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Energy Consumption in Cement and Concrete and Role of Wastes in It: A Review

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Abstract: Recently, due to technological advancement and modern development, demands and consumptions of energy in different formations are mounting gradually in the world. The present growing population, industrialization, transportation, construction, modern life styles are the main reasons for these elevated demand. In addition, natural resources are reducing gradually and production cost of energy is increasing every day. Consequently, to solve these, researches in various sectors are progressing rigorously for the sustainable development including energy saving, more utilization of waste materials, renewable energy, green building, alternative source and utilization of fossil fuels, sustainable concrete, maximum utilization of solar energy, etc. In this paper, a critical review on energy consumption in cement and concrete manufacturing have been described; in addition, role of waste materials (slag, fly ash, rice husk ash, palm oil fuel ash, ash from timber) as a supplement of cement and/or ingredient of concrete have been presented. The economical, technical and environmental advantages of waste materials as supplement of cement and concrete have been mentioned here; a probable energy saving strategy has been proposed, as well. On the basis of published documents and literatures, it can therefore be concluded that a productive, valuable and possible way of saving energy as well as sustainable concrete construction would be executed by effective consumption of these wastes as a supplement of cement and/or constituent of concrete.

Key words: Cement · Concrete · Energy · Waste Materials (Slag, Fly ash, Rice husk ash, Palm oil fuel ash)

INTRODUCTION

According to the law of energy conservation, total energy in the universe is constant and only it is converted from one system into another one. Nowadays, in this civilized world, the demands and consumptions of energy in different categories (fuel, electrical, thermal, heat, etc.) are increasing gradually due to the survival of human being to fulfil the following basic needs: accommodation, processing and consumptions of food, construction of infrastructures, industrialization, modern transportation system, education, health/medical, communications with advanced technologies, use and dependency on computer technologies, etc. For these reasons, pressure is building up regularly on the natural resources (fuel, gas, clinker, different minerals and so on) and consequently these are reducing gradually due to execution of the demands of growing population and living requirements in the planet. According to IEA (2008) report [1], manufacturing industries in general account for one-third of global energy use. As a result, direct industrial energy and process carbon dioxide (CO_2) emissions amount to 6.7 gigatons (Gt), about 25% of total worldwide emissions, of which 30% comes from the iron and steel industry, 27% from non-metallic minerals (mainly cement) and 16% from chemicals and petrochemicals production. However, concrete is one of the largest energy and materials (water, cement, clunker, aggregates) consumer. But concrete construction is the most important sector for building of infrastructures (dwelling houses, industries, roads, bridges, culverts, tunnels, etc); it is considered as the social well being and key element for the modern urban development in the globe. Concrete has many environmental advantages such as durability,

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longevity, heat storage capability and (in general) chemical inertness. In many situations concrete is considered superior to other materials including wood, glass, rubber and steel. Accordingly, concrete is used all over the world in much scale; the consumption and popularity of concrete is increasing always due to its significant multiple advantages. It is well known that cement is a vital ingredient for the production of concrete, because there is no available technology to make concrete except cement; thus, we are bound to depend on cement and concrete for modern and advanced constructions. It is found from a report of Chana (2011) that over 25 billion tons of concrete are produced annually worldwide; consequently, global cement consumption is 2.9 billion tons per year and is expected to rise to 4 billion tons by year 2020; however, most of demands are coming from China and India [2]. Thus, we have to find a way for alternative of concrete to reduce the pressure on concrete consumptions.

