Alternative Aggregates for Sustainable Construction

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Abstract - This paper summarizes the achievements of a long term research programme focused on the exploitation of solid wastes in construction. The objective of the research programme is to develop an environmental-friendly and economical process for the exploitation of solid wastes in construction. The solid wastes experimented include fly ash, timber industrial ash, rice husk ash and palm oil fuel ash. Other solid wastes include biomass particularly rice husk and palm fiber and paper sludge. Packaging wastes such as recycled expanded polystyrene and lightweight concrete has been developed. It provides an environment-friendly and economical solution to construction on soft soil, towards providing affordable quality assured fast track method and to enhance the competitive edge of the construction industry. Obstacles toward achieving commercialization are briefly discussed.

Keywords: aggregates; solid wastes; environmental; fly ash; commercialization

I. INTRODUCTION

A. Exploiting Wastes in Concrete

Among researchers who have made significant contribution to knowledge include Samarlin [1] who reviewed the impact of Kyoto Protocol. New levels of abatement of greenhouse gas emissions by the year 2012 was stipulated, on the utilization of cement extenders in concrete, and on the use of wastes as new materials. Naik et al. [2] studied the use of industrial by-products in cement-based materials. He quoted that nearly 4.2 billion tonnes of non-hazardous by-products are generated from agricultural, domestic, industrial and mineral sources. He emphasizes the need for recycling to conserve natural resources and to provide technical and economic benefits. Shoya et al. [3] studied the properties of self-compacting concrete with slag fine aggregates. He conducted the slump-flow test, the V-type funnel test and filling vessel tests for the measurement of self compatibility of fresh concrete. Mellmann et al. [4] investigated the exploitation of processed concrete rubble for reuse as aggregates. He described the feasibility of producing high-grade concrete from the rubble. Rad and Bonner [5] studied the properties and performance of recycled cementitious mortars. They attempted to link the petrological observations to the microstructural characteristics of cement gel interaction and activation. Bijen [6] proposed the use of secondary materials as a contribution to sustainability. He assessed the environmental impact in accordance with the draft ISO standards 14040 series. Ledham et al. [7] experimented on simple treatments to reduce the sensitivity to water of clayey concretes lightened by wood aggregates. They envisaged the potential use of local materials with hydraulic lime coating for the production of insulation materials. Mimoune et al. [8] used fly ash in the compound wood-cement. They concluded that the addition of fly ash did not resolve elasticity problems during decompression.

II. ASH UTILIZATION RESEARCH

A. Fly ash

Coal ash production and its use in concrete were studied by Manz and Stewart [9, 10]. They reviewed the worldwide production and utilization of coal ash from 1959 to 1989 for the UN Group of Experts on the Utilization of Ash. Quantities of fly ash recycled in each sector of the construction industry are given. Wang [11] stated that the fly ash production in China was approximately 100 million tons per year in 1997. Puch and Vom Berg [12] reported that the coal combustion by-products in Germany are being recycled at a rate over 98%. Dube [13], Uchida [14], Bland et al. [15], and Zysk & Volke [16], Colmar [17] and others [18, 19] review the use and utilization of fly ash in cement manufacturing and construction. Jagiella [20] studied the utilization of coal combustion by-products such as fly ash, bottom ash, boiler slag, flue gas desulfurization (FGD) material and fluidized bed combustion (FBC) by-products. Barringer [21] proposed a proportioning method based on the price, availability, and strength-gaining ability of the fly ash.

B. Materials Characterization

Galpern et al. [22] discussed the properties of ashes from fluidized bed with and without addition of lime/carbonate. They have reported that addition of up to 20-30% of low carbonate ash to cement does not affect the durability. Ninomiya et al. [23] studied the effects of adding carbonate to ashes during melting. High temperature phase transformations were studied by XRD analysis and the glass phase was studied by FT-IR analysis. It was shown that addition of carbonates results in a glass phase with a higher pozzolanic reactivity than the parent coal glass. Hower et al. [24] studied the quality of fly ash and its carbon content obtained from boilers converted to low-NOx combustion. Other parameters include fineness and the relative amount of glass versus
crystalline inorganic phases. It is shown that the post-conversion fly ash was higher in carbon than the pre-conversion ash from the same unit.

