International Journal of Civil
Engineering (IJCE)
ISSN (P): 2278-9987; ISSN (E): 2278-9995
Vol. 6, Issue 4, Jun– Jul 2017; 67-78

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

UTILIZATION OF SLUDGE, RECYCLED COARSE AGGREGATES IN PRODUCTION OF CONTROLLED LOW-STRENGTH MATERIALS A REVIEW

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ABSTRACT

The technological development led to rapid industrialization, which is always associated with the problem of environmental degradation. Industrial activities generate quantities of wastes more than 1,500 million tons per year, creating problem to the environment. It is now a global concern to find a socio, techno-economic and eco friendly solution to dispose industrial solid wastes. The recycling of solid wastes as a substitute for building materials is not only environmentally friendly but also cost effective. It serves as an alternative way to sustain a cleaner and greener environment. These materials are, in general, incompatible for use in the construction industry due to their high content of very fine particles, or due to their poor mechanical properties. Controlled Low Strength Materials (ClSM), can serve as an excellent means to utilize large quantities of fines without impairing its properties. American Concrete Institute 229 R describes uses of number of nonstandard materials and industrial by-products in developing controlled low-strength material. This paper presents and an overview of the work published on CLSM developed with industrial sludge, recycled concrete aggregates.

KEYWORDS: Controlled Low Strength Materials CLSM, Non-Standard Materials, Industrial Sludge, Recycled Concrete Aggregates

INTRODUCTION

Controlled low-strength material (CLSM) is a separate class of materials. American Concrete Institute Committee (ACI 229 R) describes it as a self-compacted, cementitious material, used primarily as backfill as an alternative to compacted fill other uses of CLSM includes include: foundation supports, pavement bases, sub-base, and sub-grades. Quite a few terms are currently used to describe this material, including flowable fill, unshrinkable fill, controlled density fill, flowable mortar, plastic soil-cement, soil-cement slurry, K-Krete and other various names. Typically in CLSM, the materials results in the compressive strength of 8.3 MPa or less. Currently, CLSM applications require unconfined compressive strengths of 2 MPa (300 psi) or less, so as to allow future excavation of CLSM after hardening. The upper limit of 8.3 MPa (1200 psi) allows the use of this material for structural fill under buildings, where future excavations are unlikely.

Furthermore, CLSM should not be confused with compacted soil-cement, as described in ACI 230.IR. CLSM typically requires no compaction (consolidation) or curing to achieve the desired strength. Long-term compressive strengths for compacted soil-cement often exceed 8.27MPa maximum limit established for CLSM. Long-term compressive strengths of 0.35–0.70MPa are very low when compared to concrete. In terms of allowable bearing pressure, however, which is a common criterion for measuring the capacity of a soil to support a load, 0.31 to 0.7 MPa strength is the same as a well-compacted fill. (ACI Committee 229R, 2005)

In terms of flowability of CLSM, the slump (as measured as in the case of concrete) is generally greater than 8 inches (200mm). It is self-leveling material and can be placed with minimal effort, and does not require vibration or tamping. It hardens into a strong material with minimal subsidence.

Benefits of CLSM

A few specific benefits of CLSM have been identified from various studies, which includes (i) compaction is not required, thus results in minimum labor costs, (ii) accelerated construction due to enhanced flow and self-flowing characteristics (iii) work can be undertaken under all weather conditions and even under freestanding water. (iv) Reduced equipment charges due to self-leveling characteristics (v) Using low-strength CLSM future excavations can be carried out if required (vi) These classes of materials offer a direct means to utilize a wide variety of waste materials, which otherwise pose a problem in their safe disposal.

Uses of CLSM Includes

CLSM is an economical alternative to compacted granular fill, considering the savings in equipment, labour costs and time. Placing CLSM does not require labours to enter excavation, thus a significant safety is achieved. Few notable applications of CLSM include:

- Backfill: bridge abutments, utility trenches, sewer trenches, conduit encasement, road cuts and retaining structures.
- Structural fill: foundation sub-base, pavement sub grades bases and sub-bases, floor slab, conduit bedding, sub footing
- Other applications: underground storage tanks, basements and underground structures, erosion control, thermal insulation, abandoned mines

OBJECTIVES

In this paper, an effort has been made to present the overview of the research work carried in the potential reuse of materials such as industrial sludge, recycled aggregates in the development of CLSM, which are considered as non-standard or low-strength materials. The issues related to disposal and management of these materials is of greater concerns and affects the environment to a large extent.