In contrast, all the concerns in construction industries are informed that huge quantities of waste materials are produced in the world as industrial by products (slag, fly ash, silica fume, etc.). It is reported that about 100 million tons slag produced worldwide and only a small fraction of it is utilized [3]; it can also be noted that about 450 million ton of fly ash is generated per annum, of which only 35 million ton (less than 8%) is used for different purposes [4]. There is no different and positive feature for the abundant agricultural wastes such as palm oil fuel ash (POFA), rice husk ash (RHA), sawdust ash/ash from timber (AFT), bagasse ash. Approximately 550 million tonnes rice is produced globally per year, the majority of which is grown in Asia. After milling, the rice generates a waste material known as the rice husk surrounding the rice grain. About 110 million tons of rice husk is generated per year globally (at a rate of about 20% of the weight of the product rice); from which 16.5 to 22 million tonnes of RHA is generated [5] containing over 90% amorphous silica that could be used as a substitute for silica fume. Unluckily, only a few portions of these are used for heat producing purposes in the rice processing mills but most of them are simply disposed as garbage. On the other hand, it is estimated that about 0.30 million ton of POFA is produced from the 320 palm oil industries in Malaysia. The same trend is observed for this POFA wastes also, small quantities is used for various events and rest of these are disposed as landfills. As a result, much environmental pollutions including water and soil contamination are happened; reducing the area of cultivating land and the fertility of land, etc.; lot of money is to be spent for management and discharging of these wastes as well. It is already proven that all of these waste materials contain a high amount of silicon dioxide in amorphous form and accordingly, these could be used as pozzolanic materials in concrete production that are documented in various literatures. Thereafter, utilization of these waste materials as a possible alternative in the cement and concrete construction is a great research interest and it would be probable solution for minimizing and/or reducing the above mentioned problems as well as a significant way of saving energy which is described in this paper. For energy saving, researches are also continuing to find a way of alternative fuel that is to be used in manufacturing industries. Utilization of wastes in cement industries as an alternative of fuel is another policy in this regards, some of cement companies are already established this system, especially in Europe.

Furthermore, an energy saving strategy can therefore be executed by following the easy method: produce as much concrete as require, but it has to be aware that Portland cement could be used as little as possible; this can be explained in such a way that it is required to replace as much Portland cement as possible by supplementary cementitious materials, mainly by replacing industrial by-products (slag, fly ash, silica fume) and agricultural wastes (POFA, RHA, AFT, bagasse ash) instead of cement. These ashes could also be used as ingredient of concrete. This study reviews the energy requirements by cement and concrete production, significance and role of waste materials in concrete construction; and it also prescribes a probable and possible strategy to save energy using industrial by-products and agricultural wastes to accept the energy challenge at foreseeable future in the planet.

Energy Consumption by Cement and Concrete: It is already known that most of industries, constructions, mills, factories, engine and transporting vehicles are fully depended on energy. A potential example is cement and concrete construction, one of the biggest energy consumers; while, cement is the most energy intensive substances after aluminium and steel [3]. In the cement industry pyroprocessing (processing the raw material into cement under a high temperature) is a very common technological procedure, which accounts for 74% of the energy consumption in global cement/concrete industries [6]. Grinding and milling account for 5.8% of cement/concrete energy consumption [7]. Besides, largest quantities of natural resources such as aggregates, sand, clinker and fuel are consumed by cement and concrete industry [4]. For these reasons, natural resources are depleting. Besides, price of these raw materials are increasing regularly. Total energy requirement in cement manufacturing is not fixed. It depends on the production process (wet or dry) and also varies from plant to plant and country to country. It is already documented that about 850 to 900 kcal/kg heat energy is required with new dry precalciner kiln systems, but 1300-1600 kcal/kg is required in the wet process [8]. Thus, approximately 56 to 66% energy is required in the dry process with respect to that of the old wet process (so, 34 to 44 % energy can be saved in the new dry process. However, the consumption of electricity in cement production varies between 90 and 150 kWh per ton [9]. According to the GNR database, the global average electricity consumption was 111 kWh per ton of cement [10] in the year 2006. Energy consumption varied significantly between countries and regions [10-11]. Electricity consumptions ranges from 90 to 120 kWh/t of cement as mentioned in IEA (2007) report, while different statistics observed in the United States, Mexico and Canada where typical figures are all above 120 kWh/t of cement [11]. Apart from the CO_2 capture and storage technology, it is not expected advanced technologies to cause a significant change of electricity and thermal energy consumption in cement production. It is relevant to mention that researches are still continuing to find the energy efficient way of cement production. However, electricity demand could be declined from the current average value of 110 kWh/t in cement production by year 2006 to 105 kWh/t in 2030. Besides, demand of thermal energy could also be reduced from the present rate 3.38 GJ/t in year 2006 to 3.3 GJ/t clinker in 2030 [12].

