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GREEN CONCRETE MADE WITH INDUSTRIAL WASTES -A PANACEA FOR ECOLOGICAL AND ENVIRONMENTAL PROBLEMS

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ABSTRACT
Concrete is one of the most widely used construction materials in the world. However, the production of portland cement, an essential constituent of concrete, leads to the release of significant amount of CO2, a greenhouse gas; one ton of portland cement clinker production is said to creates approximately one ton of CO2 and other greenhouse gases (GHGs). Concrete is a sustainable material because it has a very low inherent energy requirement, is produced to order as needed with very little waste, is made from some of the most plentiful resources on earth, has very high thermal mass, can be made with recycled materials, and is completely recyclable. Use of "green" materials embodies low energy costs. Their use must have high durability and low maintenance leading to sustainable construction materials. Reuse of post-consumer wastes and industrial by-products in concrete is necessary to produce even "greener" concrete. Use of coal ash, rice-husk ash, wood ash, natural pozzolans, GGBFS, silica fume, and other similar pozzolanic materials can reduce the use of manufactured portland cement clinker; and, at the same time, produce concrete that is more durable. "Greener" concrete also improves air quality, minimizes solid wastes, and leads to sustainable cement and concrete industry

1. INTRODUCTION
Concrete is environmentally very friendly material. As good engineers, we must use more of it in construction [Malhotra 2004]. Concrete has been used for over 2,000 years. Concrete is best known for its long-lasting and dependable nature. However, additional ways that concrete contributes to social progress, economic growth, and environmental protection are often overlooked. Concrete structures are superior in energy performance. They provide flexibility in design as well as affordability, and are environmentally more responsible than steel or aluminum structures [Cement Association of Canada 2004].

"The concrete industry will be called upon to serve the two pressing needs of human society; namely, protection of the environment and meeting the infrastructural requirement for increasing industrialization and urbanization of the world. Also due to large size, the concrete industry is unquestionably the ideal medium for the economic and safe use of millions of tons of industrial by-products such as fly ash and slag due to their highly pozzolanic and cementitious properties. It is obvious that large-scale cement replacement (60-70 %) in concrete with these industrial by-products will be advantageous from the standpoint of cost economy, energy efficiency, durability, and overall ecological profile of concrete.

Therefore, in the future, the use of by-product supplementary cementing materials ought to be made mandatory" [Malhotra 2004].

The production of one ton of portland cement generates approximately one ton of green-house gases (GHGs), such as CO2 and NOX and requires 1.6 tons of raw materials. These materials are primarily good quality limestone and clay. Therefore, for 1.6 billion tons of cement produced annually, we need about 2.5 billion tons of raw materials. CO2 and other GHG emissions can be reduced by the use of other cementitious materials (CM). Replacing 15% of cement worldwide by other CM will reduce CO2 emissions by 250 million tons. Replacing 50% of cement worldwide by other CM will reduce CO2 emissions by 800 million tons. This is equal to removing ¼ of all automobiles in the world [Malhotra 2004].

Sl.	Country/	Percent CO_2
1	USA	25
2	EU	20
3	Russia	17
4	Japan	8
5	China	> 15
6	India	> 10

1.1 Environmental Issues

The production of portland cement releases CO_2 and other greenhouse gases (GHGs) into the atmosphere. Total CO_2 emissions worldwide were 21 billion tons in 2002.

Environmental issues associated with the CO_2 emissions from the production of portland cement, energy demand (six-million BTU of energy needed per ton of cement production), resource conservation consideration, and economic impact due to the high cost of portland cement manufacturing plants demand that supplementary cementing materials in general and fly ash in particular be used in increasing quantities to replace portland cement in concrete [Malhotra 1997, 2004].

Fly ash is a by-product of the combustion of pulverized coal in thermal power plants. The dust-collection system removes the fly ash, as a fine particulate residue from the combustion gases before they are discharged in the atmosphere.

For each ton of portland cement clinker, 3 to 20 lbs. of NOx are released into the atmosphere. In 2000, the worldwide cement clinker production was approximately 1.6 billion tons [Malhotra 2004]. Thermal mass of concrete contributes to operating energy efficiency and reduced cooling costs, under certain climatic conditions. Longer lasting concrete structures reduce energy needs for maintenance and reconstruction. Concrete is a locally available material; therefore, transportation cost to the project site is reduced. Light colored concrete walls reduce interior lighting requirements. Permeable concrete pavement and interlocking concrete pavers can be used to reduce runoff and allow water to return to the water table. Therefore, concrete is, in many ways, environmentally friendly material. As good engineers, we must use more of it [Malhotra 2004].

