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CONVERSION OF SLUDGE INTO NOVEL MATERIALS FOR CONSTRUCTION APPLICATIONS

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A drastic global increase in wastewater sludge volume has been experienced as a result of rapid urbanisation. The disposal of sludge is likely to present a major concern to many municipalities, as sludge disposal by landfilling may no longer be appropriate owing to land scarcity and increasingly stringent environmental control. It can be foreseen that future trends in sludge management are towards minimisation and reutilization as useful resources. Incineration is one feasible means of converting bulky sludge into practically inert, odourless and sterile ash. Disposal of this significantly reduced volume of sludge ash can be subsequently handled with much smaller scales. The disposal problems will be drastically reduced if sludge, be it in the digested and dewatered, or the incinerated form, can be put to large-scale economic applications. In recent years, much attention has been focused on the studies which look into the potential use of sludge as useful resources. This paper presents a review of the research studies carried out by the authors in the area of sludge utilisation as building and construction materials. Properties of the innovative materials derived from sludge as building bricks, lightweight aggregates, and cement-like materials, their processing technology, and the suitability of the products for construction applications are discussed.
Key words: sludge, incineration, construction materials, disposal, applications

1. INTRODUCTION

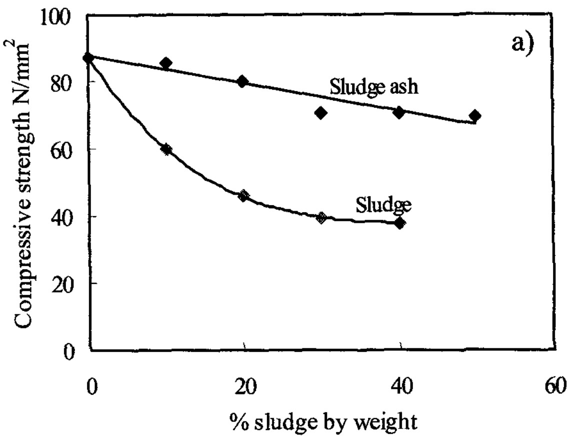
Sludge is generally disposed of through landfilling and spreading on reclaimed land. Incineration can reduce the volume of sludge but the remaining residues still require to be disposed of. All these disposal methods have varying degrees of environmental impact. Increasingly stringent environmental regulations have caused marked increase in the waste disposal requirements. The disposal of sludge from wastewater treatment is thus posing problems of high complexity to any municipality. Hence, there is a need for alternative methods of sludge disposal, such as reutilization that possibly exerts less harmful effects on the environment. Studies have been carried out by various researchers on possible applications of sludge and sludge ash as building and construction materials. The reuse of wastewater sludge in this aspect would provide good possibilities of alleviating the wastewater sludge in significant quantities. This paper provides a review of studies of the wastewater sludge for use as building and construction materials.

2. BRICKS

The use of municipal wastewater sludge mixed with clay to produce bricks had been reported by Tay [1,2,3]. A mixture of dried sludge and clay was ground and crushed into fine pieces by a crushing machine. The crushed mixture was mixed with water and extruded into brick samples. The bricks were dried and then fired in a kiln at a temperature of 1080°C for about 24 h. The results indicated that up to 40% by weight of dried sludge could be mixed with clay in making bricks. The surface texture of the bricks was uneven, mainly due to the organic component being burnt off during the firing process.

The properties of bricks produced from industrial sludge and marine clay sintered at the temperature of 1050°C. It was found that, bricks made from 100% sludge and 90% sludge with 10% clay, were prone to develop cracks during firing. The specific gravity decreased and water absorption increased with increasing proportion of clay material, which has a lower specific gravity compared to sludge. However, the 50% clay brick sample has a significantly higher rate of water absorption, which could be attributed to the high porosity of the material. Bricks of all mix proportions, other than 50% clay content, conformed to the specified water absorption limit of 7%. Shrinkage occurs during the processes of both drying and firing. The drying shrinkage increased with increasing clay content, indicating a higher shrinkage rate as the clay content increased. The firing shrinkage on contrary reduced with increasing clay content. Significant expansion can be observed on the 50% clay brick sample as it has a negative shrinkage of 11.2%.

