Chapter 1
Sustainable Development in Concrete Production

1.1 Introduction

Environmental issues such as climate change and associated global warming, depletion of natural resources and biodiversity, water and soil pollutions, generation of huge amounts of waste materials and their disposal are some of the great challenges faced by present-day civilisation. The emission of large amounts of particulate materials and various noxious gases including CO_2, the major greenhouse gas, into the atmosphere, due to rapid industrial and population expansions, is a major environmental concern and urgent action is necessary to control it. Each of these issues creates serious crisis to the future development of humankind if they are not tackled properly. The evaluation of the impact of the current developments on the environment is therefore an important agenda for present-day policy-makers and several initiatives have already been taken to tackle the problems related to these issues. Thus the term "sustainable development" was developed, which proposes a developing society, where people will live in a healthy environment with improved economic and social conditions.

The term "sustainable development" gains much attention after a United Nations report, published in 1987 (UN report 1987). It gains further momentum after a declaration published in a United Nations conference held in 1992 (Rio Summit 1992) and after the world summit on sustainable development held in Johannesburg in 2002 (World Summit 2002). According to the UN report, the term "sustainable development" is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their needs (UN report 1987). The promotion of harmony among human beings and between humanity and nature is the main aim of sustainable development. However, several environmental, social and economic factors need to be considered to attain sustainable development. In this chapter, the environmental impacts of construction industry, more precisely the impacts of concrete production, on the environment will be focused.

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1.2 Sustainability in Construction Materials

The construction industry, one of the largest industries in the world, is notorious for having a major role on the emission of CO_2 into the atmosphere. Nowadays, the pace of development of this industry is increasing enormously all over the world especially in the developing countries due to rapid economic and industrial developments and consequent development of infrastructures and standard of living. As an example, currently, the construction industry is the second largest industry in India and the total investments in this sector account for nearly 11 % of the total gross domestic product (Construction Industry in India 2008). Similarly, the construction industry in China has been experiencing consistent growth for a long time and each year China spends nearly 16 % of its gross domestic product in this sector (China construction industry no date). By the end of 2001, about 36.69 million people in China worked on the construction sector. The construction industry is responsible for 7 % of total employment in the European Union (EU) and in the EU, the US and Japan combined, it employs more than 40 million people (OECD 2008).

The residential sector consumes huge amounts of energy all over the world. The energy used in the construction sector comprises direct use at the construction site and indirect energy used in the manufacture of the building materials. In the EU, about 40 % of total final energy is consumed by the residential and tertiary building sectors (Koukkari et al. 2007). According to Joseph and Tretsiakova-McNally (2010), building construction in the world consumes around 25 % of the global annual wood harvest; 40 % of stone, sand and gravel; and 16 % of water and also generates 50 % of the global output of greenhouse gases and agents of acid rains. The rapid expansion of this sector is creating a huge environmental problem all over the world and therefore recently several initiatives have been taken to tackle such problems.

To evaluate the environmental impact of construction materials, several issues need to be considered, namely collection, treatment and production of raw materials, construction, service life and demolition and disposal. In the whole process of construction, service life of the building and its demolition, not only huge amounts of energy of all sectors are consumed but also huge amounts of CO_2 emissions are created. These activities also consume huge amounts of most non-energy-related resources, create high volumes of waste and are responsible for enormous pollution in the atmosphere, soil and water. The uses of energy and the emission of CO_2 take place at various steps, such as raw material extractions, transportation, manufacture, demolition, service life and waste processing. Table 1.1 shows a typical example of calculation of the emitted amount of CO_2 into the atmosphere at the various steps of a building life cycle (BIS 2010).

Thus, by considering the size, importance, resources use and environmental impact of the construction industry, it is necessary to produce sustainable construction materials with increasing service life but minimum maintenance future needs. Sustainability in construction is also inevitable due to stringent regulations

Table 1.1 CO_2 emitted into atmosphere at the various steps of a building life cycle (BIS 2010)

Steps	Amount of CO_2 emitted	
	Quantity (Mt)	%
Design	1.3	0.5
Manufacture	45.2	15
Distribution	2.8	1
Operation on-site	2.6	1
In use	246.4	83
Refurbishment/demolition	1.3	0.4
Total	298.4	100

that have been adopted all over the world on the emission of greenhouse gases including CO_2 into the atmosphere to limit the rise of the global average temperature. As for example, EU is currently promoting a goal of 30 % reduction in greenhouse gas emissions by 2020 compared to 1990 levels in developed countries (Koukkari et al. 2007). The targets for various measures up to 2020 in the EU include (Koukkari et al. 2007):

- 20 % improvement of energy efficiency of cars, buildings and appliances and especially:
- 30 % reduction of final energy use of buildings;
- 20 % share of renewable energy on average;
- 10 % share of biofuels;
- Nearly 0 % emissions of new power plants.

Several factors such as energy saving methodologies and techniques, improved use of materials, increasing service life of products, further reuse/recycle of materials, eco-designing and emission control need to be considered for the development of sustainable construction materials. The durability of construction material is another factor that needs to be considered seriously for sustainable construction. A durable building material has a technically better and longer service life and therefore reduces the cost and amount of materials used in repair and in new constructions in a particular time period.

Material efficiency is one of the most important components of sustainable construction materials. Correct selection of materials by taking into account their complete service lifetime and by choosing products with minimal environmental impacts can reduce CO_2 emissions by up to 30 % (González and Navarro 2006). Without compromising on the quality of the end product, the use of locally produced materials as well as of renewable and recycled sources should be encouraged. In this way, transportation costs and problems associated with the disposal of other industrial waste can also be reduced. The recycling/reusability of construction products at the end of their service life should also be considered during the selection of materials. Higher recycling/reusability of construction products after their service life can reduce the generated amount of waste and associated disposal problems.