It is well known that energy consumption is the largest environmental issue for cement and concrete manufacturing. However, cement manufacturing is one of the prime energy intensive sectors among the industrial manufacturing processes [13]; it includes direct fuel consumption for mining and transporting of raw materials. The embodied energy for cement and concrete production, as reported by Alex (2004), is presented in Table 1. It can be observed from this Table that, in concrete production, 94% of the total energy is consumed only by the cement manufacturing; the quantity is about 6 million BTU for every ton of cement. The report also includes that, in general, cement production is approximately 10 times as energy intensive as our economy; about two-thirds of total energy is used for cement production in some Third World countries. Energy consumption for concrete production looks considerably better than those for cement, because, most of the energy is consumed in cement manufacturing compared to the other ingredients of concrete [13]. This happens because the other ingredients of concrete (sand, crushed stone and water) are very low energy intensive. However, for hauling, the required embodied energy for sand and crushed stone are about 40,000 and 100,000 BTU per ton, respectively. Nonetheless, the cement, representing about 12% of concrete, accounts for 94% of the embodied energy, while sand representing a little fewer than 2% and crushed stone just under 6%, as shown in Table 1.

Meanwhile, it can be mentioned that cement and concrete production not only consume the world's most valuable fossil energy resources but also put negative impact on environment in terms of carbon dioxide emissions that is responsible for the climate change, a crucial issue being faced by the inhabitants in the globe; which has necessitated the exploitation of sustainable construction materials [14]. Furthermore, sustainable cementitious binder, sustainable concrete as well as sustainable development are the prime research area in every sector including construction industry all over the world to fulfill the following objectives: reduction of the amount of polluting and CO_2 gases emitted during the manufacture of cement and concrete; more efficient utilization of waste materials; development of low-energy demanded, long-life, flexible buildings and infrastructures; utilize the thermal mass of concrete in a structure in order to reduce energy demand. The consumption of wastes not

Table 1: Embodied Energy for Cement and Concrete Production [13]

Ingredient		BTU (ton) per ton			Energy
Name	% weight	Materials	Hauling	BTU (ton) /yard concrete	%
Cement	12	5790	504	1574	94.0
Sand	34	5	37	29	1.7
Crushed Stone	48	46.67	53	100	5.9
Water	6	00	0	0	0.0
Concrete	100	817.6		1700	100

Table 2: Energy Consumption in Cement Production [15]

		Total Energy requirements	
Sl No.	Type of cement	GJ/ton (kWh/ton)	(%)
1	CEM I (without slag)	5.72 (1587)	100.0
2	CEM II/B-S with 30% slag	4.34 (1206)	76.0
3	CEM III/A with 50% slag	3.38 (938)	59.1
4	CEM III/B with 75% slag	2.17 (602)	37.9

only performs as sustainable element but also reduces the production cost of cement and concrete; the environmental pollutions could also be minimized successfully. Therefore, all these objectives could be achieved by replacing wastes separately to the concrete or used as supplement of clinker in composite cements production. Although, the latter system is more commonly used in Europe; while in US material replacement systems are usually added directly to the concrete. How we can save energy with utilization of waste in cement is included and explained here with referring different research articles. It could be noted that utilization of waste materials from different industries are increasing regularly to replace the conventional raw materials used in the OPC clinker production, for example, slag, foundry sands, fly ash and bottom ash from derived from coal fired power plants, spent catalysts and filter clays, mill scales, etc. Blast furnace slag (BFS) contain high amount of calcium oxide, hence, the maximum level of limestone replacement by BFS is between 20 and 30%. Generally, about 10% replacements are more commonly reported in different literatures. The energy requirement for the cement manufacturing is reported by Ehrenberg and Geiseler (1997) that is shown in Table 2.

