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Industrial Wastes in Concrete Mixtures- A Review

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Abstract: Concrete is the most widely used construction material. To meet the growing infrastructure and industrial needs, huge quantities of concrete is required, which, in turn, means that large volumes of natural resources and raw materials are being used for concrete production around the world. To eliminate or minimize the negative environmental impact of the concrete industry and promote environmental sustainability of the industry, the use of waste from industries as materials for concrete making is considered as an alternative solution for preventing the excessive usage of raw materials. The wide availability of industrial wastes makes them a suitable and dependable alternative for aggregate in concrete, wherever available. In this paper, an attempt is made to present a state of the art review of papers on replacement of aggregates and fillers by industrial waste. This paper reviews the possible use of industrial wastes such as sludge wastes from marble cutting industries, sewage treatment plants, water treatment plants, paper industries etc as aggregate in the concrete industry. It aims to promote the idea of using these wastes by elaborating upon their mechanical properties. This summary of existing knowledge about the successful use of industrial wastes in the concrete industry helps to identify other existing waste products for use in concrete making. From this identification by industrial and civil engineers, significant achievements can be attained.

Keywords: - industrial waste, aggregate, cement, concrete.

I. INTRODUCTION

Concrete is a composite material composed of aggregates bonded together with fluid cement which hardens over time. It is the world's most widely used building material having properties such as fire resistance, durability, strength, maintenance free, easy installation, low installation cost, high compressive strength, custom design flexibility etc. Global production of concrete is about 12 billion tons per year corresponding to almost 1m3 per person per year. A major component of concrete is cement, which has its own environmental and social impacts. The cement industry is one of the primary contributors of carbon dioxide a major greenhouse gas. These gases are released to the environment directly through the production of carbon dioxide when $CaCO_3$ is thermally decomposed producing lime and carbon dioxide and also through the use of energy particularly from the combustion of fossil fuels .CO_2 emissions are 0.8-1.3ton/ton of cement production in dry process. SO_2 emissions are also very high.

Energy consumption is also very high at 100-150 kWh/ton of cement produced. Also it is costly to erect new cement plants. The concrete industry uses a considerable amount of natural resources to produce cement and concrete. The drawbacks of conventional concrete may also include its high self weight which makes it to some extent an uneconomical structural material. (Density of concrete is in the order of 2200-2600kg/m^3). A significant amount of water, energy, aggregates and fillers are used for production of concrete as well as construction waste from the demolition of concrete structures make it look less compatible with the environmental requirements of a modern sustainable construction industry. Adjustments and improvements to the present concrete making methods are essential in order to address environmental and economic issues.

Industrial waste is the waste produced by industrial activity which includes any material that is rendered useless during a manufacturing process such as that of factories, mills and mining operations. Some examples of industrial wastes are chemical solvents, paints, sandpaper, paper products, industrial by-products, metal and radioactive wastes. Amongst these some predominant and comparatively lesser toxic waste materials are slowly gaining popularity as additives in to concrete since they can potentially increase the strength, decrease density and prolong durability of the concrete. The successful use of such industrial waste as whole or partial replacement for conventional aggregates and fillers contributes to energy saving, conservation of natural resources, and a reduction of the cost of construction materials. It also solves the disposal problem of the wastes and hence helps in environmental protection. The aim of this paper is to introduce some of those kinds of industrial waste that have been successfully utilized as aggregates and filler replacers in making concrete in various experimental and practical environments.

II. INDUSTRIAL WASTE IN CONCRETE

A. Marble cutting sludge

Marble is a metamorphic rock resulting from the transformation of pure lime stone. Marble sludge powder is an industrial waste containing heavy metals as constitutes. Every year large quantities of marble quarrying waste are produced in the regions of Estremoz, Borba and Vila Vicosa in Portugal. Rajasthan has the potential to use 7 million tonnes of marble sludge as building materials. Hybridization of natural rubber filled with marble sludge and silica composite was prepared by adding various weights of marble sludge and silica which is vulcanized at 140 degree Celsius. They can also be used as a filler to reduce the voids. Marble sludge has a specific gravity of 2.57.

