Rev.Adv.Mater.Sci. 17(2008) 42-61

UTILIZATION OF HAZARDOUS WASTES AND BY-PRODUCTS AS A GREEN CONCRETE MATERIAL THROUGH S/S PROCESS: A REVIEW

Smita Badur and Rubina Chaudhary

School of Energy and Environmental Studies, Devi Ahilya University, Takshashila Campus, Khandwa Road,
Indore-452001, M.P., India

Recieved: January 08, 2008

Abstract. The disposal and treatment of hazardous industrial waste is very costly affairs for the industries, it has been a dormant issue. The new millennium brings challenges for the civil and environmental engineers and opportunities for research on the utilization of the solid waste and by-products and basic properties of concrete and its materials. The recycling of waste and by-products attracts an increasing interest worldwide due to the high environmental impact of the cement and concrete industries. Normal concrete is manufactured using sand and stones, but lightweight concrete can be made by using industrial by-products and hazardous solid wastes such as expanded fly ash, slag, sludge, *etc*. The Best Demonstrated Available Technology (BDAT) stabilization/solidification (S/S) can be used for treatment of concrete contaminated solid hazardous wastes and by-products. The performance of concrete is measured in terms of physical, engineering, and chemical properties.

The review describes how chemical and mineral admixtures help in the improvement of the lightweight concrete properties. Cement is replaced by the 15-35% fly ash in the concrete mix. Fly ash increases concrete strength, improves sulfate resistance, decreases permeability, reduces the water ratio required, and improves the workability of the concrete. Partial substitution solid hazardous waste does not strongly affect the strength of concrete and other properties. This mixed lightweight concrete is safe enough to be used in sustainable environmental applications, like roadbeds, filling materials, *etc.*

1. INTRODUCTION

Due to environmental degradation, high energy consumption, and financial constraints, various organizations in India and abroad, as well as United States Environmental Protection Agency (USEPA) have recommended various qualitative guidelines for generation, treatment, transport, handling, disposal, and recycling of non-hazardous and hazardous wastes [1–4]. It is now a global concern, to find a social, techno-economic, environmental friendly solution to sustain a cleaner and greener environment. The environmental technology, disposal and treatment of hazardous industrial waste has been a dormant issue that has recently been activated by the passage of the Resource Conservation and Recovery Act (RCRA) [5]. Already accumulated solid wastes and increasing annual production are a major source of pollution.

In different countries, some of such wastes are used for landfilling abandoned quarries and mines and adopting alternative method. The hazardous solids and sludges require a secure chemical landfill. Research has been conducted to recycle valuable material and reduce the volume of hazardous solid waste and other pollutants, which is harmful for living organisms. For the industries, disposal of sludge is very costly method, due to long-distance transportation and the use of illegal or question-

---

Corresponding author: Rubina Chaudhary, e-mail: rubina_chaudhary@yahoo.com

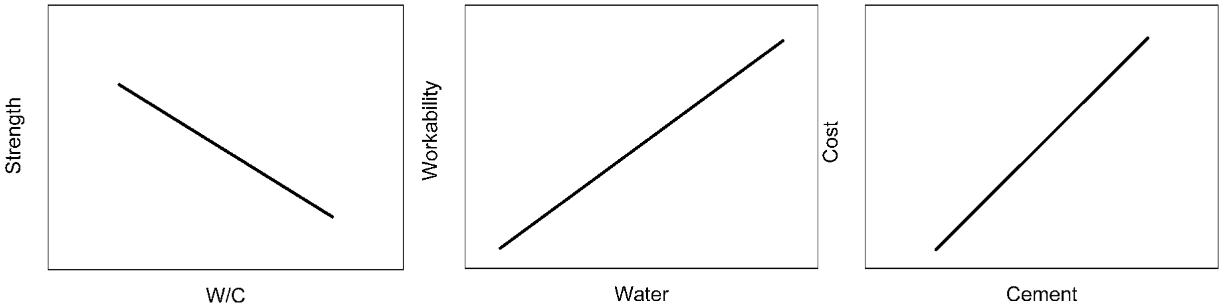

Fig. 1. Relationship of mix proportion with strength & W/C ratio, workability & water, cost &cement. Data from [25].

able disposal methods. The industries are trying to reuse solid waste material on the construction sites [6,7].

In recent years, the utilization of solid waste is the challenge for the civil and environmental engineers to utilize economic friendly supplementary cementitious materials produce at reasonable cost with the low possible environmental impact. The use of Supplementary Cementitious Materials (SCM) for *e.g.* Fly Ash (FA), Granulated Blast Furnace Slag (GBFS), Silica Fume (SF), Activated Metakaolin (AM), *etc.* which can improve various properties in fresh and hardened state of concrete and also increase the cost of construction. It is now the global concern to making economic friendly material product at lower cost with less harmful effect on environment [8]. Addition of cost saving materials by the replacement of considerable amount of cement reduces CO_2 emission during the manufacturer of Portland cement [9,10].

In India around 960 millions tonnes of solid waste is being generated annually as by-products during industrial, mining, municipal, agricultural, and other processes. It is important to use develop technologies for the utilization of solid waste consumption in concrete. Concrete preferred for construction, which is very durable require little or no maintains. The assumption is largely true except when it is subjected to highly aggressive environment. We build concrete structure in high polluted urban and many other hostile conditions where other construction materials are found to be non-durable. Recently the uses of sludge in concrete have spread it to highly harsh and hostile condition [11-13].

The extensive use of fly ash, which is abundant in India, to meet the current construction demands and to decrease the environmental damage. In the past decades concrete vastly used in mega construction project in the country. [11]

Objective of review

Review focused on utilization of industrial solid wastes and by–products (heavy metals bearing) as concrete ingredients and also discussed the mechanical and chemical properties of concrete through solidification/stabilization process.

2. CONCRETE

Concrete is an artificial conglomerate stone made essentially of Portland cement, water, sand, and aggregates. The mixing of all the materials is placed into a plastic form; a chemical reaction called hydration takes place between the water and cement, and concrete normally changes from a plastic to a solid state in about 2 hours. Theoretically, if kept in a moist environment, concrete will gain strength in practical terms (about 90%) in the first 28 days. The product cannot be treated as concrete unless all these steps are realized [14 -21].

2.1. Chemistry of concrete

Concrete industry is particularly important, since it is not only responsible for consuming natural resources and energy, but also for its capacity of absorbing other industrial waste and by-products.

Ordinary Portland Cement + H_2O + Sand + Aggregates $\rightarrow$ Hardened Concrete + Energy (Heat)

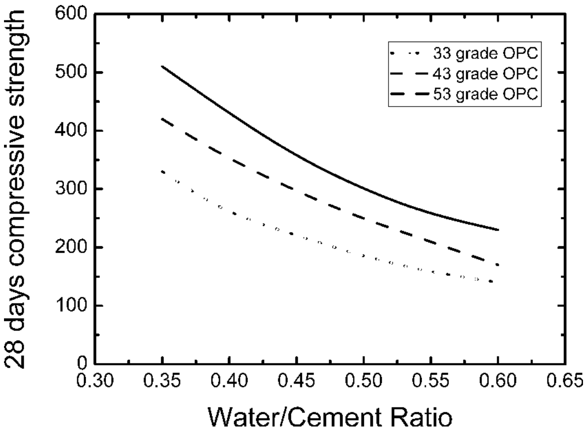

Fig. 2. Influence of water-cement ratio and grade of ordinary portland cement on the 28 days compressive strength of concrete.

The cement used in concrete is not used as a building material because it would be too expensive and not as strong as concrete [22]. Concrete can sometimes contain other substances; such as fly ash from industrial smoke stacks, which can change its properties.

When water is added to cement, each of the compounds undergoes hydration and contributes to the final concrete product. Only the calcium silicates contribute to strength. Tricalcium silicate is responsible for most of the early strength (first 7 days). Dicalcium silicate, which reacts more slowly, contributes only to the strength at later times. The equation for the hydration of tricalcium silicate is:

Tricalcium Silicate + Water → Calcium Silicate Hydrate + Calcium Hydroxide + Energy (Heat)

The majority of space is filled with calcium silicate hydrate. That which is not filled with the hardened hydrate is primarily calcium hydroxide solution. The hydration will continue as long as water is present and there are still unhydrated compounds in the cement paste.

Dicalcium silicate also affects the strength of concrete through its hydration. Dicalcium silicate reacts with water in a similar manner compared to tricalcium silicate, but much more slowly. The heat released is less than that by the hydration of tricalcium silicate because the dicalcium silicate is less reactive. The products from the hydration of dicalcium silicate are the same as those for tricalcium silicate:

Dicalcium Silicate + Water → Calcium Silicate Hydrate + Calcium Hydroxide + Energy (Heat)

The other major components of portland cement, tricalcium aluminate and tetracalcium aluminoferrite also react with water. Their hydration chemistry is more complicated since it involves reactions with the gypsum as well. Because these reactions, treated the hydration of each cement compound independently, do not contribute significantly to strength this statement is not completely accurate. The rate of hydration of one compound may be affected by varying the concentration of another. In general, the rates of hydration during the first few days ranked from fastest to slowest [23]:

Tricalcium aluminate > tricalcium silicate > tetracalcium aluminoferrite > dicalcium silicate

2.2. Mix proportion of concrete

Water, sand, and aggregate or crushed stone used in concrete production in addition to cement are also abundant. With all of these raw materials, the distance and quality of the sources have a big impact on transportation energy use, water use for washing, and dust generation [24].

