Behavior of Self-Compacting Concrete Using Different Sludge and Waste Materials– A General Overview

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***Abstract*—**Alum sludge is a waste material generated in massive quantities from treatment plants that use aluminum salt as a coagulant. Past researches evidently indicated health and environmental hazards in conjunction to its conventional disposal. limited uses of alum sludge in various industrial and commercial manufacturing processes in specific types of concrete not including self-compacting concrete has been reported. This paper presents a review on behavior of self-compacting concrete with different types of waste materials and chemical admixtures as addition in concrete mix. Data derived from many studies showed a wide range of wastes and admixtures were used for production of SCC. The compressive strength is considered the most important factor on comparison with original mixes without any addition as well as the microstructure characterization. However, the production of SCC always contains powerful superplasticizer and viscosity-modifying admixture that were necessary. The paper also reviewed the application of admixture and their performance on quality and their effect on fresh and hardened properties. The results indicated the feasibility of using waste materials in SCC mixes and appeared the most influence on the workability and long-term performance.

***Keywords*—**Self-compacting concrete, waste materials, compressive strength, alum sludge.

I. INTRODUCTION

CONSTRUCTION sector like any other industrial field is developing with time. All researchers interested are racing against time to get a variety of ways and techniques for improving properties to acquire a special type of concrete that has features different from these currently used. It is self-compacting concrete which deserves to be described as the most important development in form of technique revolution for decades.

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Self-compacting concrete is considered an ideal solution to meet needs of projects for the rapid construction processes, reduces necessity of equipment and manpower and thereby speed up construction processes. This technology represents a special importance in the world including Malaysia which is still ongoing in construction processes.

SCC has gained acceptance and received well by engineers and contractors all over the world due to the ability of this type of concrete on free flow, removes the need for compaction in fresh state, reduces time and then overall cost and improves the environmental work. These properties of rheology ease, filling ability, and passing affluence can be considered a suitable solution of problems associated with pouring and compacting in the construction sector with elements that possess congest reinforcement. SCC was first developed with most uses in Japan.

The main aim of this paper is to review the behavior of self-compacting concrete with different types of waste materials. It likewise, focuses on uses of alum sludge in construction sector. This is because it has so far remained unused in self-compacting concrete in spite of its similar chemical composition to a number of substances currently used in self-compacting concrete. Table 1 shows the chemical composition of the selected materials that include: Portland cementa, Fly Ashesb, Alum Sludgec, Marble Powderd, Bottom Ashe, Red Mudf, Silica Fumeg, Metakaolinh, and Lime Stonei.

TABLE I
CHEMICAL COMPOSITION OF PORTLAND CEMENT, FLY ASHES, ALUM SLUDGE, MARBLE POWDER BOTTOM ASH, RED MUD, SILICA FUME, METAKAOLIN, AND LIMESTONE

	a	b	c	d	e	f	g	h	i
CaO	64.0	0.37-- 27.68	0.13	83.2	1.58	13	0.90	12.3	92.9
SiO_2	20.1	27.8 – 59.4	42.3	1.12	57.7	10	95.2	79.0	3.30
Al_2O_3	5.78	5.23 – 33.99	35.0	nd	21.5	15	0.88	5.96	0.82
Fe_2O_3	2.35	1.21 – 29.63	4.94	0.05	8.56	51	0.39	0.44	0.58
MgO	1.19	0.42 – 8.79	0.29	nd	1.19	nd	nd	nd	nd
SO_3	3.53	0.04 – 4.71	0.14	nd	0.02	nd	nd	nd	nd
Na_2O	0.11	0.20 – 6.96	0.10	nd	0.14	0.2	nd	nd	nd
K_2O	0.77	0.64 – 6.88	1.87	nd	1.08	nd	nd	nd	nd
TiO_2	0.37	0.24 – 1.73	nd	nd	nd	nd	nd	nd	nd
LOI	1.63	0.21 – 28.37	11.8	nd	5.80	nd	nd	nd	nd

Notes: 1. a. b, c, d, e, f, g, h and i are % of mass.
2. Data compiled from different resource (8, 9, 13, and 18)
3. nd (no data)

The alum sludge is not a natural pozzolanic, it can be classified based on its chemical composition. This is different from one plant to another depending on source water mostly composed of silica, alumina and iron oxides of more than70% as specified by ASTM C618. For example table 2 shows the main components of alum sludge derived from ABBAS Consortium water treatment plant in Malaysia.

