be broken up into proper sizes and could be used as aggregates in future concrete mixes. Many researchers have already proven that the concrete using this sort of recycled aggregates have performed better. They can be used for filling under the pavement surfaces to form the granular base or the sub base. These concrete aggregates already have been proven for their better abrasion resistivity.

All these tools will prove to be effective weapons against overall sustainability of the concrete industry, thus helping the industry to achieve the sustainability requirements and expectations for the present and the near future to come. As per P.K. Mehta, if measures number 2 and 3 are strictly followed, they will ensure 30% savings in cement and steps 2,3 and 4 together will ensure almost 50% savings in the clinker. The other three measures will be more effective towards overall sustainability of the industry (environmental, economic and social). The success of this proposed plan will depend upon the how the federal and state agencies implement it. It has been seen from the results of the survey that these two agencies play the key role in establishing and promoting the use of new materials and process. Federal agencies being the leaders of the team bear most of the responsibility for achieving the set targets.

7. RECOMMENDATIONS AND LIMITATIONS

The paper presented has been focusing on the sustainability of the concrete industry as a whole showing how the concrete industry and its allied industries are having a great deal of impact on the environment. At the same time it has been of a major concern because of the economic and social sustainability impacts on the society. This paper has tried to shed the light on the effects and the measures to mitigate these effects of the concrete industry on environmental, economical and social sustainability. The recommendations put forth by this research paper are:

- Environment is of prime importance now and hence environmental sustainability of construction industry is of utmost importance.
- Strictly following and satisfying the tools mentioned for measuring sustainability can ensure overall sustainability of concrete and the construction industry.
- Researches should not be limited to the paper; in fact governing authorities even on the local level should strive for implementation of findings in these researches.
- Federal government should take up a major role by promoting sustainable tools and processes and making use of green materials mandatory.
- Concrete having all its major components replaced by alternative materials should be tried to develop.
- Equal emphasis should be laid on satisfying all the three aspects of sustainability, i.e. environment, economy and society.

The various possible replacements for the components of concrete have been discussed in the paper. Similarly, the changes have been proposed but no practical testing for the proposed changes has been done for the suggested form and every suggested change needs a proof to establish the worth of its necessity. The changes or replacement suggested have been discussed in many previous research papers but the data revealing the testing of these replacements are hard to find. Similarly, this paper, though has a strong theoretical reasoning to support the idea of replacement, it still lacks the necessary technical data to support the changes.

8. THE FUTURE WORK

Having sufficient literature data and opinions of experts, the foundation of future research has already been laid. Satisfying all the three aspects of sustainability being a challenge, future research related to testing of such sustainable concrete is the prime aim. Various researchers who have done the testing of the materials such as testing of concrete with blended cement, or rather concrete with ceramic waste aggregate, for example, have generally adopted the one dimensional approach towards testing. They have usually tested concrete with one replacement and have replaced cement or aggregates or added some sort of admixtures and then tested that concrete. Many researchers have proposed one dimensional change because they have been successful in replacing that one component. Researches proposing and testing concrete with four dimensional approaches have seldom been proposed.

The future work plan of the author is to test the concrete with a four dimensional approach. Each dimension will be represent the replacement of one component of concrete. The recommended approach would ensure the development of concrete which will have all three major components (cement, coarse aggregate, fine aggregate) replaced in some quantities and the optimum use of its fourth component (water) with use of water reducing agents. Flyash has been used to successfully replace cement content even up to 50%. Similarly, the author of this paper has been successful in replacing pond ash for cement in concrete for nearly up to 30% in the past. The author of this paper aims to develop greener sustainable concrete with the waste materials discussed in this paper and hence, aiming to achieve at least 30% replacement of every above mentioned component of concrete.

Concrete has a complex behavior as the performance of every its component is dependent on the behavior and performance of the others. Hence, when each individual component has been replaced and tested individually, they have satisfied and even at times exceeded the strength and performance requirements. But the nature of the concrete after simultaneous replacement would certainly be different, and studying this nature would be interesting. The future research aims to develop a sustainable concrete mix design for green concrete. That could certainly be a concrete design which could prove to be the benchmark for the future designing and testing of sustainable concrete with different alternate materials. Once the successful testing of sustainable concrete is achieved, it would not only automatically draw the attention of other researchers to look at the possibilities of using waste materials but will also give a boost to the confidence of the building or constructing firms for use of green/sustainable/non-conventional concrete.