History of CLSM

The history of CLSM dates back to 1970's. Differential settlement between trench backfills and surrounding material has long been a problem of cross drains in new construction. Differential settlement is usually the result of insufficient compaction of trench backfill material. The condition is most often observed, where utility repairs or new utility construction takes place in existing roadways. The result of the differential settlement is a shallow dip or trench often running long distances, longitudinally to the roadway with occasional trenches, extending perpendicular to the roadway centerline. A search for a solution for this problem resulted in the development of a low-strength, flowable backfill material in the early 1970's. The material was developed and patented by private industry under the trade name K-Krete (CDF - Controlled Density Fill). The practicality of the low-strength backfill was soon apparent and several similar materials were developed. Due to the number of materials and inconsistency or scarcity of information available to the public, the American Concrete Institute (ACD Committee 229 was formed to address issues relating to this type of material. The ACI committee designated the material as Controlled Low Strength Material (CLSM) and defined it.

Materials

The major components of CLSM mixture are cement, fine or coarse aggregates or both, fly ash water industrial by-products, and admixtures. Although the materials used in CLSM mixtures may meet ASTM or other standard requirements, the use of standardized materials is not always necessary. Consequently, using non-standard materials such industrial sludge, recycled concrete aggregates, as an alternate would be in the beneficial use of effective management of low-standard or waste materials. Selection of materials is very crucial and should be based on availability, properties, cost, specific application and the necessary characteristics of the mixture including flowability, strength, excavatability, density and so on.

INDUSTRIAL SLUDGE

Sludge is semi-solid slurry produced from wastewater treatment processes or from the conventional drinking water treatment process. Industrial in-house effluent treatment plant generates sludge, either from biological or physical-chemical processes. The effective management of the Industrial sludge, which is considered as hazardous waste as per Indian Government Hazardous Waste Management Rules, including raw sludge, primary sludge, activated sludge, tertiary sludge and digested sludge generated from various industries and is a major challenge In India, nearly 290 million tones of industrial wastes are generated annually of which around 7.2 million tonnes is hazardous and require careful disposal. Land filling is currently under practice. Many effluent treatment plants resulting in an increasing of sludge which in turn increasing problems in disposal. Disposal of such a huge quantity is a great challenge. The final destination of effluent treatment sludge affects the environment. Since land is limited, alternative technologies to dispose of effluent treatment sludge are essential. Incineration may be a profitable alternative technology of disposal, but the final disposition of a huge quantity of effluent treatment sludge would pose another problem. Hundreds of tonnes/ day of hazardous waste as sludge are generated every day from ETP’s. Lack of disposal sites and costs are causing a very serious concern.

Status of Common Effluent Treatment Plants (CETPs) in India

In the Indian context, given the small investment in establishing SMEs, the provision of individual effluent treatment plants is not feasible due to high capital and operating cost. The disposal of treated effluents is also problematic as every individual industry cannot reach the water body through pipeline nor can it purchase land for inland irrigation.

The Ministry of Environment and Forests, instructed various agencies to establish CETPs in industrial estates. In response to the directive issued by the Central government, the State governments started identifying the locations for establishing CETPs. Work carried out in this context till 1990 was very limited. Till 1990, India had only one CETP in Jeedimetla near Hyderabad (Andhra Pradesh). Till 2005, around 88 CETPs had been established across the nation. Table 1 shows the number of CETPs rose to more than 150 by the year 2011

Table 1: CETPs in Different States of India

Sl. No.	State	CETPs 2011
1	Andhra Pradesh	4
2	Delhi	13
3	Gujarat	26
4	Haryana	9
5	Karnataka	7
6	Maharashtra	25
7	Madhya Pradesh	1
8	Punjab	5
9	Rajasthan	11
10	Tamil Nadu	44
11	Uttar Pradesh	7
12	West Bengal	1
	Total	153

Physio-Chemical Properties of Sludge

Hema Patel et al., (2008) carried out studies on the physical - chemical characterization of textile chemical sludge obtained from various CETPs in India. The sludge obtained was examined for different physico-chemical parameters including heavy metals to devise a plan for its management. The characterization data indicated that sludge was alkaline in nature with higher electrical conductivity values. The Total organic carbon (TOC) was highly variable, ranging from 1.23 to 17.83 % and calorific value was ranging from Nil to 2066.33 Kcal/Kg. The study also suggested that, the concentrations of heavy metals like Cr, Ni, Cu, Pb, Zn, Cd and Co, when compared with the Indian rules revealed that all the heavy metals were less than the regulatory limits for all the sampling sites. This indicated that sludge obtained was a non-hazardous in nature and various other options could be explored for its suitable management other than the conventionally used options like land filling. **Table 2** indicates the physcio-chemical property values obtained in the present study and were compared with the literature values