It can be observed from this table that 5.72 GJ/ton energy is required for CEM I (without slag), while 4.34 GJ/ton, 3.38 GJ/ton and 2.17 GJ/ton energies are required for the addition of 30%, 50% and 75% slag respectively. Therefore, energy requirement is reduced to 59.1% for the 50% slag replacement as compared to CEM I (100%), thus, 40.9% energy can be saved using 50% slag with clinker. The appreciating result is only 37.9% energy required as compared to CEM I for the 75% slag replacement, in this case 62.1% energy could be saved. Since fly ash, RHA, POFA and AFT contain high percent of silica similar to slag, thus, it is expected to feed these wastes in manufacturing of cement and concrete also.

Technical and Environmental Merits of Wastes: Although waste materials bear economical and technical advantages and significance, but no remarkable uses have been observed, most of them are discharged as environmental burden. When waste materials processed properly it could be used successfully in concrete construction and it would accomplish the design requirements and criteria which is suggested by several researchers. Nonetheless, these by products (slag, fly ash) and agricultural wastes (RHA, POFA, AFT) act as pozzolans and could be used as supplement of cement in concrete production as documented in different literatures as described here. Slag is usually used in concrete because it has following advantages: improves durability and reduces porosity; improves the interface with the aggregate; shows lower cement requirement; saves energy; and shows good performance as well as better engineering properties [16]. Fly ash is consisted with mainly of tiny beads of silica, as a result, it act as a binder in the hydration process. By the effect of these beads, concrete can attain more workability and fill voids better than Portland cement-based concrete. It was reported by Cockram (2006) that addition of fly ash could also reduce required amounts of water in the mixture [17]. He also stated that use of fly ash reduces CO_2 in two ways: by reducing the demand for OPC and by absorbing more CO_2 from the atmosphere at the time of curing. It is reported from another study [13] that 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. As a result of this process, the following benefits are taken place: fly ash increases concrete strength, improves sulfate resistance, decreases permeability, reduces the water required and improves the pumpability and workability of the concrete [13]. Strength of concrete is also increased with addition of fly ash [18-19].

The agricultural by products have also capability to enhance the property of cement and concrete. For example, the surprisingly effective agricultural admixture is RHA, sometimes trademarked under the name of Agrosilica; when power plants burn rice husk with control combustion temperatures carefully, the resulting ash is to be used to significantly increase the strength and reduce the permeability of concrete. The presence of RHA in concrete improves compressive strength [20] and resistance against sulfate attack [21]. POFA and RHA could be used as supplement of cement in concrete production that are argued by many researchers. In particular, contributions of waste materials in concrete production not only save cement but also make better performance in the concrete properties such as strength, durability. For example, POFA can be used in concrete production as a cement replacement material to make good resistance against sulfate attack [22-23]. The utilization of saw dust has been observer in Switzerland in 1945 as alternatives to formwork, first produced as Durisol. The process uses mineralized wood chips which are mixed with cement and formed into blocks. The product Durisol is used extensively in Canada and a similar product named as Faswall, is available in the United States in standard sizes [17]. The consumption of AFT up to 30 % as supplement of cement has been examined by Elinwa and Mahmood in 2002, the properties of concrete with 10% AFT by cement replacement show good performance regarding desired workability and strength [24]. However, Ekrami *et al.* (2011) investigated the utilization of olive fruit waste as a source of natural dye for dying of wool sample [25].

We know very high temperature (1450°C) is required to burn raw materials in cement manufacturing which gives the clinker its unique properties, as a result, produces huge CO_2. These are generated from three independent sources, first one by de-carbonation of limestone in the kiln (about 525 kg CO_2 per ton of clinker), secondly, combustion of fuel in the kiln (about 335 kg CO_2 per ton of cement) and finally, use of electricity (about 50 kg CO_2 per ton of cement) [6]. The consumption of waste materials is one of the best solutions to achieve the goal of economic and sustainable concrete construction, the lower energy consumption and less CO_2 emission as well as environmental pollution control which have been addressed in several literatures. According to embodied CO_2 study (2007), the embodied CO_2 emission is reduced significantly due to incorporation of slag into cement. It was found that embodied CO_2 emission is reduced by 56 kg/ton (36.6%) for addition of 50% slag [26]. Ehrenberg and Geiseler (1997) reported that the total CO_2 emission would be reduced by incorporation of slag in the cement manufacturing [15]. They mentioned that CO_2 emission is 1011 kg/ton for CEM I cement (without slag), but by addition of 50% slag, emission is reduced to 539 kg/ton, thus, for addition of 50% slag total CO_2 emission is reduced to 53.3%. This figure is much better for 75% slag replacement. It is reported that the followings are three potential central measures by which the cement industry may be saved direct CO_2 emissions in the near future [6]:

- Enhancement in the energy efficiency, which is now maximum 2% feasible
- Clinker to cement ration is to be reduced by incorporation of industrial by- product
- Searching a way to use more wastes as alternative of fuel implementing the following policies: national initiatives, adequate national implementation of specific wastes and awareness.

Furthermore, analysis for blended cements shows that the savings potential in this case amounts from 300 Mt CO_2 to 450 Mt CO_2 by 2050, according to IEA (2008). The main approaches are to use the following wastes in cement and concrete productions [1]:

- Blast-furnace slag: Slag that has been cooled with water, rather than air; about half of all blast-furnace slag is already used for cement-making where the slag is water-cooled and where transport distances and costs are acceptable. Approximately 100 Mt CO_2 emissions could be reduced if all blast-furnace slag were used.
- Fly ash: It can be collected from coal-fired power plants; but the carbon content of fly ash can affect the concrete setting time. Special grinding methods are also being studied as a way to increase the reaction rate of fly ash, allowing the fly ash content of cement to increase to 70% compared with a maximum of 30% today [27]. China and India have the potential to significantly increase the use of fly ash. About 75 Mt CO_2 reductions are possible if 50% of all fly ash that currently goes to landfill could be used.
- Steel slag: The CemStar process has been developed and successfully applied in the United States and approximately 0.47t CO_2 reduction is possible by addition of each ton of steel slag [28]. In China, there are about 30 steel slag cement plants with a combined annual output of 4.8 Mt. If the total worldwide steel slag resource of 100 Mt to 200 Mt per year was used this way, the CO_2 reduction potential would be 50 Mt to 100 Mt per year; and possibly pave the way to a 50% reduction of energy use and CO_2 emissions.
- Blended cements: Now, this is a promising offer and major opportunity for energy conservation and

emission reductions, but their use would in many cases require revisions to construction standards, codes and practices. In total, the savings potential for blended cements amounts to 300 Mt CO_2 to 450 Mt CO_2 by 2050.

Thus, more utilization of waste in cement or concrete has the following multiple advantages: less use of cement and hence saving fuel, clinker as well as reduction of CO_2 emission; waste disposal problem could be solved, production cost of cement and concrete will be reduced, finally financial benefits also be achieved. Furthermore, it can easily be understood from above discussion that not only incorporation of fly ash, slag but also POFA, RHA and AFT in cement or concrete will be a great achievement in terms of energy saving, sustainable construction and CO_2 reduction without sacrificing the strength of concrete.

Probable Strategy of Energy Saving: Waste materials, especially slag and fly ash, have the capabilities to serve as alternative/supplement of cement and/or ingredient of concrete that are already explained in this paper with referring many published documents. Consequently, the authors would like to offer a possible strategy to save energy using a variety of wastes including slag, fly ash, POFA, RHA and AFT in cement plant and directly in concrete production which is described below in two different sections: direct feeding into cement plant and consumption during concrete production.