R.Rodrigues et al.[1] evaluated the various mechanical properties of concrete incorporating different ratios of marble sludge waste as cement replacement(0%, 5%, 10% & 20% of the total volume of cement) and along with plasticizer. In the study they measured the workability and bulk density properties on the fresh concrete. While compressive strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity and abrasion resistance test were conducted on hardened concrete. The mineralogical analysis showed that the predominant compound was calcite. The target consistency of (125±25mm) for the slump test was obtained for all the mixes. It was seen that there was no need to change the water -cement ratio to obtain slump value of various mixes to maintain the same level. Incorporation of superplasticizer resulted in reduction in water-cement ratio and reduction increased with an increase in the reductive power of the superplasticizer. Bulk density results did not provide significant changes a maximum change of 2.3% was obtained. However incorporation of superplasticizer increased the bulk density. Properties of hardened concrete such as compressive strength increased whereas other properties like splitting tensile strength, modulus of elasticity, abrasion resistance were decreased which is mainly due to increased replacement ratio of cement. Compressive strength increased due to the usage of superplasticizer. In general terms, marble sludge can be incorporated in structural concrete at replacement ratio of up to 10% without compromising its mechanical performance. Also, it was observed that the use of plasticizer resulted in a better mechanical performance of concrete incorporated with marble sludge when compared to concrete without plasticizer.

B. Waste foundry sand

Foundry sand is high quality silica sand that is a by-product of metal casting industries. Ferrous and non-ferrous foundries use silica sand in order to create metal casting mould and cores. During the casting process, mould can be exposed to high temperature .The moulding sand can be reused for several time until losing it moulding characteristic before the repeated exposure to molten metal and mechanical abrasion, finally when they recycled sand degrade to the point at which it can no longer be reused in the metal casting process, it is removed from the foundry and named as waste foundry sand. It is used in highway engineering.

Basar and Aksoy [2] deals with the reuse of waste foundry sand as partial replacement of sand in ready mixed concrete production. Various tests for mechanical and physical performances were carried out. The results indicated that the addition of WFS as partial replacement of sand reduced the strength performance and density and also increased the water absorption ratio of concrete mixtures. WFS exhibited lower compressive strength than conventional concrete of all age. It is due to the higher surface area of fine particle which led to the reduction of water-cement gel in matrix. Modulus of elasticity decreases. Tensile splitting strength decreases as the WFS replacement increases and the curing period decreases. Water absorption of concrete including up to 20% WFS has a water absorption lower than 6% which indicate that concrete specimen having 20% proportion of replaced regular sand with WFS could be considered acceptable. Concrete with WFS were lighter than conventional concrete due to lower density of WFS.

Results of this investigation suggest that WFS can be effectively utilized in making good quality RMC as partial replacement of fine aggregate with no adverse mechanical environmental and micro structural impact. The partial replacement should not exceed 20%.problems of disposal and maintenance cost of land filling is reduced.

C. Waste paper sludge

Ingress of water is the main cause of all major physical and chemical degradation processes affecting concrete structures. Commonly used approach to get durable water tight concrete involve increasing the density by using a low water - cement ratio. However it is difficult to avoid water ingress. An alternative approach to limit water ingress is through the use of water resisting admixtures. A range of internal water resisting materials are available. Many claims have been made on their effectiveness, including the provision of permanent reduction in water transport, superior

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resistance to deterioration processes and increased life. Paper sludge ash (PSA) is a waste generated by paper recycling industry .It is produced when dewatered paper sludge, a by-product of de- inking and re-pulping of paper, is combusted to reduce waste volume and to produce energy. The composition and properties of PSA varies according to the feedstock and combustion conditions, but is highly alkaline with pH of 12-13 and is composed mainly of calcium, silicon and aluminium.

Research conducted by Hong S. Wong et al. [3] on PSA has focused on hydraulic properties, pozzolanic reactivity and potential use as a supplementary cementitious material. PSA can have cementitious properties; it reacts with water sets and hardens. Shrinkage induced cracking is a problem of PSA. However blending PSA with ground granulated blast furnace slag improves strength development.PSA can be transformed into a super hydrophobic powder using simple low cost processing including dry milling with stearic acid. Hydrophobhicity results from the micro particulate structure induced by milling and formation of calcium stearate self assembling monolayer that coats the fractured PSA surfaces. PSA powder can be used as a partial cement replacement to improve the resistance of concrete to water ingress. It can also be used as a surface treatment to produce a water repellant and self cleaning coating. The use of PSA help in transforming a waste product into a high value super hydrophobic powder with very little processing and applying the hydrophobic powder to improve the performance of concrete.