In view of the energy and greenhouse gas (GHG) emission concerns in the manufacturing of portland cement, it is imperative that either new environmentally friendly cement-manufacturing technologies be developed or substitute materials be found to replace a major part of the portland cement for use in the concrete industry [Malhotra 2004]. Many different types of Coal Combustion Products (Ccps) are produced; for example, fly ash (Class F since 1930s, and Class C since early 1980s), bottom ash, cyclone-boiler slag, and clean-coal ash (since late 1980s, ash derived from SOx/NOx control technologies, including FBC and AFBC or PFBC boilers, as well as dry- or wet-FGD materials from SOx/NOx control technologies). In general some of these CCPs can be used as a supplementary cementitious materials and use of portland cement, therefore, can be reduced.

Today use of other pozzolans, such as rice-husk ash, wood ash, GGBFS, silica fume, and other similar pozzolanic materials such as volcanic ash, natural pozzolans, diatomite (diatomaceous earth), calcined clay/shale, metakaolin, very fine clean-coal ash (microash), limestone powder, and fine glass can reduce the use of manufactured portland cement, and make concrete more durable, as well as reduce GHG emissions.

1.2 Sustainability

Entire geographical regions are running out of limestone resource to produce cement. Major metropolitan areas are running out of sources of aggregates for making concrete. Sustainability requires that engineers consider a building's "lifecycle" cost extended over the useful lifetime. This includes the building construction, maintenance, demolition, and recycling [ACI 2004, Coppola et al. 2004, Corinaldesi et al. 2002b, Corinaldesi & Moriconi 2004b, Moriconi 2003].

A sustainable concrete structure is one that is constructed so that the total societal impact during its entire life cycle, including during its use, is minimum. Designing for sustainability means accounting in the design the full short-term and long-term consequences of the societal impact. Therefore, durability is the key issue [Moriconi 2003]. New generation of admixtures/additives are needed to improve durability.

To build in a sustainable manner and conduct scheduled & appropriate building maintenance are the keys that represent the "new construction ideology" of this millennium. In particular, to build in a sustainable manner means to focus attention on physical, environmental, and technological resources, problems related to human health, energy conservation of new and existing buildings, and control of construction technologies and methods [Coppola et al. 2004, Corinaldesi & Moriconi 2004a, 2004b, Corinaldesi et al. 2005b].

2. CONCRETE AND THE USE OF BLENDED CEMENTS

Although it is most common to make use of supplementary cementing materials (SCM) in the replacement of cement in the concrete mixture, blended cement is produced at the grinding stage of cement production where fly ash, blast furnace slag, or silica fume are added to the cement itself. The advantages include expanded production capacity, reduced CO_2 emissions, reduced fuel consumption and close monitoring of the quality of SCMs [Cement Association of Canada 2004]. "Kyoto Protocol (UN Pact of 1997, requires to reduce GHGs, including CO2)." It is now ratified. USA has not ratified it. "The Russian Government approval allowed it to come into force worldwide." By 2012, emissions must be cut below 1990 levels (in Japan by 6.0 + 7.6 = 13.6% by 2012) [The Daily Yomiuri 2004].

In Japan "(Per) household…5,000 yen green tax" per year is planned (starting April 2005). This includes "3,600 yen in tax per ton of carbon." "The revenue would be used to implement policies to achieve the requirements of Kyoto Protocol." A survey released (on Oct. 21, 2004) showed that 61% of those polled are in favor of the environmental tax." [The Japan Times 2004].

3. FOUNDRY BY-PRODUCTS

Foundry by-products include foundry sand, core butts, abrasives, and cupola slag. Cores are used in making desired cavity/shapes in a sand mold in which molten metal is cast/poured. Cores are primarily composed of silica sand with small percentages of either organic or inorganic binders.

Green sand for making molds is composed of four major materials: sand, clay (4 to 10%), additives, and water. Sand usually constitutes 50 to 95% of the total materials. Foundries in

USA generate approximately 15 million tonnes of by-products annually. Most of these by-products are land filled. Land filling is not a desirable option because it not only causes huge financial burden to foundries, but also makes them liable for future environmental costs, problems, and restrictions associated with landfilling. Furthermore, the cost of landfilling is escalating due to shrinking landfill space and stricter environmental regulations. One of the innovative solutions appears to be high-volume uses of foundry by-products in construction materials [Moriconi 2003].