Ash collected after sludge incineration at 600°C was also used to produce bricks [3]. The maximum amount of pulverized sludge ash that could be mixed with clay to produce good bonding bricks was 50% by weight. The compressive strength of bricks incorporating sludge or sludge ash is illustrated in Figure 1. The bricks containing sludge ash exhibited higher strength than those containing dried sludge and industrial sludge. The bricks with up to 10% sludge ash can have strength as high as the normal clay bricks.



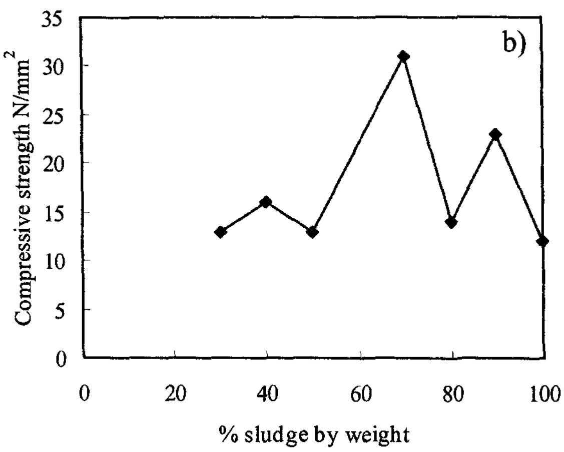


Figure 1 Compressive Strength of Bricks Made of a) Municipal Sludge and b) Industrial Sludge

3. CONCRETE AGGREGATES

Industrial sludge that contains little organic materials had been developed into regular weight artificial aggregates [4]. The raw sludge and marine clay were dried at a temperature of 105°C and pulverized separately to a suitable fineness of particle sizes below 80 micron using a mechanical pulverizer, before mixing into paste with water at appropriate proportions. The mixtures were then formed into pellets and sintered at a temperature of 1135°C. A range of construction aggregates was made from sludge and clay with clay contents of 0, 20, 50, 80, and 100% by mass.

The properties of the aggregates were examined and given in Table I. The specific gravity of the sintered sludge-clay aggregates reduced with the increase in clay content. The specific gravities of the sludge-clay aggregates were 3.23, 3.08, 2.99, 2.69 and 2.46 at 0, 20, 50, 80 and 100% clay content, respectively. The particle densities of the aggregates were 2.25, 1.84, 1.48, 1.65 and 1.77 g/cm^3 for the clay contents of 0, 20, 50, 80 and 100%, respectively. The results show that the density of the aggregate varies with increasing clay content, giving the lowest density at 50% clay content.

The aggregate strengths were assessed using the aggregate impact test, which measures the aggregates' susceptibility to impact, with lower value denotes a better quality. Results plotted in Figure 2 indicates that the aggregates' resistance to impact was reduced as the proportion of clay increased. The sintered pellets of up to 50% clay content displayed better aggregate impact values (AIV) of 19.9 to 26.3% as compared with that of 28.3% for the granite aggregates under dry conditions. Under wet conditions, all pellets exhibited better AIV between 18.1 to 27.3% compared to 38.9% AIV for granite aggregates.

The performance of the sludge-clay aggregates was evaluated by determining the compressive strengths of the concrete specimens cast from the aggregates. The 28th day compressive strengths of the concrete specimens were in the range of 31.0 to 38.5 N/mm^2. The sludge-clay aggregates of 0% clay content provided a concrete strength of 38.5 N/mm^2, which was comparable to 38.0 N/mm^2 achieved of the normal granite aggregate. The densities of concrete specimens made from the sludge-clay aggregates were all lower compared with that of 2680 kg/m^3 for normal granite aggregate.