A low water-to-cement ratio is needed to achieve strong concrete. It would seem therefore that by merely keeping the cement content high, one could use enough water for good workability and still have a low W/C (Water/Cement) ratio. The problem is that cement is the most expensive among the basic ingredients [21,25]. The dilemma is easily seen in the schematic graph of Fig. 1.

2.3. Ingredients of concrete

2.3.1.Cement

Grey cement produced by us consists of Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC). OPC has three principal grades that are differentiated by their compressive strengths, and consist of 53, 43, and 33 OPC (Fig.2) [21]. W/C ratio based on the grade of cement for the medium strength of concrete [26] shown in fig. 2. The raw materials used in cement production are widely available in great quantities. Limestone, marl, and chalk are the most common sources of calcium in cement (converted into lime through calcinations). Common sources of silicon include clay, sand, and shale. Minimum cement content in concrete is 1 m^3 [21].

2.3.2. Sand (fine aggregate)

The fine aggregate or sand may be natural or crushed. It may be available in a riverbed or in a quarry. The size of sand particles varies from a maximum of 4.75 mm down to 150 micron. Good sand must contain all the particles within the above range, that is, it should be graded sand. The sand may be sieved through the following Indian Standard Sieves [21]: 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron, and 150 micron. The sand may be classified as very coarse (zone I), medium coarse (zone II), coarse (zone III), and fine (zone IV) depending upon its grain size distribution. The sand samples were first sieved through 4.75 mm sieve and the larger particles were removed. River sand is very fine and is not suitable for concrete work (Table 1). It may be used for plastering only with the addition of some coarse sand. Very coarse sand is also unsuitable for concrete work. It may be used with the addition of finer sand. Coarse sand should be used in the structural work that is, beams, slabs, columns, and foundations, *etc.* [27].

Table 1. Color and water absorption in different type sands.

Colour	Water Absorption in percent
Blackish	0.5%
Grey	2%
Reddish	1%
Pinkish	1.25%
Brownish	0.5%

2.3.3. Aggregate (course aggregate)

Aggregate is the solid particles that are bound together by the cement paste to create the synthetic rock known as concrete. Aggregates can be fine, such as sand, or coarse, such as gravel. The relative amounts of each type and the sizes of each type of aggregate determine the physical properties of the concrete [28].

Sand + Cement Paste = Mortar

Mortar + Gravel = Concrete

Amongst all the materials, which are used, aggregates are very important. The quality of aggregates is very important since they make up about 60 to 80% of the volume of the concrete; it is impossible to make good concrete with poor aggregates. The grading of both fine and coarse aggregate is very significant because having a full range of sizes reduces the amount of cement paste needed. Well-graded aggregates tend to make the mix more workable as well. The bond between the paste and aggregate tends to set an upper limit on the strength of concrete. Bond is influenced by the surface texture, particle size and shape, and cleanliness of aggregate. Cement paste normally bonds better to a rough textured surface then to a smooth surface. Angular particle and those having rough vesicular surface have a higher water requirement then rounded materials. Nevertheless, crushed and natural course aggregate generally give substantially same compressive strength for a given cement factor. The angularity of the aggregate may cause stress concretion that affects the performance of concrete. Moreover, the strength of aggregate and its porosity affects the mechanical behavior of concrete from both strength and ductility point of view. These effects contribute to the failure pattern of concrete and determine its behavior under lateral pressure [21,29,30].

The accuracy of aggregate measurement by volume depends upon the accuracy with which the amount of “bulking”, caused by moisture in the aggregate, can be determined. The amount of bulking varies not only with different moisture contents but also with different gradations. Fine sand, for example, is bulked more than coarse sand by the same moisture content. Furthermore, moisture content itself varies from time to time, and a small variation causes a large change in the amount of bulking. For these and other reasons, aggregate should be measured by weight rather than by volume whenever possible. To make grading easier, to keep segregation low, and to ensure that each batch is uniform, it should be stored and measured coarse aggregate from separate piles or hoppers. The ratio of maximum to minimum particle size should not exceed 2:1 for a maximum nominal size larger than 1 inch. The ratio should not exceed 3:1 for a maximum nominal size smaller than 1 inch.

2.3.4. Admixtures

Sometimes, other materials are incorporated into the batch of concrete to create specific characteristics. These additives are called admixtures [21,23]. Suitable materials known as admixtures may be added to concrete mix, just before or during mixing, to modify one or more properties of concrete in plastic or hardened state as desired. Admixtures may be used for the following purposes:

- To increase the workability
- Without changing / increasing the water content
- To increase strength
- To retard the initial setting time, and
- To increase water tightness.

Admixtures are chemicals, which are added to the mix to achieve special purposes or to meet certain construction conditions [25]. Chemical admixture works as accelerator (Table 2).

Chemical admixtures: Accelerating admixtures, retarding admixtures, water reducing admixtures, air entraining admixtures, and super plasticizers. A plasticizer may be sulfonated naphthalene or melamine formaldehyde based.

It is necessary to select a suitable type of admixture, quantity, and mixing procedure depending upon the other materials and requirements. Trial mix should be prepared and tested for slump at 30 minutes and strength 7 and 28 curing days. It is important to note that an admixture is effective only when the aggregate are clean. It is possible that some admixtures may not yield the desired results because of the use of particular cement and aggregate, and under the given environment [31]. Chemical admixture also affected the properties of concrete with accelerating and retarding air and entraining water admixture. The addition of Na_2SO_4 increases the strength of concrete and the activity of Na_2SO_4 depends upon the curing days (3, 7, 28 days) and grinding [32].

2.3.4.1. Superplasticizers

Concrete's strength may also be affected by the addition of admixtures. Admixtures are substances other than the key ingredients, which are added during the mixing process. Some admixtures add fluidity to concrete while requiring less water to be used. An example of an admixture that affects strength is superplasticizer. This makes concrete more workable or fluid without adding excess water. A list of some other admixtures and their functions is given below. Note that not all admixtures increase concrete strength. The selection and use of an admixture are based on the need of the concrete user [21].

2.3.4.2. Retarders

Retarders are used to slow the set of concrete when large masses must be placed and the concrete remain plastic for a long period of time to prevent the formation of “cold joints” between one batch and the other batch of concrete. Accelerators serve to increase the rate of strength gain and to decrease the initial setting time. This can be beneficial when concrete must be placed on a steep slope with a single form or when it is desirable to reduce the time period in which concrete must be protected from freezing. The best known accelerator is calcium chloride, which acts to increase the heat of hydration, thereby causing the concrete to set up faster. [21,25]

2.3.5. Water

The major factor controlling strength, everything else being equal, is the amount of water used per bag of cement. Maximum strength is obtained by using less amount of water, and no more, required for the complete hydration of the cement. As previously mentioned, however, a mix of this type may be too dry to be workable [21]. Concrete mix always contains more water than the amount required attaining maximum strength. The amount of excess water decreases the strength of concrete. The specified water-cement ratio is the perfect medium between the maximum possible strength of the concrete and the necessary minimum workability requirements.

The strength of building concrete is expressed in terms of the compressive strength in pounds per square inch (psi) reached after a 7 or 28 day setting. This is usually referred to as probable average 7 day strength and probable average 28 day strength [33]. The degree of cement hydration increased with time and temperature, but the increase beyond 28 days was not significant [34].

2.4. Grades of concrete

Various grades of concrete are specified:

- Ordinary Concrete - M10, M15, M20;
- Structural Concrete - M25 to M55;
- High Strength Concrete - M60 to M80 [35];

The minimum average compressive strength of M20 grade concrete (15 cm cube) at 28 days should be 20 MPa (20 N/mm^2). The mix type 1:2:4 is commonly used for M15 concrete; 1:2:4 means 1 part of cement, 2 parts of sand, and 4 parts of aggregate by volume. The problem is that the quality of sand and aggregate vary greatly from one place to another. Therefore, the same ratio of 1:2:4 can't be expected to give a good quality of concrete with different types of sand and aggregate. The materials should always be measured by weight to prepare concrete. A richer concrete, that is, a concrete with a higher cement ratio is stronger and more durable [20,36-40].

K. Srinivasa Rao *et al.* [41] showed that a High Strength Concrete (HSC) which was develop by ACI mix design method was used to achieve a mix with a compressive strength of 60 MPa. Mix proportion used was 1:0.94:1.35 and W/C ratio 0.25, the size and shape of concrete were cube (150x15x150 and 100x100x100 mm) and cylinder (300x150 mm). This concrete was tested by different parameters on different ages (1, 3, 7, 28, 56, 91 Days). Small change in compressive strength after 28 days and no change in compressive strength after 56 days were reported.

2.5. ENGINEERING PROPERTIES OF CONCRETE

2.5.1. Unconfined compressive strength (ucs)

Unconfined compressive strength depends upon many factors, including the quality and proportions of the ingredients and the curing environment. The most important indicator of strength is the ratio of the water used compared to the amount of cement. Basically, the lower this ratio is, the higher the final concrete strength will be. (This concept was developed by Duff Abrams of The Portland Cement Association in the early 1920s and is in worldwide use today). A minimum W/C ratio (water to cement ratio) of about 0.3 by weight is necessary to ensure that the water comes into contact with all cement particles (thus assuring complete hydration). In practical terms, typical values are in the 0.4 to 0.6 ranges in order to achieve a workable consistency so that fresh concrete can be placed in the forms and around closely spaced reinforcing bars [21,25]. Compressive strength depends on the curing time [42,43]. Concrete showed small change in compressive strength after 28 days and no change after 56 days [41]. Strength enhancement of gravel reaches 97% at the 2.8% volumetric ratio. The roundness of aggregate assists to distribute the lateral confinement and helps the concrete element to experience higher stress [44]. The strength is increases because the formation of secondary Calcium Silicate Hydrated (CSH) gel [45].

