Low carbon building materials for sustainable construction

Said Kenai¹), *Belkacem Menadi²) and Jamal M Khatib³)

¹), ²) Geomaterials and Civil engineering laboratory, University of Blida, Algeria, ³) Faculty of Science and Engineering, University of Wolverhampton, UK

¹)bmenadi@yahoo.com

ABSTRACT

The construction industry consumes a large amount of energy and natural resources. The amount of CO₂ emission from the building industry accounts for about 7% of the total CO₂ emission in some countries. Hence, actions should be taken to reduce gas emissions. In this paper, the negative effect of the construction industry and in particular building materials is explained. Remedial actions such as increasing recycling, reuse of materials and reduce water consumption are discussed. A review of sustainable construction practices through the authors’ research own work on low-carbon building materials is given. Some examples of actions undertaken in Algeria through research and practice are presented. This includes mainly the use of cement replacement materials, local materials, recycling and better design through better insulation.

1. INTRODUCTION

Sustainable development is usually defined as the satisfaction of present needs without compromising the ability of future generations to meet their own needs (Brundtland 1987). Hence, sustainability is the development at long-term that meets three aspects: environmental, social equity and economic efficiency. This requires reduction of the consumption of raw materials, water and energy. It requires also the conservation of natural resources and the reduction of greenhouse gases emissions. Sustainability has become an important element in the design and construction of the built environment. Although sustainability is a global problem that requires a global solution, the literature gives a clear picture of the current efforts towards sustainability in developed countries but there is little information on sustainability in developing countries. In this paper, the negative effect of the construction industry and in particular building materials on the environment is explained. Actions such as increasing the reuse of materials and recycling waste are discussed. Some examples of actions undertaken in Algeria through the authors’ research own work on low-carbon building
materials is given. This includes mainly the use of cement supplementary cementitious materials (local materials) as cement replacement materials in vibrated or self-compacting concrete, recycling of construction waste and better design through better insulation.

2. EFFECT OF THE CONSTRUCTION INDUSTRY ON ENVIRONMENT

The construction industry is the most intensive energy consumer with more than 70 million of oil equivalent. It is estimated to 43% of the final energy consumed per year. It is therefore, considered as the key sector in combating global warming, adverse impacts on the environment and depletion of fossil energy resources. It should be noted that the construction industry consumes considerable amounts of natural materials. Concrete industry has increasingly been considered as one of the largest contributors to the ecological changes. However, concrete is the most widely used construction material in the world and is essential for satisfying the demand for housing and infrastructure. More than 25 billion tons of concrete are produced annually and use about 3.4 billion tons of Portland cement worldwide per year (NRMCA 2008, Malhotra 2004, Kenai 2008). Figure 1 shows the contribution of different industries to energy consumption which clearly demonstrates the important contribution of the industry of building materials such as cement and steel. In addition to consuming natural materials and energy, in producing one ton of Portland cement about one ton of carbon dioxide is released into the environment. Sustainable development in construction should translate into improved quality of life, reusable and recyclable building components, protection of the environment, efficient use of natural resources, energy conservation, water and mobility minimization of energy and waste during design and construction, better design and finally design for long-service life.

![Fig. 1 Contribution of different industries to energy consumption (NRMCA 2008)](image-url)
3. SUSTAINABLE CONCRETE INDUSTRY SOLUTIONS

The following priority actions were identified and can improve the current situation. These are concerned with the use of local materials, use of waste recycling, among other solutions. The use of local materials should be encouraged to minimize energy consumption. This should reduce the need for extraction, processing, transportation and the associated reduction in construction cost. Lime can be used in masonry construction as partial substitute for Portland cement. Natural stone and stabilized earth blocks can replace fired clay brick in the construction of walls. Local gypsum can substitute for cement mortar as a rendering material. The application of these local materials is underway in different regions of the world.