TABLE II
CHEMICAL COMPOSITIONS AND PHYSICAL TEST OF ALUM SLUDGE BY X-RAY FLUORESCENCE (XRF)

CHEMICAL ANALYSIS %										PHYSICAL TEST	
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O_3	K_2O	P_2O_3	LIO	Specific gravity	Moisture content
42.3	35.03	4.94	0.13	0.29	0.14	0.10	1.87	0.26	11.83	2.34	0.85

Note: Data compiled from Haider et al (2013), Physical and Mechanical properties of high performance concrete with alum sludge as partial replacement.

Alum sludge is a waste material generated from treatment plants that use aluminum as a coagulant still uses it in specific types of concrete without self-compacting concrete. Several experiments of the use of alum sludge in various industrial and commercial manufacturing processes have been reported. The first was in the bricks manufacture and the second was in cement, mortar, concrete manufacture by reuse of sludge as a partial replacement.

II. REVIEW OF RESEARCH ON REUSE OF SLUDGE IN CEMENT MORTAR AND CONCRETE WORK

Haider et al [1] conducted experiments on physical and mechanical properties of high performance concrete with alum sludge as a partial cement replacement. They found that the alum sludge has a chemical composition similar to clay with the presence of silica and alumina. They also found that the best replacement proportion of AS from cement is 6%, and they showed that the workability of AS concrete mix increases as the replacement levels increases but it was opposite with density.

Hanim and Abdull [2] conducted characterization of alum sludge for reuse and disposal. They were able to investigate properties of Drinking water treatment in terms of structural identity, leach ability of heavy metals, chemical composition and other properties that are important for its potential reuse and safe disposal into the environment. They were able to get results of chemical composition, density, particle density, porosity, pH, and moisture content.

Ing [3] produced a publication that deals with opportunities for water treatment sludge re-use. He noted that as alum sludge is recovered in the water treatment, it can also be used for production of cement and as secondary raw materials. Likewise, he showed that iron sludge can be disposed freely if used as an admixture for production of cement. Maha et al. [4] experimentally investigated the use of water treatment sludge to replace cement in production of paving tiles for external use. The study utilized sludge–cement replacement of 10%, 20%, 30%, 40% and 50%. The results showed all of the tiles produced comply with the minimum breaking strength of 2.8 MPA required by the standards. Additionally, the study concluded that a decrease in the breaking strength of tiles is accompanied with an increase in the amount of sludge –cement replacement. This leads to reduction in the cost of tiles and provides a safe and environmentally sound option for the disposal of water treatment sludge.

Yen et al [5] studied the replacement of clay, lime stone, sand and iron slag by drinking water treatment plant sludge, marble sludge and basic oxygen furnace sludge respectively, as a raw material for the production of cement in order to produce eco-cement. They were able to replace up to 50% of the lime stone and also other materials. These complete replacements of three wastes sludge were considered for conventional cement raw materials. The hydration of eco-cement paste increased in number because of the mass amount of $Ca(OH)_2$. Arlindo et al. [6] conducted systematic study on utilization of the sludge generated during the process of producing potable water with cement pastes and mortars exchanging 5%, 10% and 20% of the mass of cement by dewatered sludge and by sludge after thermal treatment at 105^{o}C, 450^{o}C, 700^{o}C and 850^{o}C. They concluded that the sludge dried at105oC or higher temperate can be used in cement mortar, also the incorporation of sludge in mortars can only be feasible after treatment at not less than 450oC.

Zamora [7] studied the feasibility of drinking water treatment sludge as raw materials to produce concrete and mortar at the Los Berros drinking water plant. Sludge samples were prepared by using sludge in mixtures (up to 90% in weight). Tests were performed to determine the compressive strength and bulk density (binary mixture sludge–lime, sludge-mortar and ternary mixture sludge-plaster-lime, sludge-lime-cement). Based on results, drinking water sludge can be used as a supplementary cementing material and sand substitute. Rodríguez et al [8] investigated the reuse of drinking water treatment plant sludge as an addition for the cement industry. They found that the drinking water treatment plant sludge has a chemical composition and a particle size similar to Portland cement. The mortars that were made with 10 to 30% atomized sludge showed lower mechanical strength than the control cement and decline in slump. The results indicated that the properties of drinking water treatment in majority depend on chemical compositions that are important for its potential reuse.