Placing of concrete is also very important process. It is the process of transferring of fresh concrete from the mixing or conveying device to its final place in the forms. The method of placing should be such that segregation, displacement of forms avoided. Prior to placing loose rust must be removed, forms must be cleaned, and hardened surfaces of previous concrete lifts must be cleaned and treated appropriately [20,31,36-40].

The strength of concrete is strongly dependent upon the hydration reaction just discussed. Water plays a critical role, particularly the amount used. The strength of concrete increases when less water is used to make concrete (Fig. 3). The hydration reaction itself consumes a specific amount of water [23].

2.5.2. Durability [freezing thawing resistance].

Durability is the ability of concrete to resist weathering action, chemical attack, abrasion and/or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment. Factors responsible for aggravating or deterioration of concrete are: freezing and thawing, aggressive chemical exposure, abrasion, corrosion of metals and other materials embedded in concrete, alkali aggregate reaction, high temperature and poor workmanship [21].

The durability of concrete refers to the extent to which the material is capable of resisting deterioration caused by exposure to service conditions. Concrete is also strong and fireproof. Ordinary structural concrete that is to be exposed to the elements must be watertight and weather resistant. Concrete that is subject to wear, such as floor slabs and pavements, must be capable of resisting abrasion. The major factor that controls the durability of concrete is its strength. The stronger is the concrete, the more durable it is. The chief factor controlling the strength of concrete is the water-cement ratio. However, the character, size, and grading (distribution of particle sizes between the largest permissible coarse and the smallest permissible fine) of the aggregate also have important effects on both strength and durability [25]. Both time and temperature to bulk transport properties, which directly influence concrete durability. For pavements, permeability and durability are intimately connected [46].

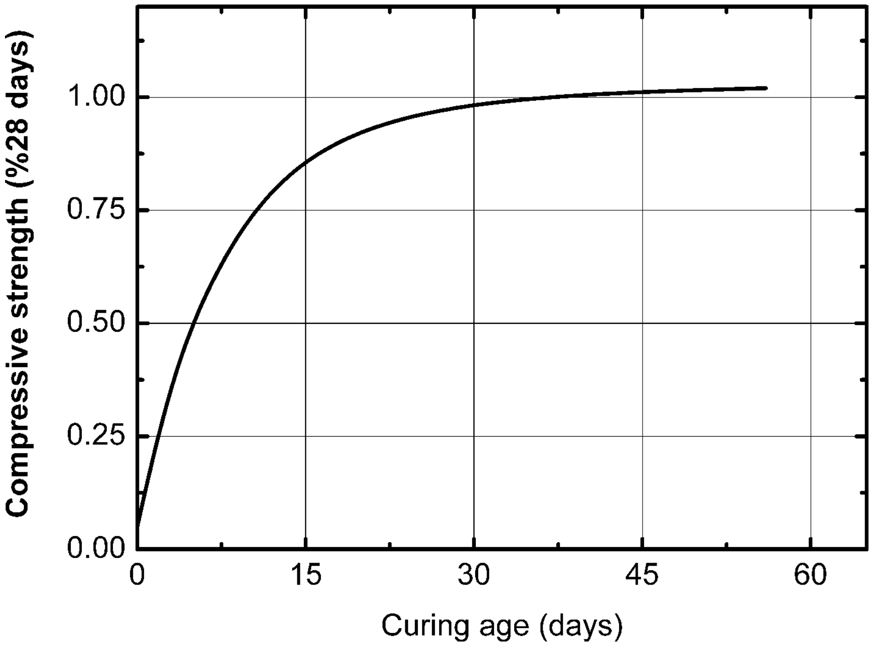

Fig. 3. Concrete strength as a function of the water to cement ratio. Data from [23].

3. UTILIZATION OF HAZARDOUS SOLID WASTE AND BY-PRODUCTS

In developing and industrial countries, large amounts of industrial waste or by-products are accumulated every year. Recycling of these materials is of increasing interest worldwide, due to the high environmental impact of the cement and concrete industries [47]. For the production of cement and concrete, very high amount of energy is needed. About 7% CO_2 is released to atmosphere during cement production. It has negative influence on ecology and future of human being [11,12]. According to industrial ecology concept for sustainable development, by-product of one industry may be a raw material for other industry. Therefore, detrimental effects of both industries to the environment can be reduced. Harmful effects of concrete on the environment can be reduced by producing durable concrete and effective usage of resources. Industrial by-products and solid wastes can be used for this purpose [11,48]. For this reason, cost, durability and environmental friendliness are important criteria used in developing concrete technologies [49].

Concrete elements containing industrial by-products or solid wastes as aggregate replacement, should be investigated with regard to these degradation causes, mechanical properties, and microstructure [50].

Normal concrete is made using sand and stones, but lightweight concrete can be made using industrial by-products such as expanded slag, clay, and sludge as aggregates. It is more difficult to achieve high strength with weaker aggregate [21,25].

3.1. By-products

Industrial by-product (class F - fly ash, slag) can be used in large amount as replacement material of cement in concrete. It can be added in a quantity of 10% to about 35% by weight of cement. It will be very beneficial in reducing CO_2 emission during production of cement, preventing the global warming [11,12]. The cement companies have the necessary expertise to mix suitable quantity of fly ash in Portland cement and blend properly [10]; fly ash should never be added at site. Fly ash can help with our solid waste problems, and it reduces overall energy use. While fly ash is sometimes used as a source of silica in cement production, a more common use is in concrete mixture as a substitute for some of the cement. Fly ash, or pozzolan, can readily be substituted for 15% to 35% of the cement in concrete mixes, according to the U.S.EPA [2] (Environmental Protection Agency). For some applications, fly ash content can be up to 70%. Thus, fly ash today accounts for about 9% of the cement mix in concrete. Water absorption, coefficient of water and chloride diffusion co-efficient was less in fly ash concrete [51].

If the class C fly ash is used in the concrete mix higher replacement level is possible. If the replacement level is more then 25%, it shows marginal reduction in the strength [52,53]. The grinding of fly ash influences the strength development in concrete [42,43]. As with the Class C fly ash, the Class F fly ash is also composed primarily of an amorphous phase and some crystalline components that include alpha-quartz, Fe_3O_4, Al_2SiO_5, $(Mg,Fe)_2SiO_4$, and CaO. The main difference was that Class F fly ash contains no reactive crystalline reactive component such as C_3A. The acid-insoluble residue (89%) of the fly ash consisted virtually of the same phases detected before treatment except for CaO [28]:

$$P = f / (c + f),$$

where, P is the percentage of fly ash, f = fly ash content in kg, c = cement content in kg [10].

The use of fly ash in concrete is the highest-volume application for fly ash. Concrete requires less water when fly ash is used in place of cement, resulting in less shrinkage and cracking [53]. According to U.S.EPA, 15% is a more accepted rate when coal fly ash is used as a partial cement replacement as an admixture in concrete [2,54].

C. Natarajan reported M20 and M30 grade of concrete mixes having different replacement level of cement with low calcium fly ash [10]. Compressive strength (*Rc*) values at 3-28 days curing period shows a fine relationship between *Rc* value and the logarithm curing time for fly ash/cement mortar at different temperature [42].

C. D. Ati [53] carried out laboratory scale study concrete mixtures were prepared by the replacement of 50 and 70% of cement with fly ash. The range of water to cement ratio was from 0.28 to 0.34. The concrete mixture was cured at temperature of 20 °C at 65% relative humidity. It was concluded that fly ash concrete showed higher strength after 28 days. The efficiency factor K was defined as the ratio of the mass of cement to the mass of the fly ash when they had equivalent effect on the water to cement ratio [55].

$$X = \frac{W}{C + KF + S},$$

where, X is the water to cement ratio, W - water content, C - cement content, F - fly ash content, S - GBFS content, and K is the efficiency factor.

The cement efficiency factor of fly ash with respect to water tightness or water permeability which is approximately 0.3. There is no effect of cement type and curing time. Efficiency factor has some effect on concrete strength formula and it is dependent on curing days and percent of replacement [55,56]. Curing temperature is important factor increase in curing temperature yielded in compressive strength for fly ash replacing percentages [42,57].

Fly ash reacts with free lime after the hydration to form calcium silicate hydrate, which is similar to the tricalcium and dicalcium silicates formed in cement curing. Through this process, fly ash increases concrete strength, improves sulfate resistance, decreases permeability, reduces the water ratio required, and improves the workability of the concrete. Fly ash with low sulfur and carbon contain is better for concrete.

There are at least a dozen companies providing fly ash to concrete producers. Other industrial waste products, including blast furnace slag, cinders, and mill scale are sometimes substituted for some of the aggregate in concrete mixes [58]. Fly ash can be introduced in concrete directly, as a separate ingredient at the concrete batch plant or, can be blended with the ordinary portland cement (OPC) to produce blended cement, usually called portland pozzolana cement (PPC) in India. Fly ash blended cements are produced by several cement companies worldwide [21].

3.2. Waste materials

Research have investigated various properties of concrete containing by-products and waste materials such as Granulated Blast-Furnace Slag GBFS), Fly Ash (FA), Bottom Ash (BA), Silica Fume, Waste Glass (WG) as mineral admixture, aggregate replacement or binding material [59].