The study demonstrates successful application of industrial sludge and marine clay sintered into hard fused masses as complete replacement of regular coarse granite aggregates in concrete. Concrete made from the sludge-clay aggregates had a lower density and hence a higher strength to mass ratio as compared with that produced from conventional granite aggregates. The aggregates made from industrial sludge manifested the attributes required of construction aggregates, and the incorporation of marine clay reduced the particle density of the aggregates, however, the impact resistance of the aggregates was concurrently reduced. The compressive strength test reveals that sintered aggregates, of all sludge-clay combinations are capable of producing concrete of structural grade between 20 and 40 N/mm^2.

Table I Physical Properties of the Sludge-clay Aggregates

Sludge-clay Aggregate		Granite	Clay content of Sludge-Clay Aggregate %				
		-	0	20	50	80	100
Particle Density	g/cm^3	2.56	2.25	1.84	1.48	1.65	1.77
Specific Gravity		2.63	3.25	3.08	2.99	2.69	2.46
Porosity	%	2.66	30.77	40.26	50.50	38.66	28.05
Water Absorption	%	1.58	0.36	2.06	2.8	2.49	1.81
Aggregate Impact Value Dry	%	28.3	19.9	20.9	26.3	29.1	30.4
Wet	%	38.9	18.1	19.3	23.7	26.3	27.3

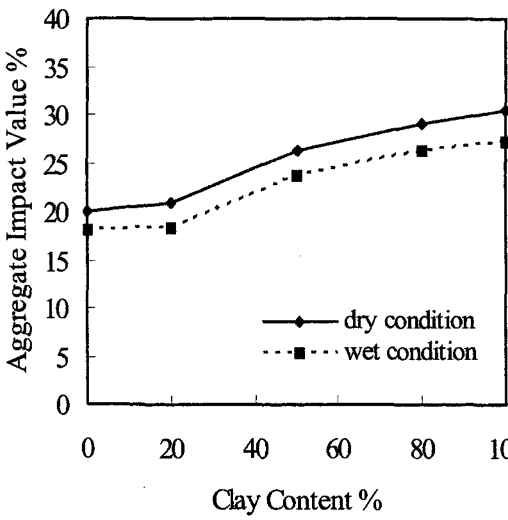


Figure 2 Influence of Mix Proportion on Aggregate Impact Value

4. CEMENTITIOUS MATERIALS

Research studies had also been conducted by the authors to examine the potential for utilizing digested and dewatered sludge to produce cementitious materials [5,6,7]. In preparing the cement specimens, the sludge was oven-dried and mixed with limestone powder at various proportions by weight. The mixtures were ground and incinerated in a furnace at different temperatures and for different durations of controlled burning. The ash collected was ground to less than 80 micron before being tested for various properties.

The cement specimens were tested for chemical, physical and compressive strength properties. The chemical composition of the sludge cement is listed in Table II. As a comparison, the chemical composition of ordinary Portland cement is also given. The limiting values [8] stated in Table II are to be regarded as valid for the manufacture of cement for general works. The four major oxides of the sludge cement were SiO_2, CaO, Al_2O_3 and Fe_2O_3. Most of the chemical compositions of the sludge cement listed in Table II were within the limiting values, with the exception for CaO and SO_3 contents. The CaO contents were low whereas the SO_3 levels were excessive.

Physical properties of the sludge cement are given in Table III. The sludge cement was rated sound since the soundness test result of 1.9 mm was well within the limiting value of 10 mm specified by British Standard BS 12: 1978. Based on the pozzolanic activity index result of 67.2%, the cement specimens exhibited low pozzolanic activity. A high water demand property of the sludge cement was indicated by the consistency test result of 82%. The sludge cement was found to be quick setting, with the initial set occurring before the specified 45 min. The final setting times were well within the limiting value of 8 hours.

The compressive strength results for 50-mm mortar cubes were analysed. The results indicate that air-cured cement mortar exhibited the highest strength obtained at all ages. The 7-day and 28-day strengths were 5.92 N/mm^2 and 6.28 N/mm^2 respectively. It may be noted that ASTM C91 Standard Specification for-Masonry Cement requires 3.45 N/mm^2 at 7 days and 6.21 N/mm^2 at 28 days. The strength of sludge cement under air curing was adequate for general masonry work.