Applications of used foundry sand

Foundry sand can be used as a replacement of regular sand up to 45% by weight, to meet various requirements of structural-grade concrete [Naik & Kraus 1999]. Use of foundry sand in concrete may result in some loss of concrete strength due to increased water demand. However, proper mixture proportioning can compensate this. Concrete of compressive strength of 42 MPa has been produced with the inclusion of foundry sand up to 45% replacement of regular sand. Flowable slurry (CLSM), incorporating used foundry sand as a replacement of fly ash up to 85% has also been produced [Naik & Kraus 1999].

Up to 15% used foundry sand can be used as replacement of fine aggregate in Hot Mix Asphalt (HMA). Bricks, blocks, and paving stones made with up to 35% used foundry sand passed ASTM requirements for compressive strength, absorption, and bulk density. Environmental impact of the use of Controlled Low Strength Materials (CLSM) incorporating industrial by-products (coal fly ash, and used foundry sand) has been reported [Naik & Kraus 1999]. The results demonstrated that excavatable flowable slurry incorporating fly ash and foundry sand up to 85% could be produced. In general, inclusion of both clean and used foundry sand caused reduction in the concentration of certain contaminants. The use of foundry sand in CLSM slurry, therefore, provided a favorable environmental performance. All fly ash slurry materials made with and without foundry sand were environmentally friendly materials [Naik & Kraus 1999].

Figure 1. Hollow Blocks with Foundry Waste Sand

Applications of foundry slag

Foundry (cupola) slag is appropriate for use as a coarse semi-lightweight aggregate in cement-based materials. It has been used as replacement of aggregate in manufacturing of structural-grade concrete [Naik & Kraus 1999].

4. POST-CONSUMER GLASS

Approximately 10 million tonnes of post-consumer glass is produced each year in USA. About 3.4 million tonnes is used primarily as cullet for glass manufacturing. There are three types of glass: borosilicate, soda-lime, and lead glass. The majority of glass manufactured in USA is soda-lime variety. Glass primarily consists of silica or silica sand.*Applications of post-consumer glass [Naik & Wu 2001]*

Crushed glass is highly reactive with cement (alkali-silica reaction). But Class F fly ash was used as a replacement of cement by mass of 45% or more, which helped in controlling alkali-silica reaction. However, ground waste glass was used as aggregate for mortars and no reaction was detected with particle size up to 100 µm, thus indicating the feasibility of the waste glass reuse as fine aggregate in mortars and concrete. In addition, waste glass seemed to positively contribute to the mortar microstructural properties resulting in an evident improvement of its mechanical performance [Corinaldesi et al. 2005a]. Mixed colored glass can be utilized in flowable self-compacting slurry or concrete [Naik & Kraus 1999]. Addition of mixed colored glass increased impermeability of concrete as the age increased. It can be used as partial replacement of sand in other cement-based materials also.

Moreover, every year, in Western Europe, Glass Reinforced Plastic (GRP) processing, widely used in several fields from buildings to furniture to boats, produces 40,000 tons of unusable scraps and fines of GRP, which are generally disposed in landfill. The feasibility of re-using such GRP materials, in the form of fine powder (about 0.1 mm in size) to produce blended cements was investigated [Tittarelli & Moriconi 2005]. Mechanical strength threshold acceptable by actual cement standards could be satisfied by replacing up to 15% of cement with GRP powder. The "GRP cements", even if they show lower mechanical strengths, could confer lightness and some ductility to cementitious products manufactured by them. Mortars manufactured by using these cements were more porous with respect to the reference mortar without GRP, due to higher water/cement and due to the absence of any noticeable binding capacity of GRP powder. Nevertheless, their capillary water absorption and drying shrinkage were lower than that of the reference mortar without GRP.

5. WOOD ASH

Wood ash is the residue generated due to combustion of bark, wood, and scraps from manufacturing operations (pulp mills, saw mills, and wood products manufacturing plants), and from CDW (construction and demolition wastes). Wood ash is composed ofboth inorganic and organic compounds. Yield of wood ash decreases with increase in combustion temperature [Naik & Kraus 2003].

Applications of wood ash

Wood fly ash has substantial potential for use as a pozzolanic mineral admixture and as an activator in cement-based materials. Wood ash has been used in the making of structural-grade concrete, bricks/blocks/paving stones, flowable slurry, and blended cements [Coppola et al. 2004]. Air-entrained concrete can be achieved by using wood fly ash up to 35%. Structural-grade concrete can be made using wood fly ash and its blends with Class C fly ash to achieve a compressive strength of 50 MPa or higher.