Study on possible usage of BA and GBFS in production of plain concrete elements was performed. It was reported that replacement of BA decreases the unit weight of briquette. Usage of BA makes feasible up to 30% partial replacement of aggregate in production of briquettes. As GBFS/Sand ratio increases in paving blocks, water absorption ratio increases too, while compression strength and freeze–thaw resistance decreases. However, these losses are under limit values; so, the standards allow up to 30% replacement ratio [50].

Heavy metals like Pb, Cd, and Cu leachate concentrations were below the analytical detection limit of atomic absorption spectrophotometer (AAS). Higher concentrations were measured for Cr, Zn, and Fe. The quantity of Cr, Zn, and Fe leached tended to increase when the initial concentration of these metals and leachate *p*Hs were growing. For higher loading percentages, the Cr leached was above U.S. EPA limits [45].

Partial substitution (15% or 30% by mass) of cement by Sewage Sludge Ash (SSA) does not strongly affect the strength of mortars cured at 40 °C for 3- to 28-day curing periods. High sulfur content in SSA does not have a decisive influence on strength development. Fineness of SSA is an important parameter for strength development of SSA/cement mortars: the coarsest fraction yields the lowest strength values. SSA showed a greater or similar contribution to mechanical development than fly ashes at early ages, but they become less efficient for longer term curing. CSGr and FSGr increased remarkably with increasing SSA replacement [60].

In this study sewage sludge was used as an additive in order to develop new construction materials. For this purpose, several mixtures of sludge cement calcium chloride and calcium hydroxide were prepared and Stabilized/Solidified (S/S). Calcium chloride and calcium hydroxide were used as accelerating additives. XRD and SEM studies were performed to determine the hydration products. The specimens were tested in order to determine their setting time and compressive strength after 28 days. Furthermore, in order to investigate the environmental compatibility of these new materials, Toxicity Characteristics Leaching Procedure (TCLP) and CEN/TS 14405 tests were carried out for the determination of heavy metals leaching [61].

Jarosite released from zinc metal extraction process is hazardous in nature. Statistically designed experiments on S/S sintered jarosite CCRs products confirmed that the compressive strength of jarosite bricks reached as high as 140 kg/cm^2 with 14.5% water absorption capacity at the combination of 3:1 ratio of jarosite and clay, respectively, but, concentrations of all the toxic elements recommended by U.S.EPA TCLP standard are not within the permissible limits. The optimum mix design of 2:1 with 15% fly ash was found to be the intermediate condition to have satisfactory compressive strength [2,62].

The addition of pozzolans or slag modified the microstructure. The outer CSH appeared less fibrillar and the cement matrix was less porous at earlier ages with use of silica fume or metakaolin. The effect of this was a reduced rate of leaching of the alkali hydroxide from the pore fluid, with which the silica fume specimen appeared to slow the expansion process, but did not prevent expansion [63].

Another study was performed to assess whether the Stabilization/Solidification (S/S) technology can be applied for treatment of “real” refinery oily sludge contaminated by heavy metals. The performance of stabilized wastes is generally measured in terms of leaching and extraction tests. The samples were cured at approximately 24 °C in the laboratory for 28 days [64]. As a result, the effects of replacement of cement (by mass) with three percentages of fly ash and the effects of addition of natural san fibers on the different parameters and impact strength of fly ash concrete. San fibers belong to the category of “natural bast fibers.” It is also known as “sunn hemp”. A control mixture of proportions 1:1.4:2.19 with W/Cm of 0.47. Cement was replaced with three percentages (35%, 45%, and 55%) of class F fly ash. Three percentages of san fibers (0.25%, 0.50%, and 0.75%) having 25-mm length were used. Addition of san fibers reduced the workability; did not significantly affect the compressive strength; increased the splitting tensile strength and flexural strength, and tremendously enhanced the impact strength of fly ash concrete as the percentage of fibers increased [65].

This study also investigated the possibilities of plain concrete containing dry sludge. The S/S mechanisms for sludge from treatment plants in a Portland cement matrix have previously been evaluated in [1, 5-7,66].

3.3. Admixtures

Industrial waste works with Mineral admixtures in concrete are summarized in [67].

Mineral admixtures used in concrete were fly ash, metakaolin, GGBS, and silica fume since many important structures built with silica fume in concrete are used for durability aspects [68].

S. Asavapisit and D. Chotklang [45] investigated the potential for utilization of alkali activated (Pulverized Fuel Ash) PFA as solidified binder to treat electroplating sludge. The early strength development of lime PFA cements in the presence of Na_2SiO_3 and Na_2CO_3 was considerably higher than the strength development of those without these compounds. The maximum strength development was achieved at 4 and 8 wt.% dosages of Na_2SiO_3 and Na_2CO_3, respectively. Aluminum oxide used as a chemical admixture (10-15% by weight of cement) is able to reduce 30% of free chloride [43].

Addition of fly ash gave measurable increase in strength with metakaolin (MK) [69]. MK concrete shows more loss and possessed lower residual strength as compared with other concretes [70].

A new highly effective alkali activator like SFA (Silica Fume Activator) showed high value of the compressive strength after 28 days curing than used activator like sodium hydroxide, sodium carbonate, and water glass [71]. Calcium hydroxide and ettringite, the main products of cement hydration, are characteristic products of the early ages of the curing process, where ettringite formation also favors the compressive strength. The best results were observed for the samples containing 3% $CaCl_2$ and 2% $Ca(OH)_2$ [61].

The alkali activation of metakaolin is a way of producing high strength cementitious materials. The processing of these materials has been the subject of numerous investigations. This tendency was most pronounced in those samples cured in sodium sulfate solutions. This behavior may be related to the change in microstructure of the cementitious matrix of the mortars cured longer than 90 days. Some of the amorphous material present had crystallized to a zeolite-like material belonging to the faujasite family of zeolites [72].

Both the produced and commercial metakaolin indicate a similar behavior concerning the strength development and the corrosion resistance. The metakaolin improves the compressive strength and the 10% w/w addition shows the optimum contribution to the strength development. The use of metakaolin, either as a sand replacement up to 20% w/w, or as a cement replacement up to 10% w/w, improves the corrosion behavior of mortar specimens [73].

3.3.1. Superplasticizers

The superplasticizers made possible to use fly ash, slag, silica fume, and many other industrial by-products and waste materials. Addition of fly ash decreases the strength, increases the desired workability of concrete; Superplasticizer/Cementitious ratio of 0.015 was reported in [65].

3.4. Water

The absorption capacity tends to increase with an increase in sludge content. This indicates that as sludge is added, the capacity to hold water increases together with a certain increase in the number of cavities inside the concrete. The porosity of the sludge resulted in the concrete having a greater absorption capacity. This in turn increased until the age of 90 days, when it decreased. This is because once the concrete acquires greater hardness and resistance, it requires less water and is not able to assimilate it as well as it had done initially [66].

The strength of concrete is very much dependent upon the hydration reaction just discussed. Water plays a critical role, particularly the amount used. The strength of concrete increases when less water is used to make concrete (Fig.2). The hydration reaction itself consumes a specific amount of water. Concrete is actually mixed with more water than is needed for the hydration reactions. This extra water is added to give concrete sufficient workability. Flowing concrete is desired to achieve proper filling and composition of the forms [23].

3.5. Engineering properties of wastes and by-products bearing concrete

The performance of concrete is measured in terms of mechanical, physical, chemical properties.

3.5.1. Unconfined compressive strength (ucs)

Compressive strength development of cement paste is strongly affected by the volume of CSH formed during cement hydration. The 28 day compressive strengths were measured for the pastes made from OPC/SF, OPC/MK, and OPC/low-calcium fly ash at various W/S ratios [74].

The high volume fly ash (HVFA) concrete showed satisfactory compressive and tensile strength at age of 1 day. It also concluded that high volume fly ash concrete showed higher strength than OPC concrete at 28 day and beyond [53].

Isa Yuksel and Turhan Bilir [50] suggested that when GBFS/Sand goes beyond 30%, compression strength increases again in paving block specimens. As the replacement of BA/sand and GBFS/Sand increases in between 50% and 100% substitution ratios, compression strength value could not be reached in control specimen’s strength, but got very close results.

Concrete is one of the most important construction materials. It is comparatively economical, easy to make, offers continuity and solidity, and can be effectively bonded with other materials. The keys to good quality concrete are the raw materials required to make concrete and the mix design as specified [24]. The test results indicated that the replacement of cement with fly ash increased the workability (Slump and Vebe time), decreased compressive strength of plain (control) concrete [65].

3.5.2 Durability [freezing thawing resistance]

Authors of [24,75] discussed strength and some durability characteristics of the concrete containing BA and high sulphate FA. The author of [50] showed that usage of partially fine aggregate of these industrial by-products has more beneficial effects on durability characteristics of plain concrete elements. In this paper, potential usages of BA in briquettes and GBFS in paving blocks and kerbs as aggregate replacement were studied. Production of a new briquette type, having similar properties with normal briquette but lighter than it, is aimed by using these byproducts and solid wastes. Also, development of durability properties of paving blocks and kerbs were objected.

Superplasticisers were used to improve the durability. Curing time and curing method affected the durability of concrete [42,57,76]. The maximum durability is reached when typical concrete ingredients are mixed at room temperature. Therefore, the relative amounts of the mineral phases in cement reacted at various temperatures can be calculated. It was shown that both time and temperature affect to bulk transport properties, which directly influence concrete durability. For pavements, permeability and durability are intimately connected [29,77].