C. Effect of Grinding

Bouzoubaa et al. [25] studied the effect of grinding on the physical properties of ASTM Class F fly ashes. The specific gravity and the fineness are significantly increased with grinding up to two hours. Ruan et al. [26] used fluid energy mills to grind fly ash. Paya et al. [27] demonstrated that the grinding fly ash increases its pozzolanic activity and enhanced the mechanical properties of mortar. A mathematical model was developed to predict the mechanical properties of mortars containing ground fly ash. Kruger [28] described means of separation of fly ash particles to obtain fractions with different characteristics. These methods include air classification, electrostatic recovery, and density separation. Yoshida et al. [29] used an air-cyclone to classify particles of fly ash to a mean diameter 2 and 6 mm. Murai et al. [30] reported that fly ash particles of less than 10 mm affect the rheology, strength, water tightness, shrinkage, and durability of self-compacting concrete in a comparable or better way than ordinary fly ash, GGBS, and limestone filler. Okoh et al. [31] investigated the kinetics of oxidation of residual carbon as a step toward producing low-carbon fly ash from high-carbon, low quality fly ash.

D. Biomass Fly Ash

Meyrahn et al. [32] reported that biomass fly ashes have very low content of heavy metals and possess pozzolanic as well as hydraulic properties. Ludwig and Urbonas [33] and Bartscherer-Sauer et al. [34] studied granulometric and chemical-mineralogical properties of fly ash from biomass-fired power stations. Kahl et al. [35] compared the composition of biomass fly ashes produced in different power stations. Dietz et al. [36] studied the composition, strength and durability properties of German biomass fly ash. Volume stability, as well as carbonation depth, sulfate resistance, and freeze-thaw resistance were investigated. It was demonstrated that additions up to 10-15% do not lead to negative effects on fly ash cement properties.

E. Hydration and Microstructure

Chang et al. [37] measured various aspects of workability, bleeding, setting, compressive and tensile strengths, pore distribution, and crystal structure of cement pastes containing fly ash from fluidized bed incineration systems. Anthony et al. [38] studied the activation of unreacted calcium by means of injecting limestone into the furnace. They report hydrated tetracalcium aluminate as the major hydration product of the activation process. Poon et al. [39] studied the influence of two different curing conditions (in water at 27°C, and in air at 15°C and 60% relative humidity) on the compressive strength, chloride, and water penetration properties of fly-ash cement pastes and mortars. Mercury intrusion porosimetry showed that curing conditions has a significant influence on the strength, porosity, and durability of cement pastes and mortars.

F. Palm Oil Fuel Ash

The pozzolanic properties of palm oil fuel ash, a waste material obtained on burning of palm oil husk and shell, was studied by Hussin et al. [40]. Compressive strength test with Portland cement substitution levels between 10-60% indicate the possibility of replacing 40% ash without affecting concrete strength. A maximum strength gain at the 30% level was achieved. Awal et al. [41] utilized palm oil fuel ash to reduce the expansion of mortar bars containing tuff as a reactive aggregate. According to the results, the palm oil fuel ash has a good potential in suppressing alkali-silica reaction expansions.

G. Applications

Cabrera and Al-Hasan [42] used a pozzolanic compound containing 70% Portland cement and 30% fly ash for maintenance, repair and strengthening of concrete structures. The compressive strength, bond strength, porosity, and permeability were measured. Lee et al. [43-53] explored the use of timber industrial ash in a variety of blended cement products such as bricks, paver blocks, lightweight palm clinker concrete, foamed concrete engineered shear wall and foamed grout for soft soil stabilization. Water permeability test system has been developed based on ISO/DIS 7031.

III. OTHER SOLID WASTES

A. Paper Sludge

Paper sludge is one of the solid wastes produced by paper industry. Paper sludge contains fragments of paper fiber. These fibers are not suitable for use in recycled paper. Disposal options include landfill and energy production. Usually in the paper production, only 65% of the paper pulp will be turn into paper, the other 35% will be the waste material in the form of paper sludge. Paper sludge contains a high percentage of very fine kaolin clay and fillers, which is used to create a smooth finish on fine paper. Besides kaolin, there are also other contaminants in the paper sludge, such as de-inking compounds, surfactants, residuals from inks and dyes, compounds from laser printing, photocopying and also coagulant that has been used to coagulate the paper sludge during the disperser process. Heavy metals is one of the contaminants exist in paper sludge. Some of these metals are toxic to plants, animals and also human being. When the paper sludge is dumped in the dumpsite, there are possibilities for leachate from the sludge to get into groundwater, stock ponds, or drinking wells. Besides, when the paper sludge is dumped in the dumpsite, it will undergo anaerobic decomposition and this will cause odor problem. A paper mill in Malaysia, produces 30 metric tonnes of paper sludge per day and the cost for transporting the paper sludge to the dumpsite is approximately RM 10,000 per month.