Experiments showed that workability decreased with increase in PSA content. There is a strong linear relationship between slump and PSA content. Super hydrophobic PSA is effective in reducing both the amount and rate of capillary water absorption. Partial replacement of cement with 12% of PSA decrease water absorption in concrete .Electrical conductivity is also decreased because of reduced internal moisture content. Gaseous diffusion and permeation is not affected by PSA content. Concrete containing super hydrophobic PSA has lower absorption even after vacuum saturation. This indicates that PSA can resist hydrostatic pressure to some extent. Super hydrophobic PSA has significant potential as an admixture or surface coating to enhance the resistance of concrete to water ingress, and therefore against a range of deterioration mechanisms. This offers a high a high value application route for a waste material that can potentially enhance the durability and sustainability of concrete structures.

D. Granitic quarry sludge

Granitic quarry sludge is an abundant waste from granite rock processing. The granite cutting industry produces large amounts of wastes, solids (generated during extraction) and sludge (produced during transformation processes). Granite fines are often referred to as quarry or rock dust, and this residue generally represents less than 1% of aggregate production or between 1% and 2% by mass of the total aggregate crushed in quarries.

The study conducted by Telma Ramos et al .[4] analysed the effect of using granitic quarry sludge as partial cement replacement on strength and durability of mortar in terms of alkali silica reaction and chloride ion ingress. For the study granitic sludge was brought from a quarry in Northern Portugal. Portland cement (specific gravity 3.16 g/cm^3) and silica fume (SF) (specific gravity 2.20 g/cm^3) was used as a reference cement replacement material.

Granitic quarry sludge dried at 105 ± 5°C for 24 h was ground to two different levels of fineness. The dried sludge ground in a ball mill for 30 min was referred to as PG (Powder from quarry Granitic sludge) and a still finer material, referred to as PGS (superfine powder from granitic sludge) was obtained from PG submitted to further grinding in a planetary mill RETCSH PM 100 using zirconia balls of 1 mm diameter, for 10 min at constant 450 rpm.
The study constituted of characterizing the dried and ground granite powder. The chemical analyses included, scanning electron microscopy (SEM) and laser particle size distribution. The mechanical and durability properties were determined on mortar produced with different cement replacement dosages as well as for different fineness levels of the granite powder. Alkali–silica reaction (ASR) of mortar containing this waste was thoroughly analysed and observations under scanning electron microscopy (SEM) were carried out after ASR testing for full understanding of the effect of granitic sludge. Chloride ion penetration testing was also undergone on mortar specimens with cement replacement by granitic powder and SEM observations detailed and completed this study.

The test results showed that the quarry granite sludge was mainly composed of silica and alumina. The chemical properties were in accordance with requirements stated in ASTM C 618 regarding pozzolanic materials. SEM observations indicated that quarry granite sludge particles were more angular, more elongated and more prismatically shaped compared to cement. SEM and laser particle size distributions showed that PG particles were slightly coarser than cement. However PGS was finer than cement and naturally, both are much larger than spherical silica fume particles. Also the study indicated that no superplasticizer was required for mortar containing PG and PGS since similar workability was obtained, when compared with control mortar, which proved to be an economic advantage for future use in concrete mix design.

It was seen that strength results for PG and PGS mortars at 28 days were lower than control, where flexural and compressive strength decreased with increase of replacement dosage. But strength loss was marginal with the use of PGS. The results obtained for alkali silica reaction showed that there was no improvement of resistance to alkali reaction for PG mortar but for PGS, expansion reduced with increase in replacement dosage though it did not attained the effectiveness of SF mortar. The result analysis with respect to chloride ingress, the coarser waste material, PG reduced chloride resistance but for PGS, finer than cement, an improvement of almost 70% was observed in the resistance to chlorides. SEM and EDS analysis on PGS specimens after chloride ingress revealed the presence of chloroaluminates, suggesting that alumina present in granite sludge ground to sufficient fineness, reacts with chlorides, thus retarding chloride penetration.

From the study conducted it can be concluded that granitic quarry sludge waste, if ground to sufficient fineness, produces a denser matrix promoting up to 38% reduction in expansion due to ASR and almost 70% improvement in resistance to chlorides (higher than SF mortar) which leads to enhanced durability without compromising workability and strength .