3.1 Supplementary Cementitious Materials (SCM)

Cement production is energy intensive and, as a result, the industry is responsible for about 5% of global carbon dioxide emissions (WCED 2009). One of the best, technically proven approaches for reducing greenhouse gas emissions and energy use in manufacturing lies in reducing the amount of clinker in cement by substituting it with other cementing materials such as ground blast furnace slag, fly ash, natural pozzolana, marble powder, wheat husk ash, metakaolin and limestone (Hadjsadok 2012, Khatib 2009, Belaidi 2013, Menadi 2009, Zhang 2008). Currently, the ratio of clinker to cement in Europe is about 51%. To reduce maintenance and energy consumption, concrete can be used in highways as it reduces rolling resistance and therefore the fuel consumption of trucks. It also decreases the need for lighting and maintenance and increases the durability and useful life of pavements (Lemay 2011). Self-compacting concrete (SCC) is one of the concrete technologies contributing to sustainable development, by using filler materials such as quarry limestone powder, natural pozzolana, slag, marble powder, metakaolin.

3.2 Recycling of Construction Waste

World production of construction waste is estimated at 400 million. Recycled aggregates are produced from the construction waste with success and are used in pavement and concrete. However, in the Middle East, recycling industry is small. In Algeria, following natural disasters such as earthquakes and floods or by ageing and degradation, buildings, bridges and industrial facilities are demolished. This waste from construction and demolition is estimated at 2.2 Mt/year but little is recycled. In addition, natural resources in certain regions of the country as Algiers, have been exhausted, beach and rivers sands prohibited from use and hence aggregates are brought and transported for a long distance.

4. CASE STUDY

Algeria is a developing country with a high need for infrastructure and housing. Hence, priority is given to building new structures to overcome the shortage of schools, hospitals and roads. Nevertheless, it has adhered to most international environmental protocols, even though as a developing country it does not have fixed targets for reducing carbon dioxide emissions, and it has not made any voluntary pledge to do so.
In order to reduce the construction industry’s impact on the environment, a research project was conducted at the University of Blida in collaboration with the local cement manufacturers and construction companies. The main aim was to develop green cement for sustainable concrete using natural pozzolana and industrial by-products such as Ground Blastfurnace Furnace Slag and limestone fines. In this project, the effect of these materials, as a partial replacement for cement, on the performance of mortar and concrete and the use of recycled materials as aggregate in concrete were investigated. Funding agencies in Algeria are encouraging research on sustainable development by the incorporation of a higher content of industrial waste and local materials in concrete.

4.1 Recycled Aggregate Concrete
The use of recycled aggregates in concrete is one of the solutions for a sustainable construction. In Algeria it is estimated that more than two million housing units are needed. This requires large amounts of construction materials. The problem is compounded by the fact that river sand required to produce construction materials is becoming rare. Therefore, the recycling and reuse of building rubble presents interesting possibilities as it reduces waste disposal and conserves natural resources through the sustainable use of existing materials. Waste storage disposal facilities are becoming a serious environmental problem, especially in the main cities where disposal sites are limited. At present the waste from construction material factories, demolition sites, earthquakes and other natural disasters is rarely used in Algeria, hence there is a need for more recycling of waste. Crushed bricks as aggregate are of particular interest, because their use can considerably reduce the problem of waste storage and reduce the extraction of raw materials. In this context, a study was undertaken on the use of recycling materials from C&DW (bricks and concrete) in concrete. The project aimed to encourage the development of a recycling industry and waste recovery in Algeria. An experimental investigation on the physical and mechanical properties of concrete made with coarse and fine crushed bricks aggregate was undertaken (Debieb 2008). In this study natural aggregate (coarse, fine or both) was substituted (by weight) with crushed bricks at rates varying from 0 to 100%. The results of this investigation indicate that it is possible to manufacture concrete containing crushed bricks that give an adequate performance (Figure 2). A further investigation focused on the effect of aggregate contaminated with either chlorides or sulphates on the performance of concrete. The results showed it was possible to substitute natural aggregate with recycled contaminated aggregate to produce a sustainable concrete with comparable performance.
4.2 Durability of Vibrated Concrete With Cementitious Materials