Other factors that greatly affect the selection of building materials are their costs and social requirements such as thermal comfort, good mechanical properties (strength and durability), aesthetic characteristics, health effect and the ability to build quickly. For example, the use of some building materials such as paints, treated wood or foams can have a toxic effect on the occupants of a building and therefore should be considered carefully. Ideally, the combination of all environmental, economic and social factors can give a clear description of a material and thus helps in a decision-making process regarding the selection of the materials suitable for buildings (Abeysundara et al. 2009). According to Calkins (2009), the materials that reduce the use of resources, minimise environmental impacts, pose no or low human health risks during their handling and service life, assist with sustainable site design strategies can be considered as sustainable construction materials.

Several codes and policies have been developed for environmentally efficient, carbon neutral, eco-designed building constructions. For example, the European commission developed a policy that takes into consideration the whole life cycle of the product, comprising three main phases: environmental impact of the products, environmental improvement of the products and policy implications. However, several problems still exist in addressing the issues related to sustainability in construction such as lack of innovation or inadequate level of skills. In the following section, sustainability in concrete production, the major construction material, will be briefly highlighted.

1.3 Sustainability in Concrete Production

Concrete is the major construction material and plays a vital rule in the development of current civilisation. It is the most used man-made material in the world since its invention. Worldwide, about three tonnes of concrete are used annually per person (Cement Concrete Aggregate Australia no date). The consumption of concrete as construction material in the world is over twice the total consumption of all other building materials including wood, steel, plastic and aluminium. It is reported that the total annual concrete production in the world is more than 10 billion tonnes (Meyer 2009). More than 0.9, 5 and 0.6 billion tonnes of Portland cement, aggregate and potable water, respectively, are necessary for the production of such an amount of concrete. The massive use of concrete as a construction material is due to its versatile properties. Properties such as strength, durability, affordability and abundance of raw materials make concrete the first choice material for most construction purposes. However, concrete production has several negative impacts on the environment, such as the emission of CO_2 and other greenhouse gases and the use of non-renewable natural resources like natural stone and water, and therefore a lot of attention has been paid recently to tackling the environmental issues related to their use in concrete preparation.

Concrete comprises various constituents and therefore the environmental impact of concrete production is a complex mechanism partly governed by the individual impacts from each of these constituents and partly governed by the combined effect of the constituents when they are mixed together. Therefore, sustainability issues related to concrete production need to be addressed by considering the individual as well as the combined effects of these constituents. On the other hand, improvement in concrete design, mechanical and durability properties and service life of concrete also need to be considered seriously as these factors also influence the environmental impact of concrete. These points will be presented briefly in the following sections. Table 1.2 outlines some topics related to the sustainability of concrete production (Eco-Serve).

1.4 Sustainability in Concrete by Improving Properties and Service Life of Concrete

The reduction of the environmental impact of concrete structures to a minimum without compromising on their performance is one of the major concerns for future sustainable development of the concrete industry. Sustainability in concrete production can be achieved by improving current practices, e.g. improvement or innovation in concrete mix and product design approaches (Khokhar et al. 2010, Joseph and Tretsiakova-McNally 2010), improvement of the performance of concrete-based products in their service lives. The improvement of mechanical and durability performances of concrete in their service life can indirectly reduce the CO_2 emission by increasing their service life and reducing the requirements of materials for repairing. In a report, it was estimated that reducing the volume of concrete by improving its mechanical strength can decrease the emissions of CO_2 by around 30 % (Habert and Roussel 2009). The use of innovative types of concrete such as high and ultra-high strength concrete and self-compacting concrete can also increase the sustainability in concrete production by giving flexibility in product design and by increasing material performance (Joseph and Tretsiakova-McNally 2010). Recent developments in self-healing concrete, which can repair cracks automatically, is an important step towards gaining sustainability in the concrete industry (Dry 2000). The use of innovative approaches in designing concrete and in using innovative materials in residential and commercial building sectors, one of the major users of concrete materials, can also reduce the amount of energy used during its service life. For example, phase change materials (PCM) can be used to increase the energy storage capacity of buildings and also to control the room temperature of buildings in summer and winter (Benz and Turpin 2007).

The use of polymeric materials as admixtures and for repair purposes and the application of nanotechnology are some recent innovations in concrete preparation, which also gives several economic and technical benefits towards obtaining sustainability. The addition of polymeric admixtures can improve several

Table 1.2 Sustainability issues in concrete production (Eco-Serve)

Environmental impact category	Societal issues	Economical issues	Some solutions
1 Land-use and exploitation of natural resources (excavations, quarrying, ground water and lime stone), mainly connected with the production of concrete constituents	Recreation versus industry. Planning of land-use. Utilisation of scarce resources.	Transportation cost. Use of local materials versus imported materials.	Innovation in production and processing of raw materials
2 Waste products from concrete production (washing/mixing water, cement slurry, form oil, rejected concrete and excess production)	Land-filling with the risk of leaching of heavy metals and hydrocarbons. Sorting and reusing.	Landfill taxes. Recycling into production. Demand from other industries.	Reusing waste materials generated within concrete production as well as from other industries
3 Emissions and energy consumption (CO_2, SO_2, embodied energy throughout production, transport and construction)	Commitment to reduce greenhouse effect and to behave in an energy conscious manner.	Energy taxes. Up-to-date production equipment and methods.	Reducing clinker content by blending other materials, optimising concrete mix design
4 Working environment (noise, vibrations, dust, accidents etc.)	Health problems.	Expenses for hospitalization and sick leave. Automated production equipment and methods.	By improving automation in concrete production, use of innovative concrete product such as fibre reinforced concrete and self-compacting concrete.