Table 2: Physcio-Chemical Properties of Sludge Hema Patel Et Al., (2008)

Parameter	Study Results	Literature
pH	8.02 - 9.0	6.8 - 9.4
Electrical conductivity (mS/cm)	2.12 - 6.63	11.5 - 11.6
Moisture content (%)	5.40 – 66.65	4.6 - 94.6
Dry solids (%)	33.35 – 94.60	5.4 - 95.4
Volatile Solids (%)	34.30 - 48.37	24.2 – 80.0
Fixed solids (%)	51.63 – 65.70	20.0 – 75.8
Total organic carbon (%)	1.23-17.82	12
Calorific value (Kcal/kg)	Nil – 2066.33	495 - 498
Specific gravity	0.84 – 1.07	0.86 - 2.4
Density (g/cm^3)	843.80 – 1065.40	1110 -1120
Cd (mg/kg on dry wt. basis)	4.248 – 5.409	0.10 - 396
Cu (mg/kg on dry wt. basis)	39.806 – 389.831	9.9 – 57.48
Zn (mg/kg on dry wt. basis)	73.480 – 386.939	0.65 – 306
Ni (mg/kg on dry wt. basis)	23.729 – 88.745	0.68 – 0.42
Co (mg/kg on dry wt. basis)	12.119 – 13.559	2.29 – 6.61
Cr (III) (mg/kg on dry wt. basis)	32.004 – 316.326	4.7 - 199
Cr (VI) (mg/kg on dry wt. basis)	BDL	4.7 – 14.00
Pb (mg/kg on dry wt. basis)	20.314 – 52.044	0.50 – 27

Gabr et al., (1999) carried out research on acid mine drainage (AMD) sludge with class F fly ash in the development of CLSM. The sludge was found to be a lime-based waste product, that when combined with Fly ash, exhibited self-hardening characteristics similar to cement. The CLSM mix was developed in which by-product material utilisation is maximised while satisfying workability and performance requirements. This study showed that, mixture of 10% AMD sludge, 2.5% Portland cement PC., 87.5% Class F FA dry wt. %, with water provided unconfined compressive strength values, within the range for classification as CLSM. This mixture satisfied the excavatability and workability requirements as well as the hardening time and stability for CLSM mix.

Ryo Fujita et al.., (2010) thoroughly investigated the applicability of CLSM with incinerated sewage sludge ash and crushed-stone powder. The incinerated sewage sludge ash used in the study was generated from municipal solid waste (MSW). The incinerated sewage sludge ash was used as a replacement of fly ash, which is the main component of CLSM. Dust powder from crushed stone production was used as a fine aggregate in the development of a new type of green CLSM, which is considered as a promising sustainable cementitious material to reduce CO_2 emissions. Test results showed that the CLSM properties had negative effects due to the presence of incinerated sludge. By increasing F/A ratio, the unit water content of CLSM was increased. To achieve adequate strength development and reasonable flow-ability the mix proportion was required to design carefully. In the present test, the leachate characteristics of new green CLSM were evaluated. And the test results showed acceptable leachate levels. From these test results, it was confirmed that a wide range of MSW could be applied as materials of the new green CLSM. But if CLSM was developed with high volume of incinerated ash, results showed the compressive strength of CLSM was lowered compared to ordinary CLSM mix. The authors reported that, newly developed CLSM showed excellent performance as backfill.

RECYCLED COARSE AGGREGATES

Uses of Recycled Aggregate

The use of recycled aggregate in the development of CLSM opens a whole new range of possibilities in the reuse of materials in the building industry. The utilization of recycled aggregates is a good solution to the problems of excess waste materials, provided that the desired quality of the product is reached. Recycling of rejected building materials is a very important issue for saving energy resources and environmental protection. The recycled concrete aggregates exhibit different characteristics from natural aggregates. The use of recycled aggregate gains importance when it is used in the development of CLSM

Many reports have shown the generation of demolition wastes in India and abroad. **Tushar et al.,** carried out studies on the use of recycled aggregates. As per report of the Central Pollution Control Board (CPCB) Delhi, in India, 48million tons solid waste is produced out of which 14.5 million ton waste is produced from the construction waste sector, out of which only 3% waste is used for embankment. Out of the total construction, demolition waste, 40% is of concrete, 30% ceramics, 5% plastics, 10% wood, 5%metal, & 10% other mixtures. **Akash et.al.,** reports on the potential use of recycled aggregates in concrete in a global scenario. The various properties of aggregates made from Construction & Demolition wastes were explained in a broader way. The study reported that, the RA provides a promising solution to the problem of C&D waste management. Based on a survey of production and utilization of RA in RAC, and the properties of RA and RAC were discussed, and was reported that RAC can be used in lower end applications of concrete. With tailor made pilot studies, RA can be used for making normal structural concrete with the addition of fly ash, condensed silica fume, etc.