The main aspects of the concrete performance that will be improved by the use of fly ash are increased long-term strength and reduced permeability of the concrete resulting in potentially better durability. The use of fly ash in concrete can also address some specific durability issues such as sulphate attack and alkali silica reaction. However, a few additional precautions have to be taken to insure that the fly ash concrete will meet all the performance criteria [75].

This study was to evaluate an alternative final destination for the growing production of sludge from sewage treatment plants. The compressive strength after 7 days provided us with some clear results indicating that the strength decreased appreciably as the proportion of sludge increased. For all the different mixtures, the compressive strength after 28 days increased in comparison with that of the previous period, but not uniformly. After 90 days, the compressive strength had recovered and, for example, the specimens containing 10% sludge reached 58% of the compressive strength of the reference concrete, and those containing 2.5% sludge reached 78% of the reference value [66].

3.6. Chemical properties of wastes and by-products bearing concrete

3.6.1. Leachability of hazardous substances

Metal leaching from the solidified wastes was assessed using TCLP, Acid Neutralization Capacity (ANC) and Diffusion as defined by the U.S. EPA, on the samples cured for 3, 7, 28, 90 days.

Metal concentrations in the leachates increased as the initial metal concentration was increasing in the solidified wastes, but there is no linear relationship between the amount of metal leached and the initial concentration. The solidified waste matrices to neutralize acid were reduced. Pb, Cd, and Cu concentrations were below analytical detection limit of AAS. In addition, metal leaching from the solidified wastes with 8 wt.% Na_2CO_3 was found in a lower concentration than from those with 4 wt.% Na_2SiO_3. This is likely because leachate pHs from the solidified wastes with 8 wt.% Na_2CO_3 ranged between 8.4 and 9.8, being adequate to stabilize most metal hydroxides whose solubilities are strongly *p*H dependent [78].

In order to assess the effectiveness of S/S, we used the TCLP test was performed on the S/S specimens. Pb and Cr concentrations in the leachate were much lower than the respective TCLP limits, indicating that S/S is a potential treatment technology for refinery oily sludge. There are no TCLP limits for Cu and Ni due to lack of available data with respect to health effects and fate and transport in the environment, at the time U.S. regulations were passed. The TCLP extract concentrations of these metals for the solidified sludge were very low, i.e., <0.4 mg/L for Cu and <2.9 mg/L for Ni [64].

Radu Barnaa *et al.* [73] carried out laboratory scale study on the investigation of the influence of the Liquid/Solid (L/S) leaching conditions on release of different chemical species from a reference po-

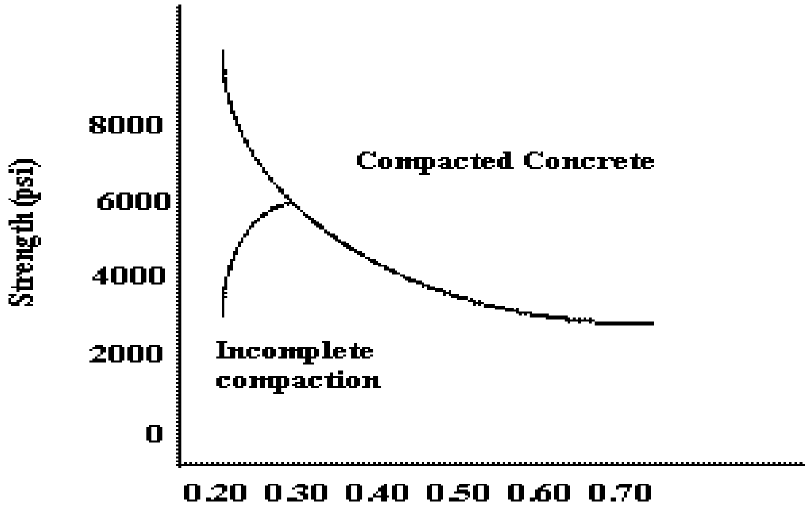

Fig. 4. Compressive strength gain with curing age of days. Data from [25].

rous material obtained by solidification of PbO and CdO with Portland cement. In order to determine the influence of laboratory leaching conditions on the release of different chemical species (NaC, KC, Ca_2C, Pb_2C, Cd_2C, and SO_2K_4) contained in a porous reference material obtained by solidification of PbO and CdO with Portland cement. This approach allowed assessing the *p*H influence on the dissolution of pollutants and the initial pore solution composition were assessed by applying a methodology consisting of two equilibrium leaching tests, the ANC and the Pore Water (PW) tests and geochemical modeling. The influence of the sample shape (monolithic) and elute hydrodynamics on the leaching of the target elements was also assessed. The comparison criteria were the elute saturation state, the cumulative release, and the released flux. It would conduct that evaluate a particular concrete formulation before predicting its performance in a special acid environment is necessary. At least, under certain circumstances, the addition of FA, SF, or MK can improve the acid resistance of concrete [74].

The solidified refinery oily sludge waste sample was ground to pass a 150 mm sieve. Each sample was subdivided into 11 sub samples, each of 3 g in weight. Each sub sample was placed in increasing amount of nitric acid (2N). Then the samples were tumbled strongly at room temperature for 48 h to reach equilibrium. The acid neutralizing capacity of the S/S wastes depends mainly on the type of waste and, to a lesser degree, on the type of binder agent, since cement types for each S/S waste reveal similar behavior to each other. The *p*H of the leachate produced from a S/S waste is directly affected by the ANC of the waste. Since heavy metal leaching is *p*H dependent, the ANC test might constitute a rapid qualitative prediction method for potential leaching of metals contained in the waste [64].

The author performed time dependent diffusion test. The diffusion coefficients (m) values for the concretes with various replacement levels of silica fume and slag. The results for the time dependent diffusion coefficients based on total time, or m_{total} values. The total time method yields the lowest m value, while the effective time approach of Stanish and Thomas yields the highest. The initial diffusion coefficients (28 day) are equal, but the secondary hydration effect in concrete containing blast furnace slag leads to a greater reduction in diffusion with time. The determination of diffusion coefficients and their time dependant behavior has an evident effect on the estimated time to corrosion [80,81].

3.6.2. Porosity and permeability

Permeability is closely related with strength and W/C ratio. Micro cracks in the initial stage are so small that they may not increase the permeability. But

Table 2. Factors influencing developed concrete with differrent wastes and by-productes.

S. No.	Type of waste or by-products	Waste or by-products %	Curing days	Admixture	Admixture %	Water/Cement Ratio	Waste/Binder Ratio	Compressive Strength (MPa)	References No.
1.	Fly ash	20	7,28	Silica fume, Metakaolin	10, 30	0.33	0.2	108-127	82 (HSC)
2.	Fly ash	20	7,28	Metakaolin	20	0.40	0.2	58.4	(NSC)
3.	-	-	7,28	$CaCl_2 2H_2O$ $Ca(OH)_2$	10-30	0.36-0.40	-	1100 (kPa)	60
4.	Fly ash	16.5 g	7,28	Silica fume, Metakaolin	16.5 g	0.4,0.45	0.6,1.6	72-90	73
5.	RHA, PA	10 - 30	1,3,7,28, 51,90,180	$Cr(OH)_3$, $Fe(OH)_3$, $Zn(OH)_3$	>25	0.45-0.70	0.1-0.3	89.37	106
6.	SA, SMW	20	3,5,7,21,28, 28,51,90	$Ca(OH)_{2,}$ lime stone	80	0.38	0.2-1	70-100	93
7.	PFyA	70	1,3,5,7,21, 28.51,91	Lime, $Na_2SiO_{3,}$ Na_2CO_3	30, 4, 8	0.5	0.1-0.5	67–200	79
8.	Fly ash	40 - 60	7,28	Superplasticizer	4.5-5.1 liters/cu.yd	0.32-0.42	0.68,1,1.5	41	54 (HSC)
9.	Fly ash, Slag	57, 8 - 35	13,5,7,21,28, 51,91,151, 265-3650	Silica fume	7, 8, 12	0.30±0.01	1.3,0.4,0.5, 0.08	87.5-112.3	10
10.	GBFS, Fly ash	15 - 60	7,14,28	-	-	0.3-0.4	0.42	15.91-51.48	51
11.	GBFS, BA	20 - 50	28	Silica fume, waste glass	2.08,2.04	0.5,0.32,0.47	4.1-4.8	42.5	50
12.	Electroplating sludge	25	7, 28	Lime	10	1	0.5	35	108
13.	-	-	3 - 28	NaCl, Al_2O_3	3, 10	0.6	-	36.67	43
14.	Hazardous Wastes, Fly ash	10, 25	28	Clay	25, 40, 50, 90	.45 - .65	0.1, 0.25	250 Kg/m^2	104
15.	Sludge	15	3, 7, 28	-	-	0.4,0.5	0.15	Equal to control	107
16.	Sludge & PFuA	0, 10, 20, 30	1-28-91	-	-	0.5	0.1, 0.2, 0.3	450, 80, 75 Kg/m^2	42
17.	-	-	3, 7, 28, 90	Silica fume, $Ca(OH)_2$	0 - 30	0.40	0.35, 0.4, 0.45, 0.50	55, 62	109
18.	POFA	10, 20, 30, 40	28, 90, 364	Lime stone	-	0.7, 0.72, 0.77, 0.87, 0.95	0.1, 0.25, 0.42, 1.5	30 – 37.6	110
19.	Sludge	2.5, 5, 10	7 - 90	Melcret PF - 75	1.68	0.55	0.1	18 - 32	65
20.	Fly ash, San fiber	35,45,55 0.25,0.50,0.75	28	Centriplast FF90 (melamine formaldehyde)	0.015	0.47 ± 0.02	0.35, 0.45, 0.55	26.7, 23.1	64

Captions: HSC = High Strength Concrete, NSC = Normal Strength Concrete, EAF = Electrical Arc Furnace, BFS = Blast Furnace Slag, SA = Sludge Ash, RHA = Rice Husk Ash, PFyA = Pulverize Fly Ash, SMW = Steel Making Waste, PA = Plating Sludge, BA = Bottom Ash, GBFS = Granulated Blast Furnace Slag, PFuA = Pulverized Fuel Ash, GFA = Ground fly Ashes propagation of micro cracks with time due to drying shrinkage and externally applied load will increase the permeability of the system [21]. Some of the wastes and by-products also participate in the structure of concrete. BA and GBFS increase workability and carbonation depth and decreases chloride permeability [50].