In Algeria, most of the cement is being blended with SCM such as limestone, slag and natural pozzolana. At least six of the 12 Algerian cement plants use natural pozzolana in the production of cement, whereas two cement plants use limestone. These cement plants usually use about 15% of natural pozzolana or 10% of limestone filler by weight as a replacement for cement. Recently, some cement factories have been increasing the clinker: cement ratio up to 35% by using a combination of two materials (usually limestone and natural pozzolana). The effect of the interaction between limestone and natural pozzolana additions on the properties of cement mortar and concrete has been investigated. The properties investigated included strength, heat of hydration, chloride ion penetration, sorptivity and resistance to sulphate attack (Ghrici 2007; Kenai 2006, Kenai 2004). The results have shown that the partial replacement of cement with 20% pozzolana and 10% limestone reduces the sorption and chloride ion permeability of concrete when the water binder ratio (w/b) ratio was reduced from 0.6 to 0.4 (Figure 3). Therefore, ternary blend concrete exhibits a better chloride ion permeability performance than plain concrete and concrete with single material replacements for a w/b ratio of 0.6. The heat output is also lower, showing the advantage of using SCM in hot climates and in mass concrete. SCM such as slag and natural pozzolana improves the long term strength, resistance to sulfate attack and permeability of cement-based materials (Ghrici 2006, Kenai 2006). The heat of hydration is also lower, showing the advantage of using cement with additions in hot climates and in mass concrete.
4.3  Durability of Vibrated Concrete Containing Crushed Sand

There has been an increasing interest in limestone fines (LSF) from limestone quarries in concrete construction to overcome inherent efficiencies in river sand in particular regions of North Africa. Crushed limestone fine sand is a by-product of the quarry process and typically does not have a significant demand due to its high content of small particles whose diameters are less than 80 μm. The introduction of high content of crushed limestone fines to concrete mixes is limited due to its negative effects on water demand and strength of concrete. However, the use of these fines at a reasonable percentage can improve the fresh and hardened concrete properties. In some countries, the content of these small particles exceeds the standard allowable limit of 5% and most of the LSF are disposed of in landfill sites. The annual production in Algeria, one of the North African countries, is 68 million tones of aggregates (fine and coarse). Nearly one half of the aggregate production goes to the building sector and one third to road construction. The fine aggregate consists of 22% (15 million tones) of the total aggregate produced. Between 8–25% of the fine aggregate contains particles whose diameters are below 80μm (i.e limestone fines) and they are mainly used in road construction and usually sold at a lower price (about the third of other types of aggregate). One option to meet the increasing demand and shortage of fine aggregate is to use more LSF in concrete as it is widely available. An experimental study of the effect of three different types of cements on durability properties of crushed sand concrete containing different amounts of limestone fines (0, 5, 15 and 25%) was investigated. The water to cementitious material ratio of 0.65 was kept constant for all mixtures. The concrete properties measured included strength, gas and chloride ion permeability and sorptivity. The results have shown it is possible to use up to 15% of
limestone fines to produce sustainable crushed sand concrete with a strength and durability (Figure 4 and Figure 5) similar to that of concrete made with natural sand (Kenai 1999, Menadi 2009, Menadi 2011). The results of this investigation as well as that of other researchers have made it possible to modify local standards, which now accept up to 15% fines in crushed sand for reinforced concrete. Currently, most construction sites in the north of Algeria and, in particular, ready-mixed concrete plants use crushed sand.