E. Photovoltaic waste sludge

Photovoltaic or PV is the technology which converts sunlight into electricity. G Quercia et al. [5] analysed the main properties of three different samples of photovoltaic silica rich waste sludge (nSS) and the properties were physically and chemically characterized in the study .Waste sludge generated from the polishing process of photovoltaic solar panels from a South Korean photovoltaic panel producer was used for the study and it gave a potential source of nano silica particles. The polishing slurries were composed of stable colloidal nano silica, fumed silica nano CaCO3 and other types of suspensions. The sludge deflocculates in aqueous solutions into nano particles smaller than 1M. The various characterization techniques adopted for the study included scanning electron microscopy (SEM) , X-ray energy dispersive spectroscopy (EDS) ,X-ray diffraction (XRD) , X-ray fluorescence (XRF) , nitrogen physical adsorption isotherm (BET method) and density by helium pycnometry.

Also a dispersability study was performed to design stable slurries to be used as liquid additives for the concrete production on site. Isothermal calorimeter was used to determine the effects on the hydration kinetics of cement pastes by the incorporation of nSS in the design slurries. A compressive strength test of standard mortars with 7% of cement replacement was performed to determine the pozzolonic activity of the waste nano silica sludge. The hardened concrete was fully characterized to determine the phase composition. SEM and EDS analysis showed that the nSS is characterized by a wide particle size distribution, containing particles in the micro- and nano- range that showed highly agglomerated state. Angular, irregular and spherical particles were also identified. The analysis demonstrated high content of SiO2 (86-95%) with Na, Al and P, other elements identified. Another observation of high chloride content in the sample was analysed to be most likely due to the use of deflocculating agents of the waste treatment or from chlorates used as oxidizing agents. The chemical analysis performed using XRF were found to be in line with those of SEM and EDS analysis. X-ray diffraction measurements were utilized to determine the presence of crystalline impurities in the silica sludge, which identified the crystalline phases of calcium carbonates and chloride containing phases (NaCl and $CaCl_2$).
The adsorption curves obtained for the silica sludge batches from BET method were of typeIV, as classified by IUPAC (International Union of Pure and Applied Chemistry), which are typical for mesoporous powders. Also using the calculated BET specific surface area, the density of the particles was calculated. Helium pycnometry results showed higher density values for the sludge batch which is accounted for the high content of CaCO3. Dispersability study with high shear energy mixer and zeta potential measurements were studied due to the high agglomerated state of the nano silica sludge. It was seen that larger agglomerates suspended in the fluid are broken when the hydrodynamic forces exceed the cohesive bonds between particles or smaller particles and breaking mechanism is dominated by the erosion and rupture of the bigger agglomerates.

The mechanical properties (flexural and compressive strength) of mortars with 7% bwoc of silica sludge are similar, and in some cases slightly higher, to the reference mortar. The silica sludges of batch 2 and 3 were classified as pozzolonic material having an activity index higher than 100. The detail characterization of the hydrated system with photovoltaic's silica rich waste demonstrated that the replacement of cement with this material influenced the amount and kind of formed hydration phases and thus the volume, the porosity and finally the durability of the tested mortars. At the level of substitution used in the study, major changes are in the amount of chemically bound water (C-S-H gel formed), the consumption of portlandite, conductivity and chloride migration. At early age filler and nucleating effect produced an increased reaction of the clinker phases; except for the silica sludge of batch 1 that had a retarding effect due to its content of water soluble P2O5 . In addition it was found that the hydration of the aluminate phases was affected depending on the CaCO3 and SiO2 content of the studied sludge samples. The results demonstrate the photovoltaic's silica-rich waste could be satisfactorily used as a supplementary cementitious material to partly replace cement concrete.