A model has been developed for relating porosity to permeability. It was determined that a linear combination of lognormal distributions can be used to describe pore structure. One of these distributions describes small pores, while the remaining two describe porosity through which bulk transport. The pore structure is very important for the prediction of permeability. The results show that permeability increases with temperature [70]. The basic trend concerning the increase of porosity with temperature was confirmed and the values of porosity determined by both methods were closer to each other with an increase of temperature. The most dramatic increase in porosity was observed at 600 °C in mercury porosimetric measurements. The values of porosity at 1200 °C were the same for the water vacuum saturation method and mercury porosimetry. This indicates a significant change of structure and disappearance of major cracks not detectable by mercury porosimetry [82].

According to Sandrolini and Franzoni [81], fine filler effects and actual W/C ratio reduction due to fine solids contents in sludge water leads to the reduction of concrete capillary water absorption and porosity, and possibly improves the durability of concrete. The porosity increased with an increase of sludge content and tends to decrease as the age of the concrete increased from 7 to 90 days. The hardening of concrete has an effect of binding the particles, which over time, decreases the number of pores [66,84].

Poor dispersion and inhomogeneity during mixing and placing may cause the cement particles to coagulate and cluster in the mix water, resulting in alternating regions of dense and high porosity hardened paste, even in instances where the use of a low W/C ratio was intended to provide an ultimately high density microstructure [85]. The water not consumed in the hydration reaction will remain in the microstructure pore space. These pores make the concrete weaker due to the lack of strength forming CSH bonds [23].

3.6.2.1. Chloride permeability

The resistance to chloride ion penetration and transport of concretes is an important feature for concrete durability. ASHTO T-227 Concrete and stripped mortar samples are taken from concrete mixtures cured for 28 days. A mortar shows higher chloride permeability in addition at constant cement content; the charges passed increase with decreasing the volume of sand in the mortar. At constant cement content, there is a direct correlation between the charge passed through concrete and the fine sand to coarse aggregate ratio. Higher W/C ratio gives higher charge passage through both concretes and mortars. Chloride permeability takes place primarily through the cement matrix [46]. The effects of various pozzolans and water to cementing materials ratios are clearly seen in the chloride diffusion values presented. Initial chloride diffusion values are higher in concrete mixtures at the higher water to cement ratio of 0.40 without the addition of pozzolans. The chloride diffusion coefficient reduces more dramatically in concrete mixtures containing pozzolans showing their long-term hydration properties [80].

The experimental work included in the current program was directed towards assessment of resistance of concrete to chloride permeability. The results are expected to be useful in connection with water permeability. The technique is similar to that described in method for measuring the chloride permeability under the effect of electric field [84].

3.6.3. Sulphate corrosion

The S/Ca (Sulphate/Calcium) ratios are much higher than those of 0.01–0.04 commonly found in pastes cured at ordinary temperatures [85,86].

Most of the Al^{3+} present in the CSH appears to be primarily substituted for Si^{4+}, [87,88] whereas the sulphate incorporated into the CSH adsorbed [89]. With moist storage, sulphate can be desorbed from the CSH. The mean S/Ca ratio of the CSH formed during the heat curing typically decreases to values of about 0.02–0.03 during storage [87,90,91] which is similar to that of the CSH that forms later. A significant amount of sulphate was taken up by the CSH during heat curing, both with mixtures containing only Portland cement as the binder and with partial amounts of SF, MK, BFS, and FS. The CSH acts like a cache and this sulphate was later released when the specimens were exposed to moisture at ambient temperature [92]. Higher percentages of metakaolin decrease the corrosion resistance [73]. Sodium sulfate attack of portland cement paste (15 mmol/l) has been presented by the author. Surface abrasion is an important durability characteristic for paving blocks [50].

The author discussed that calcium leaching in sulfate environment presents similar kinetics with respect to calcium leaching in pure de-ionized water. The precipitation of significant quantities of ettringite and gypsum resulted in, the breakdown of samples in presence of sulfates. Cracks were found predominantly in zone 2, perpendicular and parallel to the attacked surface, and partly filled with gypsum. The initiation of cracking and failure of the samples was found to depend significantly on their thickness. The proper estimation of the service life of concrete structures to sulfate attack must therefore account for these marked scale effects [93].

4. FACTORS AFFECTING CONCRETE STRENGTH AND DURABILITY

4.1. Curing days

Curing pathways, days and temperature, are very important factor for hardening of cement and concrete. Fresh concrete gains strength most rapidly during the first 28 days due to hydration of cement, which can take place only in the presence of water. The final strength of concrete depends greatly on the conditions of moisture and temperature during this initial period. The maintenance of proper moisture and temperature conditions during this period is known as curing. The purpose of curing is to prevent the loss of moisture in concrete due to evaporation, thereby, to prevent the development of high temperature gradient within the concrete, and hence, plastic cracking. Curing can be done in several ways. It was concluded that high volume fly ash concrete showed higher strength than OPC concrete at 28 day and beyond [53]. Moist curing is most common. It consists of application of water directly to the concrete or by means of continuously saturated coverings of sand, straw or hessian bags, *etc*. The curing should be done for about first 14 days of concreting [20,36-40].

Both the rate and degree of hydration, and the resulting strength of the final concrete, depend on the curing process that follows in placing and consolidating the plastic concrete (Fig. 4). By the standard and other controlled conditions one can assess curing related properties such as maturity, shrinkage, and degree of hydration. This period depends on conditions like temperature, cement type, and mix proportions. Degree of hydration and CSH gel increased with the curing age [94]. The strength of the concrete is related to the water to cement mass ratio and curing conditions. A high water to cement mass ratio yields a low strength concrete. This is due to the increase in porosity (space between particles) that is created with the hydration process. Most concrete is made with water to cement mass ratio ranging from 0.35 to 0.6. Time is also an important factor in determining concrete strength. Concrete hardens as time passes. Remember that the hydration reactions get slower and slower as the tricalcium silicate hydrate forms. It takes a great deal of time (even years) for all of the bonds to form, which determines concrete's strength. It is common to use a 28-day test to determine the relative strength of concrete [23].

4.2. Water to cement ratio (W/C)

Water plays an important role in the concrete strength. Low water to cement ratio leads to high strength but low workability. High water to cement ratio leads to low strength, but good workability. The physical characteristics of aggregates are shape, texture, and size. These can indirectly affect strength because they affect the workability of the concrete. When the water to cement mass ratio is increased, the concrete will weaken [23]. Water/cement ratio showed negative effect on compressive strength of concrete [95,96]. The quantity of water must not be more than 0.50 of the weight of cement for most applications. Water percentage also depends on the type of sand (Table 1). A large quantity of water is highly injurious for concrete as well as steel. This is the single reason for the failure or poor quality of any reinforced concrete construction. More water means lesser strength and lesser life of concrete [20,36-40,93]. Abrams [96] suggested a mathematical relationship between concrete strength and water–cement ratio:

$$fc' = \frac{A}{B^x} = AB^{-x},$$

where, fc' is the compressive strength of the concrete, A and B are experimental parameters for a given age, material, and cure conditions, and x is W/C ratio by mass:

$$x = \frac{W}{C},$$

where, W is the water content and C is the cement content [22].

G. Appa Rao [94] in discussed the water/cement ratio negative effect on compressive strength. Adopted cement/sand ratios were 1:2, 1:2.5, 1:3 and the water/cement ratio was from 0.30 to 0.65. The compressive strength was measured at the age of 3, 7, 28 days. Mainly W/C ratio is influenced the strength of concrete. The W/C ratio described the strength of concrete described by the "Abram's W/C ratio law". Compressive strength decreases as the C/S ratio and the w/c ratio increases.

4.3. Water absorption percentage

Water absorption percentage is an effective parameter for pure and mixed concrete. In the mixed concrete it is very important. Waste absorption percentage depends on the type of waste. Water adsorption percentage increases with the increase of waste (Table 1)[50,63]. Water absorption reduces the fine solid content and improves durability [83].

4.4. Temperature variations

Changes in the temperature of concrete can cause cracking. As the concrete gets hotter, it expands; as concrete gets cooler, it contracts similarly to many other materials. If the concrete tends to expand or contract, it will most likely crack [97].

Elevated temperature affects the properties of concrete such as change in moisture content, degree of hydration, and other features [34]. The degree of hydration increases with time and temperature, but the degree of hydration was not increased in significant amount after 28 day curing [98]. Fly ash/cement cured at different temperatures (20 °C and 40 °C curing temperature) shows significant increase in compressive strength (*Rc*) of concrete [34,42,57].

