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ENVIRONMENTAL IMPACT OF CONCRETE

BY

DAN BABOR, DIANA PLIAN and LOREDANA JUDELE

Abstract. The cement and concrete industries are huge. What does this mean in terms of the environment? Concrete and other cementitious materials have both environmental advantages and disadvantages.

This paper takes a look at how these materials are made, then reviews a number of environmental considerations relating to their production and use.

Key words: raw materials; concrete; portland cement.

1. Introduction

Concrete is a material used in building construction, consisting of a hard, chemically inert particular substance, known as an aggregate (usually made from different types of sand and gravel), that is bonded together by cement and water.

The Assyrians and Babylonians used clay as the bonding substance or cement. The Egyptians used lime and gypsum cement. In 1756, British engineer, John Smeaton, made the first modern concrete (hydraulic cement) by adding pebbles as a coarse aggregate and mixing powered brick into the cement. In 1824, English inventor, Joseph Aspdin, invented Portland Cement, which has remained the dominant cement used in concrete production. Joseph Aspdin created the first true artificial cement by burning ground limestone and clay together. The burning process changed the chemical properties of the materials and Joseph Aspdin created a stronger cement than that which uses plain crushed limestone would produce.

Cement production requires a source of calcium (usually limestone) and a source of silicon (such as clay or sand). Small amounts of bauxite and iron ore are added to provide specific properties. These raw materials are finely ground and mixed, then fell into a rotary cement kiln, which is the largest piece of moving industrial equipment in the world. The kiln is a long, sloping cylinder with zones that get progressively hotter up to about 1,480°C. The kiln rotates slowly to mix the contents moving through it (Fig. 1). In the kiln, the raw materials undergo complex chemical and physical changes required to make them able to react together through hydration. The most common type of cement kiln today is a dry process kiln, in which the ingredients are mixed dry. Many older kilns use the wet process.

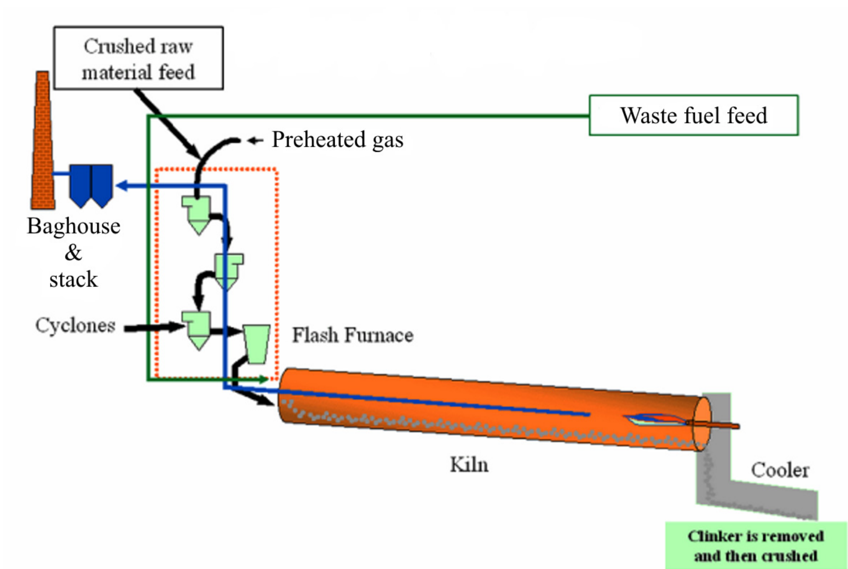

Fig. 1 – Cement kiln.

The first important reaction to occur is the calcining of limestone (calcium carbonate) into lime (calcium oxide) and carbon dioxide, which occurs in the lower-temperature portions of the kiln-up to about 900°C. The second reaction is the bonding of calcium oxide and silicates to form dicalcium and tricalcium silicates. Small amounts of tricalcium aluminate and tetracalcium aluminoferrite are also formed. The relative proportions of these four principal compounds determine the key properties of the resultant Portland cement and the type classification (Type I, Type II, etc.). These reactions occur at very high temperatures with the ingredients in molten form. As the new compounds cool, they solidify into solid pellet form called clinker. The clinker is then grounded to a fine powder, a small amount of gypsum is added, and the finished cement is bagged or shipped bulk to ready mix concrete plants.

Concrete is produced by mixing cement with fine aggregate (sand), coarse aggregate (gravel or crushed stone), water, and small amounts of various chemicals called *admixtures* that control such properties as setting time and plasticity. The process of hardening or setting is actually a chemical reaction called *hydration*. When water is added to the cement, it forms a slurry or gel that coats the surfaces of the aggregate and fills the voids to form the solid concrete. The properties of concrete are determined by the type of cement used, the additives, and the overall proportions of cement, aggregate, and water.