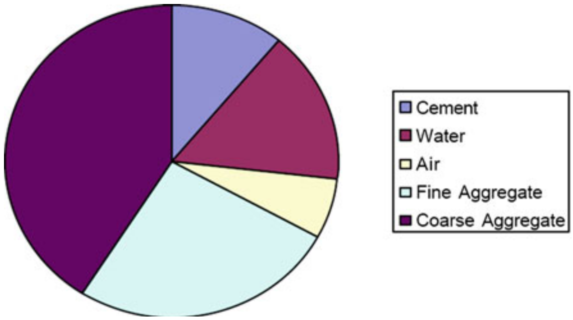


Fig. 1.1 Typical concrete mix

mechanical and durability properties of concrete and also indirectly reduce the emission of CO_2. Nanotechnology can provide huge opportunities towards gaining sustainability in concrete preparation. Improved understanding of nanostructure of cement hydration product, the only binding phases in concrete using nanotechnological tools, the use of nanomaterials such as nano silica, nano alumina and nanofibres in concrete preparation, the use of photo-catalysts such as nano TiO_2 for self-cleaning of concrete products, and the use of nanotechnology to monitor the performance during service life of concrete, are some of the recent inventions, which definitely decrease the environmental impact of concrete (Mukhopadhyay 2011). However, the toxic effect of nano-based products in human health during manufacturing and the service life of the resulting concrete products must thoroughly be investigated before their applications.

1.5 Sustainability in Concrete by Innovation in Concrete Constituents

Concrete mainly consists of at least three constituents: cement as a binding material, aggregates, the major part of concrete (normally accounting for 70–75 % of its volume) and water. A typical concrete composition is shown in Fig. 1.1. Each constituents of concrete has its own environmental impact; however, the sustainability of concrete as a material is strongly influenced by the cement and aggregate industries. The sustainability in water use in concrete has also become a big issue recently due to the huge consumptions of potable water during concrete preparation as well as the scarcity of potable water faced all over the world. Sustainability in water, cement and aggregate use in concrete preparation is highlighted in the remaining sections.

1.5.1 Sustainability in Water Use

The production of concrete needs huge quantities of potable water. About 15–18 % of the total volume of structural concrete mix is water. The concrete industry uses around 1 trillion gallons of water per year worldwide (Meyer 2005). Recent scarcity of water in many parts of the world requires the sustainable use of water in concrete production. Therefore, searching for alternative sources of concrete mixing water is necessary for sustainable growth of the concrete industry. Several types of waste or non-potable water can be considered, after treatment, as mixing water and some information is available in the literature to evaluate the acceptability of water used in concrete mixing (Abrams 1942; Steinour 1960; Kuhl 1928a, b; Neville 1997; Lobo and Mullings 2003; Cebeci and Saatci 1989). The waste water generated in concrete production can be a good option and in this way concrete production units can reach complete sustainability in terms of materials use with zero discharge. The waste water generated from sewage treatment and after domestic, agricultural and industrial use can also be considered for concrete mixing if these water samples meet some specific criteria in terms of concentrations of deleterious constituents. Seawater cannot be considered as a source of concrete mixing water due to presence of large amounts of chlorides.

Standards such as European EN 1008 (2002) and American ASTM C 1602-06 (ASTM C1602) regulate the quality of concrete mixing water, i.e. impose the restriction on the amount of deleterious components in water and allow using some type of recycled water in concrete mixing. It can be stated that some alternative sources of water can be considered as mixing water after treatment; however, while searching for an alternative source, the effect of chemical contaminants present in water on the properties of concrete produced and the health effect of chemical and biological constituents during handling must be considered seriously.

The preparation of concrete using less water by innovating in concrete mixing methodology and the use of water reducing admixtures in concrete are two good options that can help to achieve sustainability in water use in concrete preparation. The addition of chemical admixtures can reduce up to 20 % of water (Cement Concrete Aggregate Australia 2010).

1.5.2 Sustainability in Cement Production

Cement is one of the major constituents of concrete and therefore huge amounts of cement are produced all over the world. According to a report (EPA 2004), the world total annual production of hydraulic cement was about 2 billion metric tonnes (Gt) and this quantity of cement was sufficient to produce about 14–18 Gt/year of concrete (including mortars), and makes concrete the most abundant of all manufactured solid materials. In a recent report (US Geological Survey 2011), it was stated that the world annual production of cement in 2010 was 3,300 million

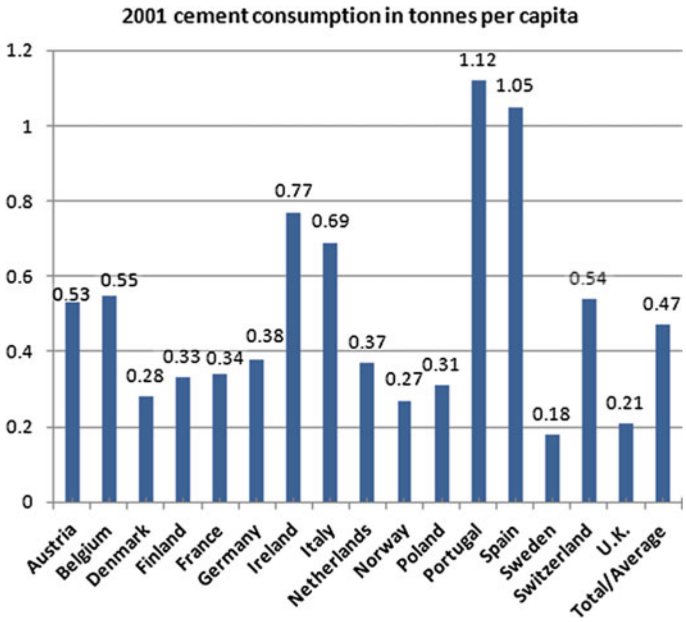


Fig. 1.2 Total annual cement consumption per capita in some European countries (Eco-Serve no date)

Table 1.3 CO_2 emissions from cement and concrete production (Wilson 1993)

	Amount of CO_2 emitted in production per		% of total CO_2
	Ton of cement (lbs)	Cubic yard of concrete (lbs)	
Source of CO_2 emission from energy use	1,410	381	60
Source of CO_2 emission due to limestone calcining	947	250	40
Total CO_2 emission	2,410	631	100

tonnes. Figure 1.2 shows the total annual consumption of cement per capita in some European countries in 2001.