Sahu et al. [9] investigated the feasibility of using drinking water treatment plant residue with fly ash to prepare mortar. Testing on compressive strength of the cement mortar made by sludge from drinking water treatment plant, fly ash from the thermal power plant and cement with or without admixture was carried out. The results showed, the highest strength was 0.47 kN/mm2 at 1% gypsum content due to the influence of gypsum on the strength of mortar. The higher strength of 2.84 kN /mm2 and 2.05 kN/mm2 was observed for hot curing and lime water curing, respectively. The lower strength were detected by decreasing the content of sludge and increasing the fly ash content. Reis and Cordeiro [10] proposed a solution for sludge generated by chemical, physical and biological steps to treat water for public supply. A solution for this sludge is used after removing its water, recycling the water removed and using the dried sludge in other activities. Possible uses as a raw material in construction sector are studied. They could be developing a natural system of dewatering. In this technology the sludge is stored in large unit which are shaped as a big bag. It is made of geotextile woven high strength polypropylene. By filling this unit and decreasing the percentage of liquid of the sludge it is considered as a natural thermal drying which may be open. This suggests possibilities for novel investigative studies with natural thermal drying. Finally, the dewatering sludge can be used.

Varela et al. [11] studied the utilization of several industrial wastes to be reused in different stages of cement making. They examined wastes from a drinking water treatment plant sludge (DWTP), sewage sludge (SS) and a spent activated carbon. Both DWTP sludge and sewage can be used as a raw material in cement making. They noted that the unsuitability of atomized DWTP sludge and SS as components of blended cements has been demonstrated. Haider et al [12] used nondestructive testing of concrete to estimate compressive strength of thermally activated alum sludge (AAS) multiple blended high performance concrete (HPC). The wastes used for HPC were AAS, silica fume (SF), ground granulated blast furnace slag (GGBF) and palm oil fuel ash (POFA). The results indicated a very positive exponential relationship between compressive strength and ultrasonic pulse velocity for binary and ternary blends of HPC mixture, with coefficient correlation (R2) equal to 0.889. Concrete quality is generally assessed by measuring its cube (or cylinder) crushing strength. Instead of expressing the strength in terms of cube strength; it is preferable to obtain a direct relation between the strength of a structural member and the pulse velocity, whenever this is possible.

Choa [13] tried to produce self-consolidating light weight concrete by manufacturing light weight aggregate from municipal solid waste incinerator fly ash. The results showed that the maximum content of municipal solid waste incinerator fly ash should be less than 30% light weight specific gravity in the range of 0.88-1.69g/cm3 and crushing strength as high as 13.43 MPa can be produced. Thniya Kaaosol [14] examined experimentally reuse water treatment sludge form water treatment plant as fine aggregates. 10% and 20% of water treatment sludge ratio in a mixture to make a hollow load bearing concrete block can reduce the cost and 50% of water treatment sludge ratio in mixture to make a hollow non-load bearing concrete block and also to reduce the cost. This could be a profitable disposal alternative in the future and will be of the highest value possible for the foreseeable future.

David [15] indicates that when aluminum water treatment plants sludge is dried, they form essentially insoluble rocks and are inert (like gravel, though not strong / hard). With these qualities, dried aluminum sludge has been used as road fill or road grade or aggregate. Dried aluminum sludge can also be poured, and so have use for back-filling beneath fiberglass swimming pools. Kazberuk [16] discussed the incineration of the sludge from water treatment plants. He considered that incineration of sludge is not a final solution since it generates ash that must be disposal of and proposed to use the ash derived from sludge as light weight aggregate. By studying the influence on mechanical and physical properties of concrete with ash can determine the maximum acceptable replacement which was 25% of natural aggregate volume. These results confirm the feasibility of using sludge light weight aggregate to produce light weight aggregate concrete and creating a go towards new studies to get commercial sludge.

Lee et al. [17] studied the limited land available for waterworks sludge disposal. The cost and environmental concern motived them to find a suitable solution. The feasibility of beneficial use of sludge from water purification plants in concrete is considered a solution. They found the particle size of the dried sludge is smaller than 3.2 μm and addition of sludge in concrete mix reduces the mechanical strength of the concrete. According to ASTM C-117-04v , the percentage of aggregate passing 200-mesh sieve (<75 μm) should be less than 5% but the main particle size of the dried sludge can be classified as silt with high plasticity that means too many fine particles in the aggregate reduces the mechanical strength of the concrete .The solution of this problem was by addition of an appropriate amount of solidification agents. The solidification agent alleviates the potential problem associated with high water absorption capacity of sludge and also participates in the hardening process. By this way use, the use of sludge in concrete mix could be considered a viable alternative use.