Direct Use in Cement Plant: Slag can be ground into powder and used as a partial substitute for OPC; the fly ash can also be used. The burning temperature of clinker is about 1400°C while the POFA, RHA, AFT could be produced at a temperature about 600°C-700°C. Thus, from the gross estimation, anyone can therefore easily be predicted that fuel energy could be saved for more utilization of wastes, but awareness would be concentrated to the properties of final product which should be kept unchanged. Besides, research findings of Ehrenberg and Geiseler (1997) [15] also support this possible energy saving policy. In this regards, the following sequence may be followed for direct utilization in cement plant:

- At the beginning, different types of wastes (slag, fly ash, palm oil fiber, shell, etc. rice husk and timber dust) can be collected from various sources as near as possible to save the transportation costs.
- Now, these wastes should be processed carefully for removal of any impurity, contaminant and hazardous materials, if any.
- Then, these would be kept into burning kiln or furnace in cement industry directly (fly ash and slag could be used directly, without burning). The produced ash then can be utilized as supplement of cement by various percentages.
- The measurement of required energy/fuel for blended cement/OPC production can be done in the plant by energy meter as energy saving comparison.
- Finally, properties of blended cement and OPC could be evaluated by different physical, chemical, mechanical and durability tests.
- Depending on the tests results a conclusion regarding energy consumption, saving and production cost could be reported.

Utilization in Concrete Construction: It is suggested by many researchers that all of these wastes act as pozzolanic materials and could be used as supplement of cement and or ingredient of concrete because of the following reasons: their contribution improves durability and reduces porosity; improves the interface with the aggregate; lowers cement requirement; saves energy; and shows good performance as well as better engineering properties, increases strength of concrete and resistance against sulfate attack. The promising by-product admixture is blast-furnace slag, when it is used as an aggregate in concrete, slag improves the strength-to-weight ratio significantly [17]. However, we can easily understand that more utilization of wastes means less consumption of cement hence, production cost of concrete would be reduced. Furthermore, it is observed from this discussion that energy saving and sustainable construction could be possible using wastes in cement and concrete because of the following reasons: effective utilization of waste in concrete production, economic concrete production, less use of cement, thus lower energy consumption, declination of CO_2 emission due to less cement consumption, solution of waste disposal problem, searching a way of sustainable development and sustainable concrete. Accordingly, the authors prescribe a direction to save energy in concrete production by the following steps:

- As like as wastes feeding in cement plant, at first it is required to collect different wastes such as slag, fly ash, palm oil fiber, shell, etc. rice husk and timber dust at the burning station.

- Hence, processing and removal of impurity is to be done according to necessity.
- Then, these wastes could be burnt in boiler/furnace for ash production; slag and fly ash do not need burning, may be directly used into grinding machine.
- Subsequently, produced ash may be collected for grinding to get required fineness of ash and measuring consumed energy by energy meter.
- Now, these ashes are prepared to use in concrete parallel to OPC and/or supplement of OPC. It is noted that, the properties (fresh and hardened) of concretes either made from blended cement or from OPC must be examined.
- Finally, a concluding remarks regarding energy consumption, saving and production cost of concretes should be presented.

CONCLUSION

Although, cement and concrete are considered as vital elements in modern infrastructural construction today, but cement is one of the most energy intensive materials and a major contributor to CO_2 in the atmosphere as well. Besides, about 1300-1600 kcal/kg heat energy and 110kWh/t electrical energy is required in cement manufacturing. On the other hand, having the technical and financial benefits, huge amount of waste (slag, fly ash, RHA, POFA, etc) are generated and dumped without any potential reuse. To minimize/solve these, we should try to: (i) reduce the cement utilization in concrete construction by consumption more wastes (slag, fly ash, RHA, AFT, POFA and other pozzolans) either in cement manufacturing or concrete production (ii) search an energy efficient way of cement manufacturing (iii) and follow the route of sustainable concrete and sustainable development. In this regards, a probable direction has been proposed by authors for accomplishing these goals. Meanwhile, Ehrenberg and Geiseler (1997) claimed that about 25% to 60% energy could be saved with incorporation of slag in cement manufacturing. Therefore, promising energy saving strategy may be found involving large amount of agricultural wastes (RHA, POFA, AFT) and industrial by-products (slag, fly ash) in cement and concrete production. However, consumption of these wastes as an alternative of fuel would be another solution to save energy. Furthermore, this waste consumption technique in cement and concrete manufacturing may save energy, make contribution in reduction of CO_2 emission; and now it is logical, useful, significant and situation demand to face the energy challenges in twenty first century for survival of human society in the planet.

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