Greater efforts are needed in the direction of creating awareness, and relevant specifications to clearly demarcate areas where RAC can be safely used.

Figure 1: Recycled Aggregates

Properties of Recycled Aggregates

Jianzhuang et al., investigated the mechanical property, structural performance and durability of recycled aggregate concrete. The author compared the obtained results with the results of conventional concrete. The observations revealed that the aggregates – cement matrix interface zone of recycled aggregate concrete consisted of loose and porous hydrates. The mix design procedure used to be same as conventional concrete's. The mechanical properties such as compressive strength, tensile strength, and shear strength are lower than conventional concrete. With reference to the durability properties the carbonation resistance, chloride penetration resistance was lower when compared with the conventional concrete. The factors such as shrinkage and creep showed an increased amount, with respect to the conventional concrete. The structural behavior of recycled aggregate concrete was slightly weaker in comparison to that of the structural elements made with natural aggregates.

Recycled Aggregates in Production of CLSM

Very limited literature is available on the use of recycled aggregates in the production of CLSM. Sasha et.al carried out experimental studies on the utilization of recycled concrete aggregate to produce controlled low-strength materials without using Portland cement. The study was carried out by developing two types of CLSMs one type with fine RCA for use in narrow and restricted locations, and another type with fine/coarse RCA for use as permanent structural fills and road bases. Typical fresh properties of CLSM containing fine RCA are shown in Table 3.

Table 3: (Sasha et al.,) Fresh Properties of CLSM Containing Fine RCA and Slag

Slag (%)	Slump Flow (mm)	Filling Capacity (%)	J Ring		Subsidence (%)
			Total Flow (mm)	Step Height (mm)	
5	135	78	381	25	4.0
10	141	63	403	43	2.0
20	160	69	367	29	0.3
30	137	75	330	19	0.3

The compressive strength of the slag/RCA mixtures was higher than that of HCFA/RCA mixtures. For both types of SCM, the strength of mortar cubes increased with increasing SCM content in the mixtures. Table 4 shows the properties of RCA/SCM mortar samples. The slag and HCFA produced strength due to their hydraulic and pozzolanic reactions. The latter is believed to be promoted by the alkalis released from the residual paste by RCA. The strength development resulting from the hydration of unreacted PC particles in the RCA was evaluated and found to have a minor effect on strength development.

Table 4: Sasha et al., Properties of Fine RCA/SCM Mortar Samples

Slag				
Slag (%)	w/b	Flow (mm)	Strength (Mpa)	
			3 Day	7 Day
5	3.00	118	0.70	0.55
10	1.63	165	1.44	2.10
15	1.00	135	3.08	4.98
20	0.75	152	4.67	5.84
30	0.54	135	5.21	6.54
Flyash				
Slag (%)	w/b	Flow(mm)	Strength(Mpa)	
			3 Day	7 Day
5	2.65	120	0.36	0.20
10	1.25	119	0.81	0.56
15	0.83	132	0.93	0.74
20	0.63	108	1.21	1.54
30	0.50	141	1.17	1.77

The study was carried out with RCA and slag, and it was found that the Mixtures of RCA and slag or HCFA gained strength without the need to add Portland cement. The strength were relatively high strength (up to 8.3 MPa), high resistance to freezing/thawing and wetting/drying as shown in the Table 5 and 6, and short hardening times are required. For CLSM with fine RCA, a slag content of 20%, expressed as percentage mass of RCA, found to produce cohesive mixtures with low subsidence and high resistance to cycles of freezing/ thawing and wetting/drying.