Seco et al. [18] reviewed the main available pozzolanic wastes useful as binder materials that was (fly ash, ground granulate blast-furnace slag, silica fume, rice husk, phosphogypsum, ceramic wastes and sewage sludge). The review included the most interesting construction materials created from pozzolanic waste such as bricks, block and masonry mortars. They aimed to improve knowledge on the application of different industrial wastes in the construction sector. This type of studies contributes in acceptance of using waste.

Chen et al. [19] had undertaken the study on production of light weight aggregates (LWA) from reservoir sediments. The proposed manner of the manufacturing process which included the dredging, depositing and dewatering, air drying, crushing, graining, heating, conveying, stock piles and packing, respectively. A rotary kiln is used in making the synthetic aggregates. According to the carried out test, the reservoir sediments can be used as primary resource materials at a range of density (1.01 g/cm3 to 1.38 g/cm3). The produced aggregates obey the requirement of ASTM C330 with bulk density less than 880 kg/m3 for coarse aggregates and engineering properties of concrete of structural light weight concrete. Also Haung et al. [20] proposed a way to produce light weight aggregates from water treatment sludge (WTs) which is generated during the water treatment process of chemical coagulant. They were able to get light weight aggregates that comply with ASTM C330 by laboratory experiments, including two phases. The first phase assessed the feasibility of manufacturing LWA from LWs and thermal cycle and the second phase investigated the particle density of aggregates. The engineering properties of concrete made from LWA comply with ASTM C330.

III. Review On Waste Materials For Self-Compacting Concrete

Bouzoubaa et al. [21] showed that the production of SCC needed chemical admixtures. There are two types of them. The first is high range water reducing admixture (supperplasticizer) which gives SCC more than 150 Mpa of compressive strength, while the second type is viscosity-modifying. Aghabablou et al. [22] carried out experiments in the laboratory to investigate the effect of different types of superplasticizer on fresh and hardened of self-compacting concrete. Four types of polycarbxylate ether-based superplasticizer admixture were used. The admixtures have same main chain and same polymer structure but different molecular weight and different side chain density of carboxylic acid groups. The main effect of these admixtures was at early ages whereas at the ages beyond 7 days, the strength became independent of the admixture type. This complies with requirement of ASTM C494 that sets to do some tests in case of incorporation of different types of superplasticizer. Piekarczyk [23] investigated the effect of using different admixtures from different sources. The results indicated that it is impossible using these admixtures together even if they have similar chemical composition.

In another research Zhu and Gibbs [24] presented some results from using different limestone and chalk powders in SCC. They concluded that the different limestone and chalk powders with suitable superplasticizer depend on type other than on the fineness of the powder used. For compressive strength, their results demonstrated, higher values with using limestone powder than chalk powder due to chemical activity of limestone. Therefore, the potential of using limestone and chalk powders could be achieved for production of SCC. Herbudiman and Saptaji [25] conducted some laboratory experiments to replace fly ash by recycling traditional roof tile powder as a binder and filler. Results depend strongly on different parameters (cement, roof-tile powder, coarse aggregate, water content, and superplasticizer) that need trial mix to reach high workability and high strength of SCC concrete. They managed to replace fly ash by roof-tile powder with largest compressive strength of 67.72 MPa using (water-powder ratio = 0.32, superplasticizer = 1.5%, roof-tile powder = 20%, roof-tile powder = 5%, coarse aggregate = 45%). This way of recycling waste materials would be beneficial for selection of best percentage that will reach optimum workability and strength of SCC.

Gristsada [26] conducted experimental study on production of SCC using unprocessed rice husk ash and pulverized fuel ash with ternary combinations of Portland cement (OPC), unprocessed rice husk ash (RHA), and pulverized fuel ash (FA). The investigation of the properties of SCC showed deceased water requirement and high workability using OPC, RHA and FA. They proposed mix proportion to control slump flow in the range of 675 to 725 mm. SCC mixtures with RHA / FA were lower compressive strengths than that the SCC mixture containing OPC. While, SCC mixtures prepared using FA gained higher compressive strength than mixture prepared using RHA. This is due to smaller particles of FA filled voids within the mixture, decreasing porosity and water demand.

Mehmet and Erthan [27] studied the permeability properties of self-compacting rubberized concrete with or without fly ash. They also investigated the fresh and hardened properties.