The production of cement poses several sustainability issues that need to be handled properly to lessen the environmental impacts. The production of cement is a highly energy consuming process. The formation of cement clinker generally occurs at about 1,450 °C and limestone is the major source of raw material. According to Getting the Numbers Right (GNR) data for the year 2006 (CSI Report 2009), the thermal energy consumption for the production of one tonne of cement clinker was 3,690 MJ.

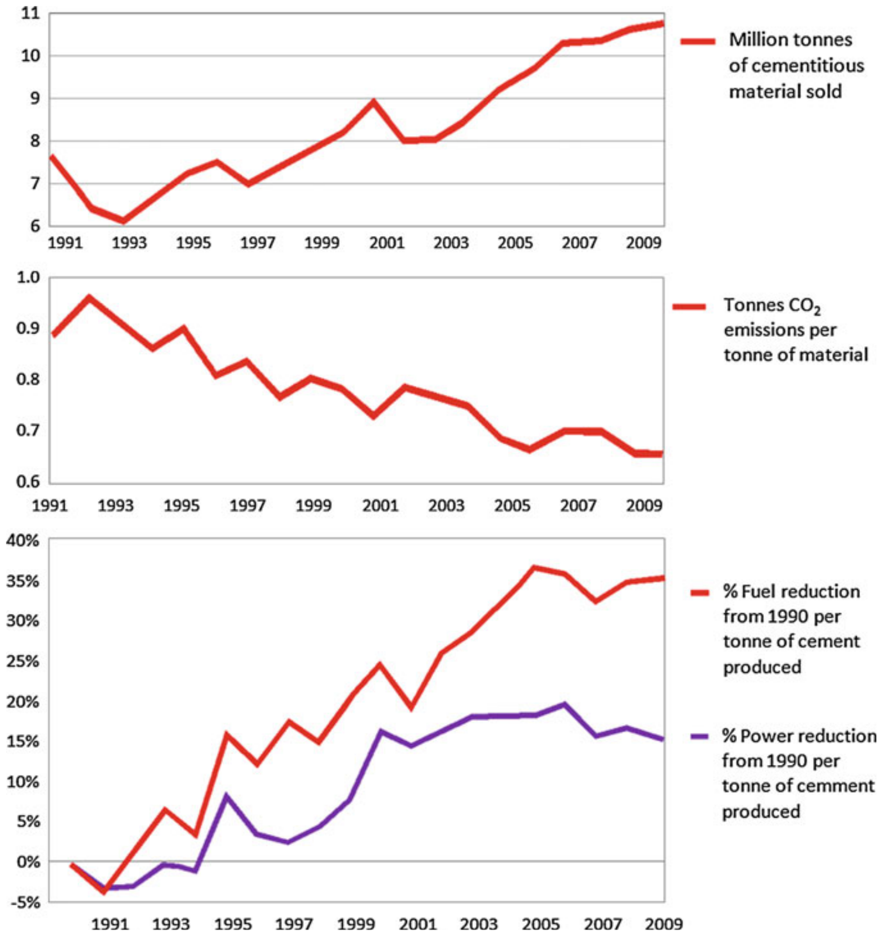


Fig. 1.3 Reduction in CO_2 emission and increase in fuel and power efficiency in Australian cement industry due to sustainability initiative (Cement Concrete Aggregate Australia, 2010)

After the power sector, the cement industry is one of the major CO_2 emitting sectors. The use of huge amounts of fuel as well as de-carbonation of limestone emits massive amounts of CO_2 and other gases into the atmosphere. It is widely accepted that the production of one tonne of cement roughly emits 1 tonne of CO_2. Table 1.3 shows the amount of CO_2 that is emitted during the production of cement and concrete. Therefore, the major focus to achieve sustainability in the cement industry is the reduction of greenhouse gases including CO_2 emissions into the atmosphere.

For a long period, cement industry has been working steadily to increase processing efficiency and decrease energy consumption due to significant consumption of energy as well as the emissions of toxic gases and particulate matters including CO_2 during cement manufacturing. These efforts also reduce the negative environmental impact of the cement industry.

For example, due to improvements in fuel efficiency as well as in power utilisation technology in Australian cement manufacturing industries, a reduction of about 23 % in emission of CO_2 per tonne of cement production was observed in 2009, in comparison to that observed in 1990, which is depicted in Fig. 1.3 (Cement Concrete Aggregate Australia 2010). However, the application of modern technology to reduce CO_2 emissions and improving the fineness of cement clinker for getting better technical properties can increase the thermal and electrical energy consumptions. Research is going on to develop nano-catalyst to reduce the clinkering temperature which will subsequently reduce the emission of CO_2 (Sobolev et al. 2006).

One recent global effort is the "The Cement Sustainability Initiative (CSI)". A total of 24 major cement producers, which account for about one-third of the world's total cement production with operations in more than 100 countries, got together to reach the goal of sustainability in cement industry. In this initiative, four points were identified to control the emission of greenhouse gases: thermal and electric energy efficiency, alternative fuels, clinker substitution, carbon capture and storage (CCS) (CSI Report 2009). Except for the last point, which is still at a demonstration stage, positive impacts of the other three points can already be seen.

Carbon capture and storage (CCS) is not yet a fully developed technology and additional research and demonstration are necessary to get benefits from this technology. However, several feasibility studies were already conducted and gave promising results. Post combustion capture techniques such as chemical absorption, membrane technology, oxy-fuel technology and carbonate-looping technology are some promising technologies that can provide solutions to control CO_2 emission. Moreover, technological, societal and economical aspects of these technologies must properly be addressed before their application.