From the investigation, it was found that under air curing, the cement specimens with 50% sludge fired at 1000°C for 4 h exhibited the highest compressive strength. The sludge masonry binder was also tested as a partial replacement material for Portland cement to produce blended cement [9,10]. The properties of the blended cement were examined at various replacement proportions up to 50%, and the results are given in Table IV.

The water demand of the cement mortar to achieve a standard consistency was observed to increase with the addition of sludge masonry binder, due to its high water demand property. The increase in water demand was especially pronounced beyond the replacement of 30%. The soundness ranged from 1.8 to 41.2 and the SG ranged from 3.17 to 3.29. The bulk density of the blended cement, determined to be in the range of 722 - 838 kg/m^3, decreased with the increasing percentage of sludge binder replacement. The setting times of the blended cement reduced with increasing replacement levels. Compressive strength test results of the blended cements indicate that up to 30% of the Portland cement can be replaced by the sludge masonry binder without deteriorating the strength.

5. CONCLUSION

Wastewater sludge and pulverized sludge ash could be used to produce bricks. The maximum percentages of dried municipal sludge and municipal sludge ash that could be mixed with clay for brick making are 40% and 50% by weight, respectively. The compressive strength was 37.9 N/mm^2 for 40% dried sludge and 69.4 N/mm^2 for 50% sludge ash. For industrial sludge, the maximum percentage that could be incorporated into marine clay

Table II Chemical Analysis in Percent by Weight

Component	Portland Cement	Sludge ash 500°C	Sludge Cement	Limiting value [8]
SiO_2	20.86	20.33	24.55	18-24
CaO	63.30	1.75	52.11	60-69
Al_2O_3	5.67	14.64	6.61	4-8
Fe_2O_3	4.11	20.56	6.26	1-8
K_2O	1.21	1.81	1.05	< 2.0
MgO	1.04	2.07	2.07	< 5.0
Na_2O_3	0.17	0.51	0.17	< 2.0
SO_3	2.11	7.80	4.88	< 3.0
Loss-on-ignition	1.91	10.45	0.30	< 4.0

Table III Physical Properties of the Sludge Cement [5]

Property		Sludge cement	Portland cement
Fineness	m^2/kg	113	116
Soundness	mm	1.9	0.9
Bulk density	kg/m^3	685	866
Specific gravity		3.33	3.16
Consistency	%	82	27
Pozzolanic activity Index with cement	%	67.2	100
Setting time	min		
Initial		40	180
Final		80	270

Table IV Properties of Blended Cements

Sludge masonry binder replacement %	Standard consistency %	Soundness mm	Final setting time h : min	Specific gravity	Apparent bulk density kg/m^3	Compressive strength N/mm^2
*0	27	0.9	4 : 30	3.16	866	28.20
5	28	1.8	4 : 05	3.17	838	29.31
10	30	7.3	3 : 50	3.17	791	28.80
20	31	8.7	3 : 45	3.20	767	28.62
30	32	9.2	3 : 35	3.25	750	26.84
40	40	27.8	3 : 30	3.28	736	8.12
50	42	41.2	2 : 50	3.29	722	6.32

*Control sample with 100% ordinary Portland cement

for brick making was 60%, while 30% provide the optimum strength of 31 N/mm^2.

Sintered aggregates produced from industrial sludge and marine clay at a temperature of 1135°C can be used for complete replacement of regular aggregates in concrete. The 100% sludge pellets were suitable for use in concrete paving blocks or even other structural applications, providing concrete strength of 38.5 N/mm^2.

The study of using dewatered sludge mixed with limestone to produce cementitious material had determined the optimum condition and mix composition that produced the highest possible strength development of the cement specimens. Under air curing, the cement made from mixtures of sludge and limestone in equal amounts by weight fired at 1000°C for 4 h under controlled firing exhibited the highest compressive strength. Evaluation of the mortar cube strength shows that it is possible to produce masonry binder made of sludge that would satisfy the strength requirem39ents of the ASTM standard for masonry cement. The sludge masonry cement can be used to replace up to 20% by weight of ordinary Portland cement to produce blended cements without compromise in mortar strength.

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