B. Rice Husk

Rice is a basic food in Asian countries such as Malaysia, Thailand, Indonesia, India and Japan. It is abundantly available in most part of the world. Substantial amounts are also cultivated in various countries in America and Europe. The present world rice production of
about 400 million tons per year will probably increase in the future, owing to the great increase in population, particularly in Asian countries. When rice grains are husked, the husks make up about 14 to 35%, depending on the variety of rice. Since the husks have a low bulk weight of about 100 kg/m³, they take up 560 to 1400 million m³. Although rice husk has its traditional uses, it is mostly under-utilized and causing disposal problem in most countries. It is estimated that 54 million tons of rice husk is produced in China every year. According to a recent study, Malaysia generates about 3.41 million m³ of rice husk annually. Innovative exploitation is crucial to avoid the waste of energy and environmental pollution.

IV. LIGHTWEIGHT CONCRETE

Lightweight concrete containing palm clinker fine aggregate and micronized silica was known as TIA composite. It is a mixture of cement, fine sand, water and special foam, which once harden results in a strong, lightweight concrete containing millions of evenly distributed, consistently sized air bubbles. It differs from conventional concrete in that the use of coarse aggregates is eliminated. The density of TIA composite is determined by the amount of foam added to the cement, sand and water mixture. TIA composite’s density ranges from 250 to 1800 kg/m³, as compare to 2400 kg/m³ for conventional concrete. Therefore, the weight of a structure built of TIA composite will be reduced significantly. TIA composite is water-resistant and possesses enhanced sound and thermal insulation properties. Foam generation requires a foaming agent and a foam generator. A foam generator is developed from a compressed air vessel incorporating a foaming compartment which allows the foaming agent to be agitated by a stream of compressed air.

Fine sand, cement and water are mixed in accordance with the design-mix charts taking into consideration suitable property-enhancing materials like fiber and other pozzolan and/or cementitious products. Cement and Sand are mixed first. Water is then added to the mix to form slurry. Foam is then added to achieve controlled density. If 1 liter of this mix weighs 1 kg then the density is 1000 kg/m³ (Normal concrete has a density of 2400 kg/m³). Curing is the same as normal concrete. TIA composite can be remolded after 16 hours. TIA composite is recommended to be moist-cured at least for the first 2 days.

The water/cement ratio must be strictly followed since too little water might cause the cement to draw its requirement from the foam, causing the latter to collapse partly or in total. The foam allows any density of concrete from as low as 250 kg/m³ to 1800 kg/m³ to be produced with an optimum ratio of strength-to-density. The possible wide range of densities achievable thus offers multiple and diversified applications, such as site mixing, off-site mixing, prefabrication, pre-cast or cast in place.

An average compressive strength of 2.86 MPa has been achieved for TIA composite cubes with an average density 650 kg/m³ subjected to 28 days of standard moist-curing. Tests on other densities revealed that 28-day strength exceeding 15 MPa is achievable depending on the density of the mix. Studies also show that compressive strength of above 20 MPa is possible with the addition of short fiber and mesh reinforcements. TIA composite is expected to have a life span of over 100 years. Previous investigation has shown that sectioned blocks of similar foamed concrete cast 10 years ago indicated only 75 percent of the cement hydrated. It is expected that the strength would continue to increase with continuing hydration. The availability of TIA composite in many cases provides a better alternative to other man-made products such as clay bricks and other insulation materials.

Curing is essential as in conventional concrete, as cement-based elements need moisture for hydration at an early age. This is particularly true in the presence of direct sunlight that is known to cause rapid dehydration of concrete surfaces. Curing compound can be applied as an alternative barrier. TIA composite is also suitable for special roof deck with enhanced acoustic thermal insulation and water proofing properties. TIA composite of density between 250 – 550 Kg/m³ is primarily used for thermal insulation or fire protection. It uses only cement (or with a small proportion of sand), water and foam for insulation board as an alternative to polystyrene, polyurethane or mineral wool, with no hazardous elements to health and environment.

V. ENGINEERED COMPOSITE WALL SYSTEM

A composite building system is developed from a combination of lightweight concrete containing micronized silica and recycled expanded polystyrene (EPS) insulation panels for wall and floor. The system offers advantages of economy and speed, comfort and energy efficiency. The salient features include the use of EPS panel with interlocking profile, webs and pipes, designed to achieve enhanced acoustic and thermal insulation properties compared to the traditional building system.