Fig.4 Compressive strength for concrete mixtures with different type of cement (MENADI 2011)

Fig.5 Gas permeability for concrete mixtures with different types of cements (MENADI 2011)
4.4 **Strength and Durability of Self-Compacting Concrete**

Self-compacting concrete (SCC) has been successfully used in many construction projects, mainly in structural members with complex forms and heavily congested reinforcement. It is a highly flowable concrete with minimal segregation that can flow into place under its own weight and compacted without any external vibration. This later could be obtained by the use of high amount of fine fillers (cement and mineral admixtures) in order to avoid aggregate settlement. The use of SCM is well accepted because of its improvement of concrete properties and also for environmental and economic reasons. The influence of Algerian slag on the properties of fresh and hardened SCC has been investigated (Boukendakdji 2009, Menadi 2012). The fresh properties of SCC were determined using slump flow, V-funnel flow time, J-ring, U-box filling height and geotechnical test method sieve stability tests. An optimum slag content of 15% seems to give a good SCC mixture with workability retention of about 60 minutes. A decrease in compressive strength was obtained with an increase of slag. Some applications of this by a local construction company are underway in slabs, bridges piers and foundations. Menadi (2013) examined the effect of using slag with different fineness to partially replace the cement in SCC and found that the strength and shrinkage of concrete are reduced with increasing amounts of slag whatever the fineness used (Figures 6 & 7).

![Compressive strength of SCC containing slag with various finenesses](MENADI_2013)

**Fig. 6** Compressive strength of SCC containing slag with various finenesses (MENADI 2013)
4.5 Use of Waste Cork for Insulation

The development of materials from waste wood is an interesting alternative to save energy and to preserve the environment. An experimental study was conducted to develop a cement composite insulating material from cork waste (Kenai 2007). The experimental study deals with expanded and raw cork mixed with cement in ratio $\text{Cement/Cork by volume (C/L)} = 1/1$, $1/2$ and $1/3$. Preliminary tests to optimize the mix were carried out. The physical, mechanical and thermo-physical characteristics of this composite material were then studied. The feasibility of the composite material was investigated by fabricating blocks to which cement rendering was applied and the bond between these blocks and the cement rendering measured. The use of waste cork as the only aggregate in concrete has given a composite material with bulk as low as 614 kg/m$^3$. The results indicate a good compatibility between cork and cement. The compressive strength varies from 2 to 15 MPa and the flexural strength varies from 0.56 to 3.20 MPa. The coefficient of thermal conductivity was low and varied from 0.19 to 0.34 W/m°K. The thermal conductivity obtained is lower than that of foam concrete, autoclave concrete and gypsum and is comparable to that of cellular concrete, expanded clay, fired bricks and clay foam. However, water absorption by capillary and by immersion was high. The composite with expanded cork has a better mechanical performance than that with raw cork. Nevertheless, the composite with raw cork has better insulating and acoustic performances. The possibility of using this composite material in roof insulation and as partition walls is proved.

4.6 Cement Stabilized Soil

Earth construction is widespread in desert and rural areas because of its abundance and cheap labour and could be an alternative sustainable construction material for low cost housing in Algeria. An experimental study was conducted to optimize the compaction of the soil stabilized and improve physical and mechanical properties (Bahar 2004, Kenai 2006). The improvement of stability in water and the reduction of
the withdrawal by the strengthening of the earth by the straw have also been demonstrated (Bouhicha 2005).

5. CONCLUSIONS

The concrete industry is the largest consumer of energy and natural resources and hence contributes heavily to environmental degradation. In order to get a sustainable construction that is environment friendly, there is a need to use local materials and low-energy-based materials. The use of recycled aggregates and other recycled materials such as cork, limestone fines is an alternative solution and should be encouraged at the design stage of a project. The use of cement replacement materials such as slag and natural pozzolana in vibrated and self compacting concrete should be encouraged as they reduce carbon dioxide emission and give durable concrete.

REFERENCES


Khatib, JM, Menadi, B. and Kenai, S. (2009), "Effect of cement type on strength development of mortars containing limestone fines", Excellence in Concrete Construction through Innovation – Limbachiya & Kew (eds), Proceedings of the conference held at the Kingston University, United Kingdom, 9 - 10 September 2008, Edited by Hsein Y. Kew and Mukesh C. Limbachiya, Taylor & Francis

Lemay, L. and Ashley, E. (2011), "The Sustainability of Concrete Pavements. Report CSR03, National Ready Mixed Concrete Association, Silver Spring, MD, USA.