In the next two sections, two common practices used to reduce global fuel consumption and emissions of CO_2 into the atmosphere of the cement industry, namely the use of alternative fuels and waste materials, will be briefly described.

1.5.2.1 Use of Waste Materials in Cement Kiln and Clinker Production

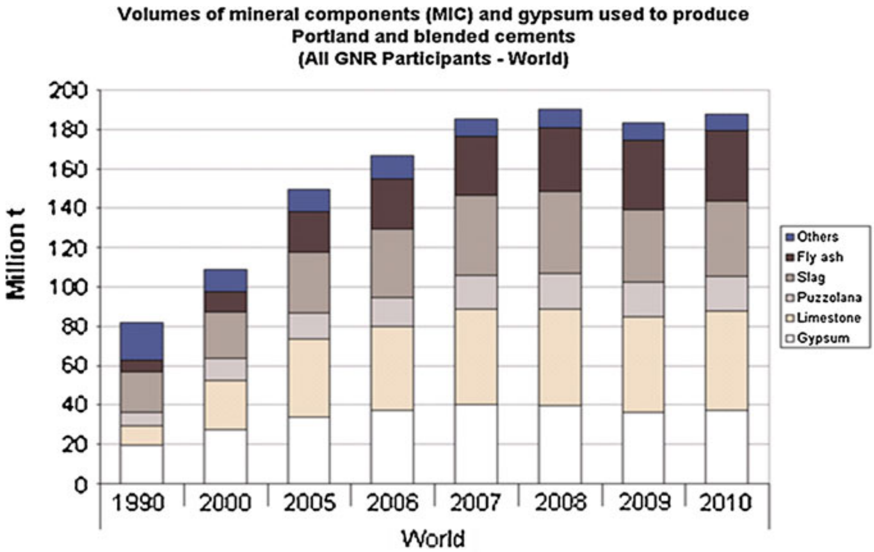
Several waste materials are nowadays used in cement kiln either as alternative fuel or as raw materials. According to a GNR report in 2006 (CSI Report 2009), globally 7 % of total fuel energy consumption in manufacturing of cement came from alternative fuels comprising biomass and energetic waste materials. Biomass has a great potential to be used as alternative fuel in cement kiln. Pure biomass such as animal meal, waste wood, saw dust and sewage sludge can be used to replace large amounts of fossil fuels and has the potential to reduce the emitted amounts of CO_2. Cement kilns can burn some waste materials such as used motor oil, spent solvents, printing inks, paint residue, cleaning fluids, waste textiles, papers and plastics, scrap tires, relatively more safely than an MSW incinerator because the extremely high temperatures in cement kilns result in very complete combustion with very low pollutant emissions (Knuttgen and Muench 2009; Wilson 1993). The use of waste materials in cement production can reduce the problem associated with their incineration or land-filling. Land-filling of these wastes could emit another greenhouse gas, methane, which has 21 times higher global warming potential than that posed by CO_2.

Some waste materials contain raw materials used in cement clinker manufacturing and therefore these materials can be used to replace some of the raw materials in cement clinker production too. The high temperature processing of waste in the production of cement clinker can destroy toxic organic compounds without the formation of dioxins, fix metals in the product and use mineral content as a constituent of clinker. Using some types of waste in clinker production may lower CO_2 emissions if the source of the calcium is different from $CaCO_3$. Extensive literature is available on the use of waste such as red mud, MSWI ash, steel mill scale, leather scraps and shavings, construction and demolition waste and various sludges in the production of clinker (Caponero and Tenorio 2000; Espinosa and Tenorio 2000; Galbenis and Tsimas 2006; Monshi and Asgarani 1999; Saikia et al. 2007; Trezza and Scian 2007; Vangelatos et al. 2009). The increasing production of belite-based cement can also reduce fuel requirements, which has also been an active research area for a long time (Odler 2000).

1.5.2.2 Blended Cement: Reduction of Clinker Content in Cement

A significant proportion of the total cement used in the world was of blended cement, produced by replacing a given amount of normal cement by supplementary cementing materials (SCM). According to GNR data (Geragthy no date), the global ratio of clinker to cement was 78 % in the year of 2006. Thus, about 400 million tons of clinkers in 2,400 million tons of cement produced on 2006 were replaced by other materials. Several natural materials such as natural pozzolans, ground limestone and waste materials such as blast furnace slag, coal fly ash and silica fume are extensively used as SCM in the preparation of blended cement. The impact of these materials on the properties of concrete is already well-known and reviewed extensively (Taylor 1997). The use of any type of SCM in cement production is location specific depending upon its availability. Similarly the whole amount of a waste material cannot be used in concrete preparation. For example, fly ash is produced in coal fired power plant and fly ash containing high amount of carbonaceous materials cannot be used as SCM. Fig. 1.4 shows the annual use of some SCM and gypsum by world-wide GNR participants to produce blended cements and Portland cement as reported in a CSI GNR Data (2010).

The reduction of the amount of cement used in the production of cement mortar and concrete by the use of natural and waste materials as SCM lowers the atmospheric emission of CO_2, reduces energy consumption, improves several concrete properties with increased service life and conveniently reduces the