The concrete cured at 20 °C for 28 days had a higher degree of cement hydration and lower capillary porosity than the concrete cured in water of the same temperature for 7 days followed by exposure to outdoor air for 21 days, but had opposite trend compared to the concrete cured in 35 °C water for 7 days followed by exposure to outdoor air. However, the differences in the degree of cement hydration and capillary porosity for the concrete cured in these different conditions were not significant. This suggests that the reference thin sections of concrete cured at 20 °C in moist condition for 28 days may be used to estimate the W/C of concrete cured in a tropical environment for at least 28 days, including 7 days moist curing without the need to determine the degree of cement hydration of concrete under investigation [34].

5. DISCUSSION

Landfilling is not a desirable option for the disposal of solid hazardous waste materials. It is not a liable method because of future environmental costs and problems associated with landfilling regulations [99]. This method increases load of toxic metals and other contaminants in the landfill, potentially increasing the threat to ground water contamination. Increasing economic and financial factors also dictate that industry should look forward to recycling and reuse of waste material as a better option to landfilling [100].

Wastes and by-products can be used in addition to concrete without the need for large changes in its preparation. Its granulometric properties indicate that it can be used in fine sand in production. Waste content of 10% or more cannot be used because it significantly delays the setting of the cement and reduces its mechanical properties, especially in the short term. For all waste and by-products contents, the strengths increase as the curing time of the concrete increases [66]. Some waste materials have 60-90% water holding capacity, which is not beneficial for concrete [50,62]. In the worst case the compressive strength was 4.5 Mpa. After 28 days the same concrete had reached strength of 6 MPa and after 90 days, 18 MPa, which would allow it to be used for road bases and subbases, and as a filling material [7,9,10,12,14,28]. In general, it would be suitable for any application that does not require high strengths, especially not in the short term [32,42,45,50]. The porosity and the absorption coefficient increase with an increase in waste content and decrease as the curing time increased [52,53,56,62]. The deformability of concrete also increases with the increase of waste contents [61,62,67]. The density of the concrete decreases with an increase in waste content and increases as the curing time increases [24,69,94].

With reference to our previous study on concrete M15 [101] and geopolymer [99] the mixed concrete is a desirable option to utilize or reuse of solid hazardous waste materials. Solidified materials are weak and contain significantly less cementitious materials and more water, for example concrete. Due to waste addition, CSH hydration is poisoned. In these situations, ettringite plays an important role - it increases strength and durability characteristics. UCS increases with a decrease of crystalline phases [91,98].

It also affects the cost of construction cement and sand very important and costly material. The replacement of them by waste and by-products gives an opportunity to manufacture economic concrete for the construction material.

The review concluded that the developed mixed concrete showed high strength, improved sulfate resistance, decreased permeability, reduced the water ratio required, and improved the workability. Partial substitution of solid hazardous wastes does not strongly affect the strength of concrete and other properties.

6. APPLICATION OF CONCRETE

Concrete serves as a better alternative for the utilization or recycle of the solid hazardous waste materials. Properties of mixed concrete can be listed as follows:

Strength: different solid hazardous waste materials used in mixed concrete. It shows 70-85% strength of pure concrete.

Durability: concrete shows long-term durability by the use of mineral admixtures; many important structures are manufactured using the concrete with silica fume, which positively affects on durability aspects.

Leaching: about 85-90% of heavy metals and other contaminants are solidified and stabilized in the concrete matrix.

Mixed concrete named “Green concrete”. It is used as filling materials, pavements and roadbeds, *etc*. This concrete also affects the cost of construction comparable to pure concrete.

7. RECOMMENDATION

S/S technology (BDAT) can easily and cheaply handles large quantities of waste materials and by-products containing heavy metals, as an alternative to OPC (ordinary Portland cement). It is available world wide yet its utilization is still limited. The continuing needs to use this economic and enviromental-friendly waste management technique.

8. CONCLUSIONS

This mixed concrete is safe enough to be used in environmental applications, like roadbeds, filling materials, *etc.* Thus, due to the beneficial use of the immobilized material, this type of industrial wastes and by-products usability appears to offer a promising way to improve sustainable environment in developing countries.

ACKNOWLEDGEMENT

The author would like to thank Dr. Kavita Kabra (Research Associate ar NEERI, Nagpur, India) for fruitful discussion. The School of Ebergy and Environmental Studies, Devi Ahilya University, Indore, India, is greatefully acknowledged.

REFERENCES

[1] *Hazardous wastes resource center, technological and environmental issues, treatment technologies, landfills* (August 2004) www.etc.org.

[2] *U.S. Environmental Production Agency, Hazardous waste management system, identification and listing of hazardous waste; proposed exclusion* (August, 2003) www.epa.gov.

[3] S.C. Saxena and C.K. Jotshi // *Progress in Energy and Combustion Science* **22** (1996) 401.

[4] J.K. Hammitt // *Journal of Hazardous Materials* **22** (1989) 101.

[5] P.F. Fennelly, M.A. Chillingworth, P.D. Spawn and M.I. Bornstein, Surveying Massachusetts hazardous wastes, GCA Corporation Bedford, Mass, 01730 // Environmental Science and Technology, **11** (1977) 762.

[6] N. Almeida, F. Branco and J. R. Santos // *Building and Environment* **42** (2007) 810.

[7] B. Chatveeraa, P. Lertwattanaruk and N. Makula // *Cement and Concrete Composites* **28** (2006) 441.

[8] C. Natarajan // *The Journal of Corrosion Science and Engineering* **7** (2005) 1.

[9] P.K. Mehta // *Concrete International* **24** (2002) 23.

[10] V.M. Malhotra // *The Indian Concrete Journal* (1999) 609.

[11] K.G. Babu and G. S.N. Rao // *Cement and Concrete Research* **24** (1994) 277.

[12] P. Asokan, *Application of coal combustion residues for hazardous waste management* (PhD, progress report, 2004, Indian Institute of Technology, Bombay, India).

[13] A. Pappu, M. Saxena and S.R. Asolekar // *Building and Environment* **42** (2007) 2311.

[14] R.E. Shaeffer and M.G.Hill, History of Concrete Building Construction from Reinforced Concrete: Preliminary Design for Architects and Builders (American Society of civil engineers, 1992).

[15] *Cementitious properties, concrete properties*, www.ce.memphis.edu.
[16] C. V. Nielsen and M. Glavind // *Journal of Advanced Concrete Technology* **5** (2007) 3.
[17] C. W. Condit, *American Building: Materials and Techniques from the First Colonial Settlements to the Present* (University of Chicago Press, Chicago, 1968) p. 90.
[18] N. Shigeyoshi and H. Makoto // *Concrete Journal* **37**(1999) 4.
[19] *Schmidt Hammer Test*, www.ce.ufl.edu.
[20] *Note on Mix Design Method* (Building Research Establishment Laboratory, Department of Environment (DOE), London, UK, 1975).
[21] M.S.Shetty, *Concrete Technology theory and practi*cal (S. Chand, New Delhi, 2006).
[22] J. Thomas Abraham and C. Richard Sloan, *Analysis and Repair of Cracking in TVA's Fontana Dams Caused by Temperature and Concrete Growth*, 13th ICOLD Proceedings, New Delhi, (1979).
[23] http://matse1.mse.uiuc.edu.
[24] J.P. Won, Y.S. Lee, C.G. Park and H.G. Park // *Magazine of Concrete Research* **64** (2004) 429.
[25] *History of Concrete Building Construction*, www.ce.memphis.edu.
[26] M.C. Natarajan, N. Dhang and A.P.Gupta // *The Indian Concrete Journal* (1999) 111.
[27] J.K. Desai, *Suitability and Availability of Sand Deposits in Gujarat State of India with Reference to their Petrography Pancholi* (Bulletin Of The International Association Of Engineering Geology No 29, 1984).
[28] P. Lawrence, M. Cyr and E. Ringot // *Cement and Concrete Research* **35** (2005) 1092.
[29] A.M. Neville, *Properties of concrete* (Longman ELBS, fourth edition, Malayasia. 1997).
[30] *ACI 221Rguide for use of normal weight and heavy weight aggregate in concrete* (American concrete institute, Michigan, USA, 1996).
[31] M. Cyr, P. Lawrence and E. Ringot //*Cement and Concrete Research* **36** (2006) 264.
[32] Q. Jueshi, S. Caijun and Z. Wang // *Cement and Concrete Research* **31** (2001) 1121.
[33] K. Ezziane, A. Bougara, A. Kadri, H. Khelafi and E. Kadri // *Cement and Concrete Composites* **29** (2007) 587.
[34] S. Zhang and M. Zhang // *Cement and Concrete Research* **36** (2006) 1947.
[35] *Method of making, curing and determine compressive strength of accelerated cured concrete test specimens*, Indian Standards (IS): 9013-1978.
[36] S. Mathur, *U.K.G Vittal Geotechnical*, *Engineering Division Central Road Research Institute* (2006) 1.
[37] *Code of Practice for Plain and Reinforced Concrete*, Indian Standards (456 – 2000, BIS, New Delhi).
[38] *Manual of Concrete Practice*, yearly publication (American Concrete Institute, 2000).
[39] ACI Committee 211.1 (1991); *Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete*, ACI Manual of Concrete Practice Part 1, (2000, Michigan, USA).
[40] ACI Committee 211.4R (1993); *Guide for Selecting Proportions for High Strength Concrete with Portland Cement and Fly Ash*, ACI Manual of Concrete Practice Part 1, (2000, Michigan, USA).
[41] K.S. Rao, M.P. Raju and P.S.N. Raju // *Journal of Structural Engineering* **32** (2005) 221.
[42] J. Paya, J. Monzo, M.V. Borrachero, E. Peris-Mora and F. Amahjour // *Cement and Concrete Research* **30** (2000) 543.
[43] K. Thangavel, T.M. Balasubramanian and N.S.Rengaswamy // *The Indian Concrete Journal* (2000) 203.
[44] D.P. Bentz and C.J. Haecker // *Cement and Concrete Research* **29** (1999) 615.
[45] S. Asavapisita, S. Naksrichumb and N. Harnwajanawong // *Cement and Concrete Research* **35** (2005) 1042.
[46] D.M. Roy, *Concrete Microstructure* (Materials Research Laboratory The Pennsylvania State University G.M. Idorn, Consult A/S Strategic Highway Research Program National Research Council Washington, DC (1993) SHRP-C-340 ISBN: 0-309-05254-8).
[47] L. Bertolini, M. Carsana, D. Cassago, A.Q. Curzio and M. Collepardi // *Cement and Concrete Research* **34** (2004) 899.
[48] P.K. Mehta // *Concrete International* **23** (2001) 61.
[49] P.K. Mehta // *Concrete International* **21** (1999) 27.
[50] I.Y. Ksel and T. Bilir // *Construction and Building Materials* **21** (2007) 686.