2. Raw Material Use

The raw materials used in cement production are widely available in great quantities. Limestone, marl, and chalk are the most common sources of calcium in cement (converted into lime through calcination). Common sources of silicon include clay, sand, and shale. Certain waste products, such as fly, can also be used as a silicon source. The iron and aluminum can be provided as iron ore and bauxite, but recycled metals can also be used. Finally, about 5% of cement by weight is gypsum, a common calcium- and sulfur-based mineral. It takes 1,455…1,597 kg of raw materials to produce one ton of finished cement, according to the Environmental Research Group at the University of British Columbia (UBC).

Table 1
Typical Concrete Mix

Component	Percent by weight, [%]
Portland cement	12
Sand	34
Crushed stone	48
Water	6

The water, sand and gravel or crushed stone used in concrete production in addition to cement are also abundant (typical proportion of a concrete mix are shown in Table 1).

With all of these raw materials, the distance and quality of the sources have a big impact on transportation energy use, water use for washing, and dust generation. Some aggregates that have been used in concrete production have turned out to be sources of radon gas. The worse problems were when uranium mine tailings were used as concrete aggregate, but some natural stone also emits radon.

Fly ash is a fine, glass-like powder recovered from gases created by coal-fired electric power generation. Power plants produce millions of tons of fly ash annually, which is usually dumped in landfills. Fly ash is an inexpensive replacement for Portland cement used in concrete, while it actually improves strength, segregation, and ease of pumping of the concrete. Fly ash is also used as an ingredient in brick, block, paving, and structural fills.

Fly ash concrete was first used in the USA in 1929 for the Hoover Dam, where engineers found that it allowed for less total cement. It is now used across the country. Consisting mostly of silica, alumina and iron, fly ash is a pozzolan – a substance containing aluminous and silicious material that forms cement in the presence of water. When mixed with lime and water it forms a compound similar to Portland cement. The spherical shape (Fig. 2) of the particles reduces internal friction thereby increasing the concrete's consistency and mobility, permitting longer pumping distances. Improved workability means less water is needed, resulting in less segregation of the mixture. Although fly ash cement itself is less dense than Portland cement, the produced concrete is denser and results in a smoother surface with sharper detail.

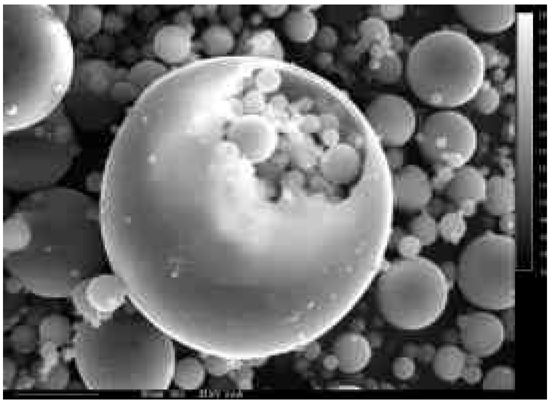

Fig. 2 – A spherical shape of fly ash particles.

The use of fly ash from coal-fired power plants is beneficial in two ways: it can help with our solid waste problems, and it reduces overall energy use. While fly ash is sometimes used as a source of silica in cement production, a more common use is in concrete mixture as a substitute for some of the cement. Fly ash, or pozzolan, can readily be substituted for 15…35% of the cement in concrete mixes, and for some applications fly ash content can be up to 70%. Fly ash today accounts for about 9% of the cement mix in concrete. Fly ash reacts with any free lime left after the hydration to form calcium silicate hydrate, which is similar to the tricalcium and dicalcium silicates formed in cement curing. Through this process, fly ash increases concrete strength, improves sulfate resistance, decreases permeability, reduces the water ratio required, and improves the pumpability and workability of the concrete. Fly ash is widely used in Europe as a major ingredient in autoclaved cellular concrete (ACC); in the United States, North American Cellular Concrete is developing this technology.

Other industrial waste products, including blast furnace slag, cinders, and mill scale are sometimes substituted for some of the aggregate in concrete mixes. Even recycled concrete can be crushed into aggregate that can be reused in the concrete mix, though the irregular surface of aggregate so produced is less effective that sand or crushed stone because it takes more cement slurry to fill all the nooks and crannies. In fact, using crushed concrete as an aggregate might be counterproductive by requiring extra cement–by far the most energy–intensive component of concrete.

3. Energy

Energy consumption is the biggest environmental concern with cement and concrete production. Cement production is one of the most energy intensive of all industrial manufacturing process. Including direct fuel use for mining and transporting raw materials, cement production takes about 1,758 kWh for every ton of cement. The industry's heavy reliance on coal leads to especially high emission levels of CO_2, nitrous oxide and sulphur, among other pollutants. A sizeable portion of the electricity used is also generated from coal.