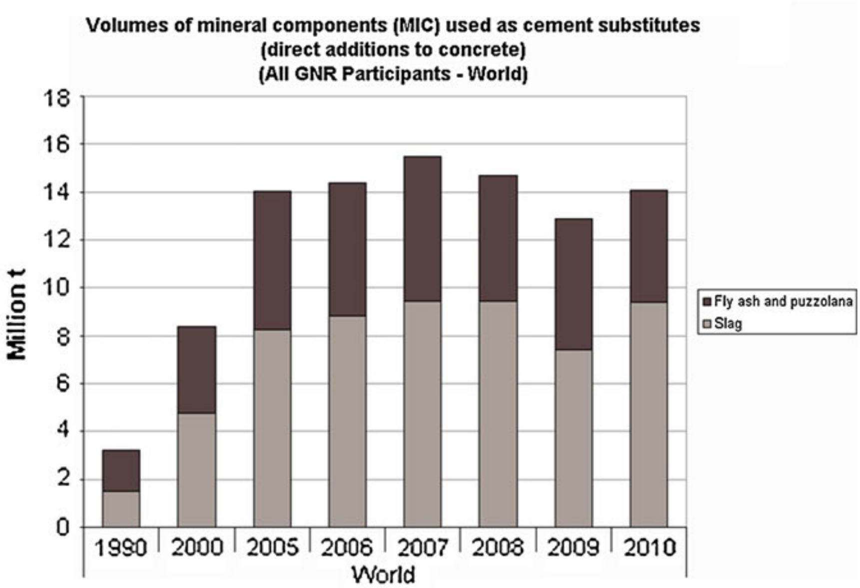


Fig. 1.4 Annual use of supplementary cement materials (MIC) in the preparation of blended cement and Portland cement by the cement industry (CSI GNR Data 2010)

problems associated with the disposal of these waste materials (Roskovic and Bjegovic 2005; Anand et al. 2006, Taylor 1997). Roskovic and Bjegovic (2005) observed around 25 and 29 % reduction in CO_2 emissions due to the substitution of 25 and 30 % of cement clinker by fly ash and slag respectively.

1.5.3 Sustainability in the Aggregate Industry

It is estimated that the global demand for aggregates used in construction is growing 4.7 % annually and in 2011 the global demand was 26.8 billion metric tons with a cost of $201 billion (Indian Concrete Journal 2008). Aggregates typically account for 70–80 % of the concrete volume and nearly for 92–96 % of asphalt pavement. Therefore, they play a substantial role in concrete properties such as workability, strength, dimensional stability and durability. Conventional concrete contains sand as fine aggregate and gravel in various sizes and shapes as coarse aggregate. Aggregates are one of the most abundantly used materials due to being major constituents of concrete.

Both fractions of aggregates (fine and coarse) are normally collected by mining. Sand and gravel are mined in two major techniques: in-stream extraction and land mining. Mined aggregates and rock are obtained by various ways such as blasting and dredging. Aggregates can be used at the size produced by nature due to weathering or after crushing larger stone. Washing, blending to grading requirements are generally done after extraction and processing of aggregates. As the fuel, labor and maintenance costs are the major expenses of the aggregate industry, aggregates are normally mined near the intended market because the cost of transportation is the major expense in this industry (Meador and Layher 1998, Ayenagbo et al. 2011).

In comparison to the environmental impact from cement production, aggregate mining or production has little impact as only simple extraction without fundamental alteration of material is necessary to obtain aggregates. However, recently, the mining of aggregates and rock is becoming an ecological problem in many parts of the world as the demand for sand and gravel is increasing rapidly due to rapid infrastructure activities all over the world. Aggregate mining is now creating ecological imbalance in several ways: damaging biodiversity of nearby areas, causing erosion in the coastal and river bank, polluting water by increasing turbidity and suspended solid mater, destroying livelihood of the peoples that rely on fishing, increasing flood, noise and dust pollutions, damaging landscape and generating waste in mining as well as in the processing sites. The mining, transportation and processing of aggregates also consume energy and therefore those processes also emit CO_2 into the atmosphere, although not so significant as that observed in cement production.

However, these problems are region specific and can be overcome by proper planning and policy implementation. The reclamation and stabilisation of pits, surface quarries and underground mines that result from aggregate mining should also be done. Another way that can make the aggregates industry more sustainable is through increased efficiency and improved technology in extraction and processing of aggregates. Reduction in dust during the processing stages is also important.

Sustainability in concrete production can be achieved by innovation in aggregate use too. The scarcity of high quality aggregates in construction sites can be solved by proper engineering of local aggregates to produce quality concrete, which will help to overcome CO_2 emission problem. The use of rejected aggregates in aggregate processing plants should also be considered in the future. The use of waste materials as aggregate in concrete is another good option to meet the sustainability goal in concrete production.

1.6 Use of Waste Materials as Aggregate in Concrete

The production of waste materials is an unavoidable stage of all industrial and human activities. This waste is now creating big environmental and economic problems all over the world. The management and treatment of industrial solid waste and municipal waste has recently been gaining importance worldwide. This waste ranges from relatively inert, e.g. glass bottles, excavated soil, construction and demolition waste, to hazardous waste with high concentrations of heavy metals and toxic organic compounds. Several discussions and initiatives were already taken to decrease the amount of waste production and its recycling/reusing. Several benefits can be achieved by recycling waste materials in other processes, such as decrease energy consumption, solve disposal problems, reduce deforestation and natural resources and reduce the health risks on human and other biotic components.

In 2004, 2006 and 2008, the total generation of waste in the 27 countries in European Union amounted to 2.68, 2.73 and 2.68 billion tonnes, respectively (Eurostat 2011). According to this statistics, each European Union citizen produced on average about 5.2 tonnes of waste in 2008 of which 196 kg were hazardous. Construction (859 million tonnes or 32.9 % of the total) and mining (727 million tonnes or 27.8 % to the total) are the major economic sectors that generated the greater part of wastes in 2008 (Fig. 1.5a). Out of the total waste generated from these two sectors, 97 % of waste was mineral waste or soils (excavated earth, road construction waste, demolition waste, dredging spoil, waste rocks, tailings etc.). The share of mineral waste and soils in relation to total waste and total hazardous waste produced was 65 % (Fig. 1.5b) and 41 %, respectively.