9. CONCLUSION

The environment that we live in has changed drastically over years. This planet and its climate have varied over the period of time and now have already suffered some changes that cannot be reversed. These changes caused to the environment were the result of technological progress and never ending needs of mankind. Hence, now to control these changes and mitigate their effects sustainable processes and materials have to be developed. These materials should be such that they not only satisfy environmental sustainability but at the same time take care of the economic and social aspects of sustainability. It's now our responsibility to develop more better and innovative designs with selection of best and long lasting materials. This will not only ensure long lasting structures but also help minimize wastages. The players in the cement and concrete industry must start taking responsibilities for the designs and lifecycle of the structures.

Many green materials and procedures of concrete and construction have already been developed and are already there in the market, but the scale of their use in the construction industry in not very encouraging. The players in the industry feel that even the technical expertise to handle and use these materials should be developed and so training the manpower is very essential. Skilled manpower can be achieved by including the updated information of green materials and technologies in the academics of upcoming engineers in colleges.

Looking at the overall picture it can be concluded that it is the time for the federal agencies to act fast. Unless some initiatives are taken by them, the use of green materials and products would not be made possible on a larger scale. Spending large amount of time and money on researches is good but these attempts would not be fruitful if they are not implemented. Hence an immediate plan of action almost identical to the cyclic diagram proposed in the previous part of the paper needs to be acted on. Developing the governing codes, training enough people through college coursework or specialized training school and enforcing the use of the materials and product should be the three major steps in the plan of action. Giving out subsidies to the companies developing green materials and products to help them sustain in the competitive market could be a giant step and the boosting factor towards promotion of these materials in the market.

Making the construction agencies understand the advantages of using these green materials and the urgency of their usage would really be a milestone in promoting the use of these materials. This plan of action would be a stepping stone towards achievement of the goals established by the Kyoto protocol and the dream of achieving the low carbon emissions and having a healthier environment would be able to be realized. The concrete industry would then be able to brighten its image by addressing all the aspects of sustainability and thus keep on serving the mankind in generations to come.

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APPENDIX-1: QUESTIONS ASKED IN THE SURVEY

1) What is the estimated yearly production and what is the rate of increase in concrete consumption every year?

2) What sustainability issues are related to the concrete production?

3) How important do you think are these sustainability issues?

4) What is the present status regarding the use of green concrete in your firm?

5) What are the possible ways the concrete industry can overcome these sustainability issues?

6) What kinds of substitutes are commonly used for the concrete production?

7) What is the total market share of the green concrete as compared to conventional concrete?

8) How comfortable are the contractors using this green concrete? Are there any special measures taken to promote their use?

9) What substitutes are viewed the most economical for replacing the conventional concrete?

10) Are there any methods or rules that can make environmental, economical and social sustainability go hand in hand?

11) What is the risk factor involved in use of green concrete?

12) Has green concrete been able to satisfy the safety and quality requirements comparing to conventional concrete?

13) How can the industry make recycling of concrete more efficient?

14) Are owners readily accepting the green concrete? If not then what are the factors that are bothering them with the use of green concrete?

15) How efficient are the codes that related to green concrete?

16) What governmental policies promote the use of green concrete?

17) Do you have a short and long term goal to make concrete sustainable?

18) Where do you see the concrete industry by the year 2020, when it comes to sustainability and green concrete?

APPENDIX-2: IRB APPROVAL

NDSU NORTH DAKOTA STATE UNIVERSITY

Institutional Review Board
Office of the Vice President for Research, Creative Activities and Technology Transfer
NDSU Dept. 4000
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Federalwide Assurance #FWA00002439
Expires April 24, 2011

June 21, 2010

Mr. Ankush Agrawal
Dept of Construction Management and Engineering

Re: IRB Determination of Applicability for project titled:
"Achieving a Sustainable Concrete Design and Construction"

Thank you for your inquiry regarding the need for IRB review of your project. At this time, the IRB office has determined that the above-referenced protocol does not require Institutional Review Board approval or certification of exempt status because it does not fit the regulatory definition of 'research involving human subjects'.

> *Dept. of Health & Human Services regulations governing human subjects research (45CFR46, Protection of Human Subjects), defines 'research' as "... a systematic investigation, research development, testing and evaluation, designed to contribute to generalizable knowledge." These regulations also define a 'human subject' as "... a living individual about whom an investigator conducting research obtains (1) data through intervention or interaction with the individual, or (2) identifiable private information."*

While this project is presumably 'research' as defined above, it does not involve 'human subjects' because the questions in the survey do not elicit any information about individuals. Instead, the questions pertain solely to objective information regarding use of concrete in construction project design. This determination is based on the survey provided on 6.21.2010, and previously.

We appreciate your intention to abide by NDSU IRB policies and procedures. Best wishes for a successful project!

Sincerely,

Teri Grosz, MS, CIP
Manager, Human Research Protection Program