The vast majority of the energy consumed in cement production is used for operating the rotary cement kilns. Dry-process kilns are more energy efficient than older wet-process kilns, because energy is not required for driving off moisture. In a modern dry-process kiln, a pre-heater is often used to heat the ingredients using waste heat from the exhaust gases of the kiln burners. A dry-process kiln so adapted can use up to 50% less energy than a wet-process kiln. Some other dry-process kilns use a separate combustion vessel in which the calcining process begins before the ingredients move into the rotary kiln – a technique that can have even higher overall efficiency than a kiln with pre-heater.

While cement manufacturing is extremely energy intensive, the very high temperatures used in a cement kiln have at least one advantage: the potential for burning hazardous waste as a fuel. Waste fuels that can be used in cement kilns include used motor oil, spent solvents, printing inks, paint residues, cleaning fluids, and scrap tires. These can be burned relatively safely because the extremely high temperatures result in very complete combustion with very low pollution emissions. For some chemicals thermal destruction in a cement kiln is the safest method of disposal.

A single cement kiln can burn more than a million tires a year, according to the Portland Cement Association. These tires have a higher fuel content than coal, and iron from the steel belts can be used as an ingredient in the cement manufacturing.

Energy use for concrete production looks considerably better than it does for cement, because the other components of concrete (sand, crushed stone, and water) are much less energy intensive.

4. CO_2 Emissions

There are two very different sources of carbon dioxide emissions during cement production.

Combustion of fossil fuels to operate the rotary kiln is the largest source: approximately 3/4 t of CO_2 per ton of cement. The chemical process of calcining limestone into lime in the cement kiln also produces CO_2. Combining these two sources, for every ton of cement produced, 1.25 t of CO_2 is released into the atmosphere. Worldwide, cement production now accounts for more than 1.6×10^9 t of CO_2 emissions from all human activities.

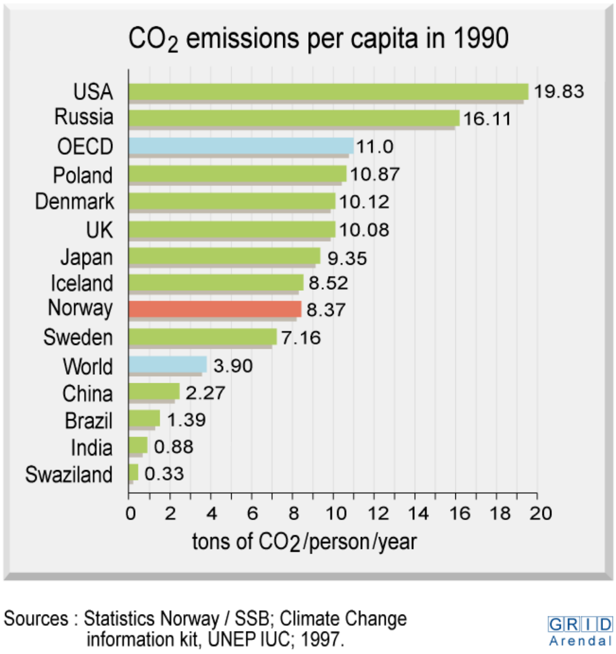

Fig. 3 – Emissions of CO_2 per capita 1990 (selected countries).

The Fig. 3 shows emissions of CO_2 per capita in 1990. CO_2 can be emitted as byproduct from the use of fossil fuel, by combustion, land-use conversion and cement production.

The most significant way to reduce CO_2 emissions is improving the energy efficiency of the cement kiln operation. Dramatic reductions in energy use have been realized in recent decades, switching to lower CO_2 fuels such as natural gas and agricultural waste. Another strategy, which addresses the CO_2 emissions from calcining limestone, is to use waste lime from other industries in the kiln. Substitution of fly ash for some of the cement in concrete can have a very large effect.

5. Other Air Emissions

Besides CO_2 both cement and concrete production generate considerable quantities of air-pollutant emissions. Dust is the most visible of these pollutants. It's estimates total particulate (dust) emissions of 360 pounds per ton of cement produced, the majority of which results from the cement production handling raw materials, grinding cement clinker, and packaging or loading finished cement, which is grounded to a very fine powder.

The best way to deal with the dust generated in cement manufacturing would be to collect it and put it back into the process. This is done to some extent, using mechanical collectors, electric precipitators, and fabric filters (bag houses).

Recycling the dust is difficult; firstly it has to be treated to reduce its alkalinity. Some cement kiln dust is used for agricultural soil treatments and the rest (of that collected) is often land filled on site.

In addition to dust produced in cement manufacturing, dust is also generated in concrete production and transport. Common sources are sand and aggregate mining, material transfer, storage (wind erosion from piles), mixer loading, and concrete delivery (dust from unpaved roads).