Substantial amounts of waste materials are also recovered, as seen in Fig. 1.6a. In the case of non-hazardous mineral waste originating mainly from construction and mining activities amounted to 754 million tonnes and represented 69 % of the total waste recovered (Fig. 1.6a). The recoveries of all types of waste also gradually increased from 2004 to 2008. For example, the recovery of mineral waste and animal and vegetable waste increased from 2004 to 2008 by 177 million tonnes or 31 % and 15 million tonnes or 30 %, respectively. The recovery rates of some waste materials over time are presented in Fig. 1.6b.

Sustainability in the construction sector can also be achieved by reuse/recycling of waste produced in several other industrial processes as raw materials or as secondary energy sources in construction material production; nowadays, cement and concrete production consumes huge amounts of these materials. Waste

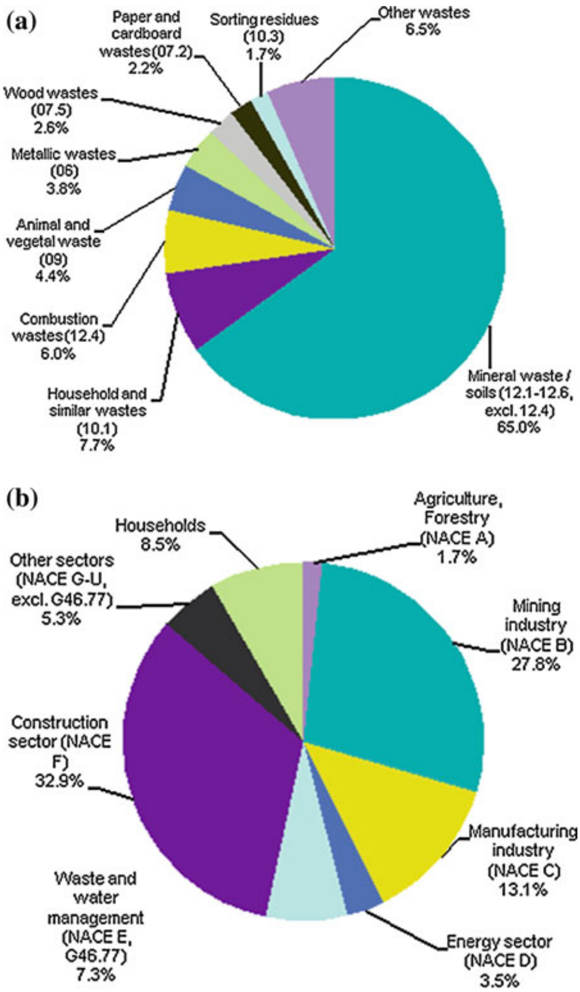


Fig. 1.5 The generation of total waste in European Union according to: **a** economic activity, **b** waste categories (Eurostat, 2011)

materials can be used as fuel in cement kilns or in brick preparation, as raw material for cement clinker/brick, as mineral additions to cement, or as granular material in cement mortar and concrete production.

Although vast amounts of waste material can be consumed in the production of cement clinker and blended cement, that consumption can be increased substantially if waste is used as aggregate in cement mortar and concrete. The use of waste material in this way can also solve problems of shortage of aggregates in construction sites, reduce environmental problems related to aggregate mining and, in some cases, reduce the cost of concrete production. The interest in using waste materials as aggregates is rapidly growing all over the world, and significant research is underway on the use of construction and demolition waste, granulated