[51] C. Natarajan // *The Journal of Corrosion Science and Engineering* **7** (2005) 1.

[52] F.J. Huyen and J.W. Meusel // *Journal of cement concrete and aggregate* **3** (1981) 40.

[53] C. D. Ati // *Journal of Material in Civil Engineering* (2003) 153.

[54] T.R. Naik, P.E. Vasanthy, S. Shiw and S. Singh, *Use Of High-Volume Class F Fly Ash For Structural Grade Concrete*, www.uwm.edu.

[55] K.G. Babu and G.S.N. Rao // *Cement Concrete Research* **26** (1996) 465.

[56] S.E. Hedegaard and T.C. Hansen // *Materials and Structures* **25** (1992) 381.

[57] G. Li and X. Zhao // *Cement and Concrete Composite* **25** (2003) 293.

[58] K. G. Babu and D. S. Babu // *Cement and Concrete Composite* **26** (2004) 605.

[59] J. Paya, J. Monzo, M.V. Borrachero and E.P. Mora // *Cement and Concrete Research* **29** (1999) 87.

[60] O. Malliou, M. Katsioti, A. Georgiadis and A. Katsiri // *Cement and Concrete Composites* **29** (2007) 55.

[61] P. Asokan, M. Saxena and S.R. Asolekar // *Journal of Hazardous Materials* **B137** (2006) 1589.

[62] T. Ramlochan, M.D.A. Thomas and R.D. Hooton // *Cement and Concrete Research* **34** (2004) 1341.

[63] A. K. Karamalidis and Evangelos A. Voudrias // *Journal Of Environmental Science And Health* **A39** (2004) 961.

[64] R. Siddique // *Cement and Concrete Research* **34** (2004) 37.

[65] S. Valls, A. Yagüe, E. Vázquez and C. Mariscal // *Cement and Concrete Research* **34** (2004) 2203.

[66] *Extensive literature study for Petrographic analysis of aggregate and concrete*, Indian Standard (IS): 9103-1999.

[67] A. Buchwald and M. Sehulz // *Cement and Concrete Research* **35** (2005) 968.

[68] N.P. Malivaganam // *The Indian Concrete Journal* (1999) 55.

[69] C.S. Poon, S. Azhar, M. Anson and Y. Lung // *Cement and Concrete Research* **25** (2003) 83.

[70] V. Zvivica // *Bulletin Material Sciences* **27** (2004) 179.

[71] A. Palomo, M.T. Blanco-Varela, M.L. Granizo, F. Puertas, T. Vazquez and M.W. Grutzeck // *Cement and Concrete Research* **29** (1999) 997.

[72] G. Batis, P. Pantazopoulou, S. Tsivilis and E. Badogiannis // *Cement and Concrete Composites* **27** (2005) 125.

[73] D.M. Roy, P. Arjunan and M.R. Silsbee // *Cement and Concrete Research* **31** (2001) 1809.

[74] I. Demira and M. Orhanb // *Building and Environment* **38** (2003) 1451.

[75] P. Kumar and S.K. Kaushik // *The Indian Concrete Journal* (2003) 1503.

[76] K. S. Rebeiz // Cement and Concrete Composites **17** (1995) 119.

[77] S. Asavapisit and D. Chotklang // *Cement and Concrete Research* **34** (2004) 349.

[78] R. Barnaa, Z. Rethyb and, L.T. Barnac // *Journal of Environmental Management* **74** (2005) 141.

[79] N.T Michelle, A. Boddy, R.D. Hooton and M.D.A. Thomas // *Cement and Concrete Research* **36** (2006) 200.

[80] K. Stanish and M.D.A. Thomas // *Cement and Concrete Research* **33** (2003) 55.

[81] F. Sandrolini and E. Franzoni // *Cement and Concrete Research* **31** (2001) 485.

[82] D.P. Bentz // Cement and Concrete Composites **28** (2006) 427.

[83] L. Zuda, Z. Pavlýk, P. Rovnanýkov, P. Bayer and R. Cerny // *International Journal of Thermophysics* **27** (4) 2006 1228.

[84] A.M. Harrison, N.B. Winter and H.F.W. Taylor // *8th ICCC Brazil* **4** (1986) 170.

[85] D. Bonen and S. Diamond // *Journal of American Ceramic Society* **77** (1994) 1875.

[86] C. Famy, *Expansion of heat-cured mortars* (PhD thesis, Imperial College of Science, University of London, 1999).

[87] I.G. Richardson // *Cement and Concreter Research* **29** (1999) 1131.

[88] I. Odler // *7th ICCC, Paris 1980* **4** (1981) 493.

[89] C. Famy, K. L. Scrivener, A. Atkinson and A. R. Brough // *Cement and Concrete Research* **31** (2001) 795.

[90] M.C. Lewis and K.L. Serivener, *A microstructure and microanalytical study of heat cured mortars and delayed ettringite formation*,In: *Proceedings International Congress on the Chemistry of Cement, 10th,Gothenburg*, **4** (1997) 409.

[91] A. Roy, E.C. Harvill, F.K. Carteledge and M.E. Tittlebaum // *Journal Hazardous Material* **30** (1992) 297.

[92] D. Planela, J. Sercombeb, P. Le Bescopb, F. Adenotc and J.M. Torrentid // *Cement and Concrete Research* **36** (2006) 137.

[93] K.L. Lin and C.Y. Lin // *Cement and Concrete Research* **35** (2005) 1999.

[94] G.A. Rao and B.K. Raghu Parad // *Journal of Structural Engineering* **32** (2005) 207.

[95] I.C. Yeh // *Cement and Concrete Research* **36** (2006) 1865.

[96] F.A. Oluokun // *ACI Material Journal* **91** (1994) 362.

[97] N.J. Bhal and J.P. Jain // *The Indian Concrete Journal* (1999) 503.

[98] R. Malviya and R. Chaudhary // *Journal of hazardous materials* **B137** (2006) 267.

[99] D. Khale, *Development of Fly Ash Based Geopolymer and its Utilization for Solidification/Stabilization of Hazardous Waste (Heavy Metals)* (PhD Thesis, Devi Ahilya university Indore, India, 2007).

[100] D. Khale and R. Chaudhary // *Journal of Material Sciences* **42** (2007) 729.

[101] R. Malviya, *The Performance Evaluation of Solidification/Stabilization Process for Hazardous Waste (Heavy Metals)* (PhD thesis, Devi Ahilya university Indore, India, 2005).

[102] J.R. Conner, *Chemical fixation and solidification of hazardous waste* (Van Nostrand Reinhold, New York, 1990).

[103] E. Barth, P. Percin, M. Arozarena, J. Zieleinswski , M. Dosani, H. Maxey, S. Hokanson, C. Pryately, T. Whipple, R. Kravitz, M. Cullinane, L. Jones and P. Malone, *Stabilization And Solidification Of Hazardous Wastes* (Noyes Data Corporation, New Jersey, USA, 1989).

[104] A. Roy, E.C. Harvill, F.K. Carteledge and M.E. Tittlebaum // *Journal Hazardous Material* **30** (1992) 297.

[105] I.B. Singh, K. Chaturvedi, R.K. Morchhale and A.H. Yegneswaran // *Journal of Hazardous Materials* **141** (2007) 215.

[106] S. Asavapisit and N. Ruengrit // *Cement and Concrete Research* **27** (2005) 782.

[107] P.H. Shih, J.E. Chang, H.C. Lu and L. C. Chiang // *Cement and Concrete Research* **35** (2005) 2110.

[108] A.R. Silva, L. Mater, M.M. Souza-Sierra, A.X.R. Correa, Rafael Sperb and C.M. Radetski // *Journal of Hazardous Materials* **147** (2007) 691.

[109] G.A. Rao // *Cement and Concrete Research* **31** (2001) 443.

[110] W. Tangchirapat, T. Seating, C. Jaturapitakkul, K. Kiattikolmol and A. Siripanichgorn // *Waste Management* **27** (2007) 81.