III. WASTES FROM TREATMENT PLANTS

A. Sludge from water treatment plant

The sludge generated in the water treatment plant is composed of organic and inorganic materials in solid liquid and gaseous state. The chemical substances like aluminium and ferric salt may result in iron aluminium rich sludge which is highly toxic. Similarly another important environmental problem is the untreated saw dust. The recent researches evaluated the possibility of producing a light weight concrete from the treated saw dust and sludge.
Almir Sales et al. [6] addresses the effective utilization of the water treated sludge and the saw dust for the preparation of a light weight concrete. The mechanical property of this light weight concrete was studied. The experiment for the preparation of light weight concrete was done on Sao Carlos Water Treatment Plant in Brazil. The sludge collected from the decantation tank is initially drained in a geotextile blanket and pre dried at ambient temperature. Then it is ground in a grinder until the grain size becomes 0.6 mm. the saw dust produced as a waste from industry is mixed with this grounded sludge and mould into round pellets of diameter 14mm. The mass ratio of sawdust, sludge and water is 1:6:4.5. The pellets are dried in a furnace at high temperature. The mechanical properties of concrete were determined based on ABNT standards and these properties of concrete containing composite were compared with the properties of concrete containing crushed stone. The composite produced has a unitary mass of 672kg/$m^3$and its axial compressive strength and specific mass is 1.1 MPa and 1847 respectively categorizing it as light weight non structural concrete. The thermal conductivity of concrete from composite is 1.89W/Mk, which was 23.2% less than normal concrete. The proportionality of elastic modulus in relation to strength obtained from concrete with composite is similar to reference concrete. The thermophysical and light weight of this composite presented a wide application in the production of blocks and to stuff flag stones. This will reduce the weight of building and increase thermal comfort. It also played adequate mechanical properties for the application in non structural elements.

B. Sludge from waste water treatment plant

Sewage sludge ash (SSA) is produced by incineration of sewage sludge. In this paper S Valls et al .[7] studied the physical and chemical characteristics of sewage sludge ash and its use as a raw feed for cement clinker and as cementitious compounds. The studies showed the basic characteristics of SSA such as that the specific gravity and standard deviation of SSA were found to be 2.5 and 0.3 indicating the material is comparable to light sand and less dense Portland cement while its porous nature is indicated by its low density. From oxide composition (SiO2,Al_2O_3 and CaO) of SSA mean deviation, coefficient of variation is calculated and the variation falls around the latent hydraulic and pozzolonic region and the amorphous content of SSA also indicates its potential to use as a cement compound. It can also be used in aerated concrete due to its high Al content. This paper also refers to the use of SSA in concrete related applications such as it can be used as a filler material in concrete due to its fineness. Skid resistance resulted in concrete slabs and corrosion resistance has found to improve by the addition of 4% and 20% of cement. Blocks produced with 10% addition of SSA as aggregate have greater strength, higher density and lower absorption properties. Its low strength, workability, light properties and thermal properties which made them used in bulk quantities in CLSM, aerated and foamed concrete. It also acts as a very good binder since no problems like segregation and bleeding has been reported. The data shows a reduction in compressive strength with increasing SSA content which suggests a positive strength contribution from SSA in long terms. Recent researches have shown that the additions of nano materials were effective in improving the microstructure and density of cement paste containing SSA, resulted in improved mechanical properties. One of the drawbacks of SSA was the reduction in workability in using SSA as a sand component due to its alleged effect of normal porosity or absorption characteristic. Super plasticizers are one option to consider as an admixture to counter act higher water demand resulting from the use of SSA in mortar and concrete.

IV. CONCLUSION

Sludge from the marble extraction industry can be incorporated in concrete with partial replacement of cement up to 10%. It is also observed that the use of plasticizers improves the mechanical performance of concrete with marble sludge by offsetting the decline of its properties relative to conventional concrete.

It was found that replacing Portland cement with 12% hydrophobic PSA reduced water absorption, sorptivity and conductivity by 84%, 86% and 85% respectively, with no major detrimental effects on hydration, strength and density. Granitic quarry sludge waste, when ground to sufficient fineness, produced a denser matrix promoting up to 38% reduction in expansion due to ASR (alkali silica reaction) and almost 70% improvement in resistance to chlorides, without compromising workability and strength.

Photovoltaic's silica-rich waste silica was found to be used as a potential SCM to partly replace cement in concrete. Waste Foundry Sand was found to be effectively utilized in making good quality RMC (Ready Mixed Concrete) as a partial replacement of fine aggregates with no adverse mechanical, environmental and micro-structural impacts; however, the partial replacement should not exceed 20%.

Up to 10% of treatment plant sludge can be added to concrete for use in certain very specific applications.
The concrete produced with a composite which was obtained by the combined use of water treatment sludge and sawdust displayed adequate mechanical properties for application in non-structural constructive elements.

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