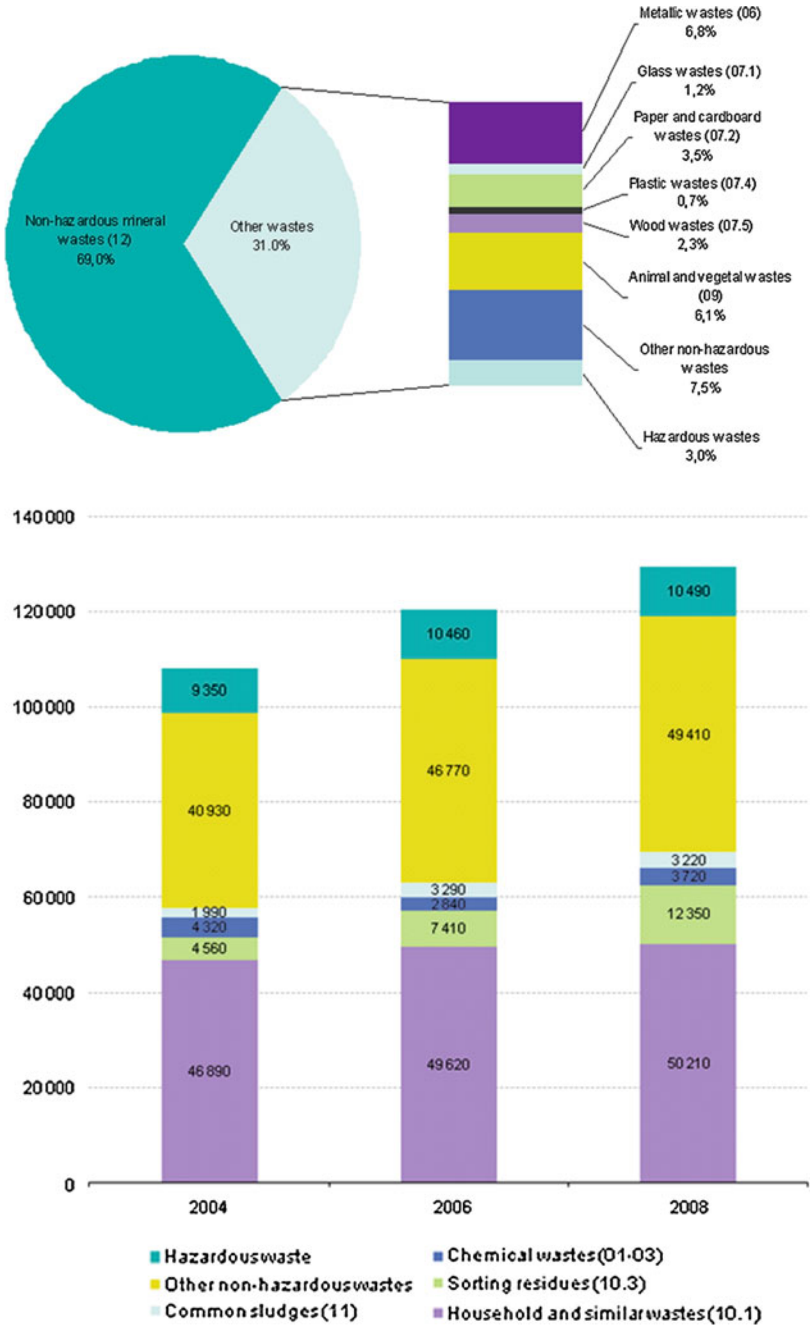


Fig. 1.6 Recovery of various waste materials in European Union in 2008 (Eurostat 2011)

coal ash, blast furnace slag, waste glass, waste plastics, rubber waste, sintered sludge pellets and other materials as replacement for traditional aggregates.

Depending on its properties, waste can be used in the cement and concrete industry without treatment or after treatment. Some types of waste have to be treated because they contain detrimental components or perform poorly. Preliminary physico-chemical and mineralogical characterisation of waste is therefore necessary before using the material in cement-based systems. Waste materials may be mixed with other materials to prepare aggregates too. Most industrial and municipal waste contains quite large amounts of toxic constituents, and therefore waste that contains contaminants should also be assessed for environmental impact as part of a proper evaluation of any waste materials that may be used as constituents in concrete. This indicates that chemical, civil, material and environmental engineering approaches are necessary before waste can be used safely and effectively in the construction industry.

However, before application of waste materials in construction, the cost factor needs to be considered seriously as it plays a vital rule particularly in the replacement of low-cost materials such as aggregates. To analyse the feasibility of a waste material as aggregate in concrete production, it is necessary to check factors such as possible environmental impact of waste if it remains unused for a long time, existence of other cost effective technology to recycle waste, comparison of cost of waste material with natural aggregates and technical feasibility of end-product. The identification of special properties inherent to recycled materials, which can show the advantages of waste material-based product over natural aggregates-based product, can be beneficial to reach the technical as well as economic viability of the use of waste materials (Meyer 2005).

1.7 Overview of the Book

The contents of this book describe comprehensively the use of several waste materials as aggregates in concrete production. The book is divided into a total of seven chapters including introduction. The second and third chapters describe the properties of industrial waste and construction and demolition waste used as aggregates respectively. The fourth and fifth chapters describe the properties of concrete containing aggregates generated from industrial waste and construction and demolition waste respectively. The sixth chapter discusses a quantitative procedure developed by the authors to estimate the properties of concrete containing construction and demolition waste as aggregates. In Chap. 7 current codes and practices developed in various countries to use construction and demolition waste as aggregates in concrete preparation are discussed.

The most promising waste that can be used as aggregate in the production of new concrete is that generated from demolition of construction materials. The waste generated from old concrete structures is one of the largest single components of solid waste and a promising material that can be used as aggregate in new concrete

Table 1.4 Produced and recycled amounts of concrete and asphalt pavement wastes in three European countries (Oikonomou 2005)

Country	Year of reporting	Type of waste	Amounts in millions metric ton	
			Produced	Used
Sweden	1999	Asphalt pavement	0.80	0.76
Denmark	1997	Demolition waste	1.5–2.0	Small quantities
		Concrete	1.06	0.90
		Asphalt pavement	0.82	0.82
		Ceramics (bricks, etc.)	0.48	0.33
Germany	1999	Asphalt pavement	12	6.0
		Other road materials	22	11
		Demolition waste	23	4.0
		Building and demolition waste	9.2	9.2

preparation. This waste is produced in the demolition of old structures and in destructions due to natural calamities. In a report in 1996, it was reported that each person of the European Union generated annually, on average, 500 kg of construction rubble and demolition waste (Oikonomou 2005). So, by considering a similar situation in other parts of world, it can be seen that a huge amount of concrete rubble and other construction waste is generated annually all over the world. Recycling of this waste should be encouraged because of reasons such as sustainable development of construction and concrete industries, protection of natural resources from further depletion and overcoming disposal problems. Therefore, recycling of construction waste as aggregate in concrete production is widely practiced in several European countries and in Japan. Table 1.4 shows generated and recycled amounts of some construction wastes in three countries in Europe.

The use of construction rubble as aggregates in new concrete production is a promising option to deal with the costs involved in the disposal of this waste, the scarcity of natural aggregates and the cost necessary for transportation of natural aggregates. However, several technical challenges need to be overcome to produce high-quality waste construction-based aggregates that can be used in all confidence to replace natural aggregates. If the economics related to recycling allow, it is also necessary to determine the possible application of this type of aggregate where the quality of the aggregates is less important. Several standards and codes of practice for using concrete rubble as aggregates in concrete preparation were developed and implemented in several countries, which is helping to achieve a much needed sustainability in the construction sector.

1.8 Conclusions

In conclusion, it can be stated that the implementation of stringent rules and regulations to overcome the impact of present development on the environment as a result of increasing global consensus on environmental issues require looking for sustainable development in various industrial sectors including the construction industry. Subsequently several steps have been initiated to minimise the impact of construction industry on the environment and to adjust on time to the changing political and societal scenario. Sustainability in construction is a complex issue that can be achieved by considering several individual factors that need to be addressed properly, some of which are briefly discussed in this chapter. Vast amounts of waste materials, an inevitable subproduct of human activities, are creating several environmental and economic problems, but are presently used or about to be used for construction purposes. The use of this waste will enhance the environmental suitability of construction industry and help in attaining the sustainability in construction sector. To use various waste materials as aggregates in concrete preparation, changes in the existing specifications and codes should be made without compromising the quality of the product.

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