Dust emissions can be controlled through water sprays, enclosures, hoods, curtains, and covered chutes.

Other air pollution emissions from cement and concrete production result from fossil fuel burning for process and transportation uses. Air pollutants commonly emitted from cement manufacturing plants include sulfur dioxide (SO_2) and nitrous oxides (NO_x).

SO_2 emissions (and to a lesser extent SO_3, sulfuric acid, and hydrogen sulfide) result from sulfur content of both the raw materials and the fuel. Strategies to reduce sulfur emissions include use of low-sulfur raw materials, burning low-sulfur coal of other fuels, and collecting the sulfur emissions. Lime in the cement kiln acts as a scrubber and absorbs some sulfur.

Nitrous oxide emissions are influenced by fuel type and combustion conditions (including flame temperature, burner type, and material/exhaust gas retention in the burning zone of kiln). Strategies to reduce nitrogen emissions include altering the burner design, modifying kiln and pre-calciner operation, using alternate fuels, and adding ammonia or urea to the process.

6. Water Pollution

Another environmental issue with cement and concrete production is water pollution.

At the batch plant, wash water from equipment cleaning is often discharged into setting ponds where the solids can settled out.

Some returned concrete also gets put into settling ponds to wash off and recover the aggregate.

7. Solid Waste

While the cement and concrete industries can help to reduce some of our solid waste problems (burning hazardous waste as cement kiln fuel and using fly ash in concrete mixtures), one cannot overlook the fact that concrete is the most visible component of construction and demolition waste.

Of the concrete that is recycled, most is used as a highway substrate or as a clean fill around buildings.

Concrete waste is also created in new constructions.

When it is possible to use pre-cast concrete components instead of poured concrete, doing so many offer advantages in terms of waste generation.

Material quantities can be estimated more precisely and excess material can be utilized. By carefully controlling conditions during manufacture of pre-cast concrete products, higher strengths can be achieved using less material.

8. Health Concerns

Working with wet concrete requires a number of precautions, primarily to protect the skin from the high alkalinity. Rubber gloves and boots are typically, all that are required to provide protection.

Concrete is generally very safe; it has been one of the most inert of our building materials. As concrete production has become higher-tech, however, that is changing.

A number of chemicals are now commonly added to concrete to control setting time, plasticity, pumpability, water content, freeze–thaw resistance, strength, and colour.

Workability agents or superplasticizers can include such chemicals as sulfonated melamine–formaldehyde and sulphonated napthalene formaldehyde condensates.

Air-entraining admixtures function by incorporating air into concrete to provide resistance to damage from freeze–thaw cycles and to improve workability. These materials can include various types of inorganic salts (salts of wood resins and salts of sulphonated lignin). Fungicides, germicides, and insecticides are also added to some concretes. Because of these chemical admixtures, today concrete could conceivably off gas small quantities of formaldehydes and other chemicals into the indoor air.

Concrete floors and walls can cause moisture problems and lead to mold and mildew growth, which cause significant health, which cause significant health problems in certain individuals. There are two common sources of moisture: moisture wicking through concrete from the surrounding soil and moisture from the house that may condense on the cold surface of concrete. To eliminate the former, provide good drainage around a foundation, damp proof or waterproof the outside of the foundation walls before backfilling, provide a layer of crushed stone beneath the slab, and install a polyethylene moisture barrier under the slab (protected from the concrete with a layer of sand if possible). To reduce the likehood of condensation of concrete surfaces, they should be insulated.

9. Conclusions

Cement and concrete are vital components in building construction today. Concrete has many environmental advantages, including durability, longevity, heat storage capability, and chemical inertia. In many situations concrete is superior to other materials such as wood and steel. But cement production is very energy intensive – cement is among the most energy-intensive materials used in the construction industry and major contributor to CO_2 in the atmosphere.

To minimize environmental impact, we should try to reduce the quantity of concrete used in buildings, use alternative types of concrete (with fly ash), and use that concrete wisely.

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"Gheorghe Asachi" Technical University of Iaşi,
Department of Concrete Structures, Building Materials, Technology and Management
e-mail: danbabor@ce.tuiasi.ro
dianaplian@ce.tuiasi.ro
ljudele@ce.tuiasi.ro

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IMPACTUL BETONULUI ASUPRA MEDIULUI

(Rezumat)

Industria cimentului şi betonului este într-o continuă dezvoltare. Utilizarea betonului, precum şi a altor materiale cu caracter cimentoid, în corelaţie cu mediul înconjurător prezintă avantaje precum şi dezavantaje. Se evidenţiază cîteva aspecte ale impactului utilizării acestor materiale de construcţii asupra mediului înconjurător.