Kushwasha et al. [28] tried to find out the effect of addition of Red Mud as waste product from the aluminum industries. The mix (Red Mud + SCC) consists of fly ash, cement, sand, coarse aggregate, superplasticizer (Glenium sky 784), viscosity modifying admixture (Glenium Stream 2) and Red Mud. The mix proportion used in experimentation was: fly ash/cement 1:3.5, Red Mud (0 to 8% and 10%, 12%, 15, 16%), water/ cementations 0.33, 700 ml/100kg of superplasticizer and 100 ml/100kg of viscosity modifying admixture. The results demonstrated that the optimum percentage of Red Mud was up to 2% whereas the compressive strength starts decreasing. However, the losing stay down 4% so it can be used at percentage of 4%. Depending on the results, it is possible to use Red Mud for construction sector and then reduce the environmental impact.

Nanthagopalan and Santhanan [29] studied the possibility of production of self-compacting concrete with manufactured sand on fresh and hardened states. They were able to get medium compressive strength (25 to 60 MPa) of SCC. Juma et al. [30] used Rice Husk Ash (RHA) as a partial replacement of cement in SCC. RHA has a highly reactive index which could be improving the microstructure of Interfacial Transition Zone (ITZ) between the cement paste and the aggregate. They are able to partially replace cement by 20% and ultimate strength of SCC without viscosity modifying admixture by using high powder content.

Mohammed et al. [31] conducted laboratory study to produce SCC with high partially replacement cement by limestone (LS) and Fly Ash (FA). They studied the effect on composition, microstructural and hydration characteristics at early age by mixing several techniques, X-Ray diffraction, mercury intrusion porosimetry, scanning electronic microscope (SEM), energy dispersive x-ray (EDX) analysis, image analysis and thermo-gravimetric. Due to high reactive of fly ash the results showed a good quality of self-compacting concrete.

Akram et al. [32] studied the feasibility of production of low cost self-compacting concrete by incorporating some percentages of bagasse with cement, fine aggregate, coarse aggregate as well as superplasticizer and viscosity modifying admixture. The successful utilization of bagasse ash in SCC reduced the cost and solved the problem of environmental concern. Also Brahim et al. [33] investigated the utilization of plastic waste as partial replacement of sand in self-compacting rubberized mortar and studied the fresh and hardened properties. The percentage of replacement was 0 to 50%. The higher percentage gave higher density.

Mohammad [34] studied three types of curing conductions (7, 28 days under water and 28 days in air) on properties of three types of mixes (fly ash, silica fume, fly ash and silica fume with different percentages in three mixes). Tests were conducted on the mixes with different mixes and curing. The optimum percentage obtained was 15% of silica fume showed higher compressive compared with 30% of fly ash whereas; the curing with 28 days gave higher compressive strength.

Corinaldesi and Moriconi [35] investigated the properties of SCC using limestone powder, fly ash, and recycling aggregate powder as filler with superplasticizer. The results showed improvement when compressive strength of SCC is determined at age of 1, 3, 7, 28, days, respectively.

Rafat [36] developed an experimental program to produce self-compacting concrete using coal bottom as partial replacement of fine aggregate with three percentages (10%, 20%, and 30%) as compared with control mix of 0% of coal ash. Tests were conducted to find compressive strength, abrasion resistance and chloride permeability up to 365 days while water absorption and sorptivity were conducted up to 28 days.

Uysal and Yilmaz [37] investigated mechanical properties of SCC containing limestone powder (LP), basalt powder (BP) and marble powder (MP) as a partial replacement of cement. One mix control and nine mixes with mineral admixtures were prepared. Tests were conducted to find workability, air content, compressive strength, ultrasonic pulse velocity and modulus of dynamic and static. They achieved SCC by mixing of LP, BP and MP as replacement of fine aggregates.

Elyamany [38] evaluated the effect of two groups of filler, the first was pozzolanic (silica fume and metakaolin) and the second was non pozzolanic on the fresh and hardened properties as well as flow-able concrete. Several techniques were used to get information about composition, microstructural and hydration characteristics of two types of mixes (pozzolanic and non pozzolanic). Segregation and bleeding resistance are affected by type of filler. It is found that non-pozzolanic fillers decrease them as compared with pozzolanic fillers. For flow-able filler type has insignificant effect on water absorption.

IV. Conclusion

Depending on the results obtained from recent studies on waste materials, the potential of reusing alum sludge as a substitute material in construction sector can be a promising solution. Thus, there is needed to do more laboratory experiments to determine maximum percentages that could be used as a substitution on construction material especially in self-compacting concrete. Focusing on their effect on fresh and hardened properties of self SCC and critical reviews offers perception of reusing it to produce suitable strength according to kind of required work as well as its usefulness for future research. Finally, recent researches strive and are directed towards finding environmentally friendly solutions ensuring a more sustainable development.

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