Table 5: Sasha et al., Freezing and Thawing, Wetting and Drying of CLSM with RCA

Freezing and Thawing			
Slag (%)	Mass Loss (%)		Average
	Sample I	Sample II	
CLSM with Fine RCA			
5	12.05	12.56	12.30
10	17.19	16.89	17.04
20	3.39	4.07	3.73
30	3.48	3.31	3.39
Wetting and Drying			
Slag (%)	Mass Loss (%)		Average
	Sample I	Sample II	
CLSM with Fine RCA			
5	16.23	14.58	15.41
10	15.25	15.84	15.55
20	5.52	5.70	5.61
30	6.40	6.09	6.24

Table 6 Sasha et al., Freezing and Thawing of CLSM with RCA

Freezing and Thawing			
Slag (%)	Mass Loss (%)		Average
	Sample I	Sample II	
CLSM with Fine/Coarse RCA			
10	9.88	9.71	9.79
20	10.67	10.12	10.40
Wetting and drying			

Table 6: Contd.,			
Slag (%)	**Mass Loss (%)**		**Average**
	Sample I	**Sample II**	
CLSM with Fine/Coarse RCA			
10	4.26	3.85	4.05
20	4.29	3.79	4.04

The investigation reported that the strength was relatively high, which renders the mixture not suitable for applications that require future excavation. At the lower slag contents (5% and 10%), the strength met the range required for future excavation (<2.1 MPa), but the mixtures had high subsidence. CLSM with fine/coarse RCA and slag contents of 10% and 20% showed high resistance to freezing/thawing and wetting/drying cycles and a quick hardening time, or time required to load can be applied as determined by the Ball Drop Test (ASTM D 6024). The strength of these mixtures was above that required for CLSM with possible future excavations, but within the strength range required for structural fills and road bases. The main difference found between mixtures with 10% and 20% slag was the hardening time, which was 8 and 5 h for each mixture, respectively.

Etxeberria et.al., investigated the use of recycled fine aggregates for control low strength materials (clsms) production. Table 5 shows a typical chemical composition of Recycled aggregates.

Table 7: Etxeberria et al., Chemical Composition of Recycled Aggregates

Chemical Composition of Recycled Fine Aggregate	
Fe_2o_3	3.28
MnO	0.06
TiO_2	0.33
CaO	20.21
K_2O	2.41
P_2O_5	0.10
SiO_2	57.43
Al_2O_3	10.85
MgO	2.65
Na_2O	1.63
LOI	0.03

The CLSM was produced in the present study with recycled aggregates, replacing the natural aggregate up to 30%, and obtained the same acceptable properties as the control CLSM, when it was produced in 20–25% of air content, 110 kg of cement per cubic meter and a w/c ratio of 1.79. It was necessary to increase the amount of cement paste and reduce the w/c ratio in the CLSM produced with 40% or higher percentages of recycled fine aggregates, in order to maintain the same flowability and compressive strength as a CLSM made with natural aggregate, The authors indicated that, CLSM made with 40–50% recycled fine aggregate, with 20–23% of air content in fresh state, needed 125 kg of cement (13% more than in conventional CLSM) and w/c ratio of 1.74 to achieve similar properties to those of standard CLSM. In CLSM materials manufactured with 100% of recycled aggregate, a 135 kg of cement per cubic meter of the mix, and a w/c ratio of 1.72 was required. The rise of compressive strength from 7 days to 28 days was higher in CLSM, produced with high percentages of recycled aggregates, when the recycled aggregates had a high amount of ceramics as their component. CLSM density affects the material properties of both the fresh and hardened states, making it critical to have well-controlled values. The density of fresh state should be between 1.65 and 1.75 kg/dm3 (from low to high percentages of recycled aggregate use).

The main highlight of this study was CLSM made with recycled aggregate replacing natural aggregate obtained suitable properties in both its fresh and hardened state, being self-compacted and was easily excavatable in its hardened state.

CONCLUSIONS

Following concluding remarks were drawn:

- Green CLSM can be developed by utilizing industrial sludge from various sources. However, for the CLSM developed with high volume of incinerated ash, the results showed the compressive strength of CLSM was lowered compared to ordinary CLSM mix.
- Newly developed CLSM with industrial sludge showed excellent performance as backfill.
- The burning issues related to the disposal of huge quantity of industrial sludge generated can be solved by utilising in CLSM
- By leaching is needed for real construction. The CLSM developed with incinerated sludge and crushed stone powder and showed that blast furnace slag cement and insoluble incinerated sewage sludge ash are useful material for leaching problems.
- Recycled aggregate-based flowable fill can be used in a substantial number of construction applications, such as bridge abutments fills, trench fills, and foundation fills.
- The CLSM developed by RCA was self compatible and easily excavatable in its hardened state.

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