The engineered composite wall system is a novel method of construction. It combines the art of manufacturing a modular system formed from a self-compacting lightweight reinforced concrete and a method of vertically moulding it. The system is aimed at providing a new and improved moulded building panel, construction and connection methods for optimal control of the moulding and interconnecting process for such precast building panels, towards enhancing construction safety, quality and productivity.

A long felt need in the construction industry is to find a durable, yet relatively inexpensive construction method and material that would allow the construction of attractive and durable homes in a quick and economic manner. Although the thrust of this need has initially been to provide housing for low-income families or for the first time home buyers, any such construction method and material could also be easily adapted for more expensive homes and multi-family housing units.

VI. SOFT SOIL FOUNDATION SYSTEM

A method of improving soft ground containing organic material may consist of cement, water, fly ash, micronized silica, bentonite and a lightweight particles such as
volcanic ash. The composition is injected at prescribed locations to effect replacement of portions of the soft ground. The composition which solidifies in situ can be used in combination with lightweight friction piles to offer the optimum solution for soft soil stabilization. TIA composite in the form of slabs of 600mm thick can be cast to achieve required level. Experimental construction of load bearing block with hollow section in filled with lightweight concrete has been done in Sibu Sarawak.

VII. RESEARCH SHOWCASE – ALTERNATIVE AGGREGATES

A. Biomass aggregate

Twenty years of intensified research into the synthesis of biomass aggregate www.biomass.org.my is beginning to create the impact. It is derived primarily from the innovative exploitation of solid wastes from controlled incineration of biomass. A novel process for the synthesis of micronized silica from controlled incineration of biomass in a rice husk-fired power plant has won the EC cogen award in 2003. It has been initiated in collaboration with a rice mill in Bukit Raya, Kedah, Malaysia. Cementitious composites and concrete products containing micronized silica have attracted much research interest and the award of research grants. A summary of research showcase is available online via a research achievement portal www.1.net.my. The effective use of information and communication technology enables interested researchers to share useful research knowledge and skill towards exploration and discovery beyond the frontiers of knowledge. A rotary furnace is developed to provide controlled incineration of rice husk to study the effect of incineration temperature and retention time on the quality of rice husk ash. The system will be integrated with opposed jet mill to produce micronized silica.

B. Recycled aggregate

Recycled aggregates are defined as aggregates resulting from the reprocessing of mineral construction materials (i.e. composed predominantly of crushed concrete and brick masonry). Waste aggregates produced from construction industry have increased rapidly around the world [56]. Construction waste such as material wasted on construction sites generated from ordering errors, damages caused by third parties, vandalism at site, effect of weather, rework, inventory of materials not well documented, damage caused by workers, supplier errors, wrong material delivery procedures, poor attitudes of workers etc. as well as demolition waste, may provide source material. Recycled aggregates can contain, in some circumstances, significant quantities of natural aggregates; but excessive quantities of other materials such as wood, metal and plastic need to be removed before the aggregate is fit for use.

With world population hitting the 7 billion mark at the end of 2011, there is a need to assess the demand for sustainable construction materials. Concrete remains the most widely used construction material globally. The annual production of concrete is estimated to be 7 billion cubic meter. The demand for aggregate is estimated to be 15 billion tons per year. Effort to use alternative aggregates have to consider technical, environmental and economical advantages. Singapore BCA has approved the use of copper slag as an alternative aggregate in concrete. Expanded coal aggregate [57] has been studied in UTHM for the development of a mix design nomograph.

VIII. CONCLUSION AND CHALLENGES AHEAD

Much attention is focused recently on the commercialization of research products. Despite the fact that researchers are given tax exemption on income such as royalty received from the commercialization of their research products, the success rate of commercialization has been modest in Malaysia. Most researchers need support services from patent agents to draft patent specification and the involvement of successful businessmen in the preparation of winning business plan. There is also a need for researchers to be aware of the mindset of businessmen in order to enhance their negotiation skill.

A method of soft soil stabilization with foamed concrete and biomass aggregate has been experimented in Sibu Sarawak. It is envisaged that such system is competitive and have potential to expedite the development of the areas with deep deposit of soft soil. Innovative foundation system with the utilisation of used tyres is being experimented in some projects. The engineered wall system which is expected to revolutionize the construction process has been demonstrated in UTHM to pave way for industrialization.

ACKNOWLEDGMENT (HEADING 5)


REFERENCES