6. PULP AND PAPER MILL RESIDUAL SOLIDS

More than six million dry tonnes of residual solids from primary clarifiers are generated each year in USA. Pulp and paper mill sludge is composed of cellulose fibers, clay, ash-bearing compounds, chemicals, and moisture. 50% of residuals are landfilled, 25% is incinerated, and the final 25% is utilized in some way. Solids are removed at the primary clarifier by sedimentation or dissolved air flotation. Such solid residuals consist mainly of cellulose fibers, moisture, and paper making fillers (kaolinitic clay, calcium carbonate, etc.).

7. RECYCLED AGGREGATES

In addition to cement, water and aggregates are the other primary constituents of concrete mixtures. "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 concrete making every year. In the current context of increasing waste production and growing public awareness of environmental problems, recycled materials from demolished concrete or masonry can be profitably used in different ways within the building industry.

At present, these materials are mainly used untreated as obtained from demolition for excavation filling, roadbeds, or floor foundation. However, if suitably selected, ground, cleaned and sieved in appropriate industrial crushing plants, the rubble from building demolition could become useful for more ambitious applications.

Several authors [Coppola et al. 1995, Dhir et al. 1998, Hansen 1992, Kasai 1988] have studied the possibility of using recycled aggregates to prepare structural concretes. A Technical Committee (CEN/TC 154) have recently drawn 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. These studies show that, in recycled-aggregate concrete, mechanical strength loss occurs, which is strongly dependent on the recycled aggregate quality; in fact, this loss is completely eliminated when recycled aggregates consist of demolished concrete belonging to a strength class equal to or higher than that of the new concrete in which they will be used [Coppola et al. 1995]. Moreover, the fine recycled aggregate fraction is particularly detrimental to both mechanical performances and durability of concrete. Therefore, the possibility of reusing this fraction in other ways has recently been examined [Moriconi 2005a].

Recycled-aggregate fractions up to 15 mm, although containing masonry rubble up to 25-30%, proved to be suitable for manufacturing structural concrete even if employed as a total substitution of the fine and coarse natural aggregate fractions [Corinaldesi & Moriconi 2001]. Moreover, the fine fraction with particle size up to 5 mm, if reused as aggregate for mortars, allowed excellent bond strengths between mortar and bricks, in spite of a lower mechanical performance of the mortar itself [Corinaldesi et al. 2002a, Moriconi et al. 2003]. Also the masonry rubble can be profitably treated and reused for preparing mortars. Finally, even for the finest fraction produced during the recycling process, that is the rubble powder, an excellent reuse was found, that is as filler in self-compacting concretes [Corinaldesi et al. 2002c, 2005b, Corinaldesi & Moriconi 2003, 2004b].

Post-consumer wastes and industrial by-products must be used in concrete to make "greener" concrete. Glass, plastics, tires, and wood fibers can be used. Recycling of industrial by-products is well established. Use of coal fly ash in concrete started in the 1930s, and volcanic ash has been recycled for several millenniums in mortar and concrete (in Egypt, Italy, Mexico, India, and other places). Recycling minimizes solid waste disposal, improves air quality, minimizes solid wastes, and leads to sustainable cement and concrete industry.

Use less portland cement. Use less water. Use applications specific, high-quality, durable aggregates [Malhotra 1997, 2004]. Use chemical admixtures. Trade Emissions (refers to air emissions economic mechanism to reduce global greenhouse gases). Fundamental laws of nature say that we cannot create or destroy matter; we can only affect how it is organized, transformed, and used. Obey the rules of nature: use only what you need and never use a resource faster than nature can replenish it.

8. CONCLUSIONS

Generally, large volumes of by-product materials are disposed in landfills. Because of stricter environmental regulations, disposal cost is escalating. Recycling not only helps in reducing disposal costs, but also helps to conserve natural resources, providing technical and economic benefits. Eliminate waste and take life cycle responsibility/ownership.

Foundry sand can be used as a replacement of regular sand in concrete, flowable slurry, cast-concrete products, and other cement-based materials. Foundry slag can be used as semi-light weight coarse aggregate in concrete.

Glass can be used as a partial replacement of fine aggregate in concrete. Wood ash can be used to make structural-grade concrete, blended cements, and other cement-based materials. Structural-grade concrete can be made with pulp and paper mill residual solids.

Wangari Maathai, 2004 Nobel Peace Laureate, said "When we destroy our resources, when our resources become scarce, we fight over them. And many wars in the world are actually fought over natural resources," (in October 2004). She is known as "the Tree Woman of Kenya" because she has planted over 30 million trees since 1977.

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