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Production of Synthetic Aggregates from Different Wastes as a Paper wastes, a Clay soil and a Waste Management Option.

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ABSTRACT

The Paper is aimed to produce newly driven construction materials for non-structural civil and construction applications at construction industry to minimizing material wastage in building construction projects and to maximize waste material utilization. The main focus of the Paper is to identify the existence of production of synthetic aggregate and producing synthetic aggregate from industry, construction and other wastes. It is also the intent of the paper to show the ways and techniques of production of the proposed construction materials.

Key Words: Synthetic Aggregate, Composite Wastes,

I INTRODUCTION

In most developed and developing countries with increasing population, prosperity and urbanization, one of the major challenges for them is to collect, recycle, treat and dispose of increasing quantities of solid waste and wastewater. It is now well known that waste generation and management practices have increased several alarming issues on the socio-economics, human health, aesthetics and amenity of many communities, states, and nations around the world (Meyers et al., 2006; Louis, 2004). Industrialized economies extract vast quantities of natural resources from the environment to provide modern amenities and commodities.

On the other hand, pollutants associated with the production and consumption of commodities, as well as post-consuming commodities, go back into the environment as residues (Moriguchi, 1999). Although varying in degree and intensity, the solid waste problem around the world is exacerbated by limited space and dense populations (Melosi, 1981). The problem of collecting, handling and disposing of wastes is dealt with using different techniques and approaches in different regions. A waste management hierarchy based on the most environmentally sound criteria favors waste prevention/minimization, waste re-use, recycling, and composting. In many countries, a large percentage of waste cannot presently be re-used, re-cycled or composted and the main disposal methods are land filling and incineration. In addition, traditionally, managing domestic, industrial and commercial waste consisted of collection followed by disposal, usually away from urban activity, which could be waterways, Open ocean or surface areas demarcated for the purpose viz. landfills. With the increased volume and variety of hazards posed by new waste products, the situation has exceeded its saturation point at many localities (McCarthy, 2007).

In 2006 the USA land filled 54% of solid wastes, incinerated 14%, and recovered, recycled or composted the remaining 32% (EPA, 2008). The percentage of solid waste disposed at landfills accounted for 3% in Japan (2003), 18% in Germany (2004), 36% in France (2005), 54% in Italy (2005) and the USA (2005), and 64% in the UK (2005). As legislation becomes more stringent and land filling becomes less cheap option. For example, there has been a significant reduction in the amount of wasteland filled in the UK and Italy. In 1995, Italy land filled 93% of solid waste, and the UK 83%. Recent studies have revealed that waste disposal processes have considerable impacts on climate change due to the associated greenhouse gases (GHGs) emission (Elena, 2004; Sandulescu, 2004; USEPA, 2002). Land filling processes are found to be the largest anthropogenic source of CH 4 emission in the United States.

In 2004, there were 140.9 Tg of CO2 equivalent of CH4 (approximately 25% of the United States' annual CH4 emission) emitted from the landfills, which shared 2.65% of the national global-warming damage. In addition, 19.4 and 0.5 Tg of CO2 equivalent of CO2 and N2O were, respectively, released from the combustion processes (USEPA, 2006). These evidences show that waste disposal systems are one of the most significant contributors to potential climate change, as the associated-emission cannot be effectively mitigated under current management conditions. Moreover, Incineration is also cannot be recommended as an efficient method since it is also creating toxic gases and GHGs. In addition, wide range of waste materials (sewage sludge, industrial waste) is increasingly spread on agricultural land as soil amendments. These undoubtedly produce a number of positive effects on soil quality, but also raise concern about potential short-term (e.g. pathogen survival) and long-term effects (e.g. accumulation of heavy metals).

Climate change will also become a major incentive to the use of biosolids on agricultural land, especially in regions where longer periods of low rainfall and mean higher temperatures are expected. In many parts of the world (e.g. Europe, USA) agricultural soils receive large volumes of soil amendments. Approximately 5.5 million dry tones of sewage sludge are used or disposed of annually in the United States and approximately 60% of it is used for land application (NRC, 2000). The application of biosolids to soil is likely to increase as a result of the diversion of waste away from landfill sites, and due to increasing cost of artificial fertilizers (UNEP, 2002; Epstein, 2003).

Simply application of waste as an amendment to agricultural lands made some environmental problems such as air pollution due to tiny particles of coal fly ash (CFA). Therefore, it is worthwhile to find out alternative methods for waste disposal. Consequently, unconventional synthetic aggregates were produced from different waste materials (sewage sludge, paper waste, oil palm waste, sugarcane trash, starch waste, CFA, wood chips, coir dust, cattle manure compost, chicken manure compost etc.…) to utilize them in agriculture as a soil amendment, fertilizer support, and potting media for containerized plant cultivation (Jayasinghe & Tokashiki, 2006; Jayasinghe et al., 2005, 2008, 2009 a, b, c,d,e,f,g). These synthetic aggregates proved that they can be utilized in agriculture very effectively. Moreover, these kinds of unconventional synthetic aggregate production have not much been reported in

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the literature. Therefore, this part of the paper describes the production, characterization and different utilization methods of synthetic aggregates in Engineering.

II WHAT IS A SYNTHETIC AGGREGATE (SA)?

Aggregate structure is schematically shown in Figure 1. It is composed with rigid or composite materials, fibrous materials and a binder.

2.1 Rigid or composite materials

Sewage sludge, sugarcane trash, wood chip, CFA, compost, soil etc. can be regarded as rigid materials. The rigid materials give the rigidity and the strength of the aggregate by enmeshing into fibrous matrix. Figure 2 shows the scanning electron microscopic (SEM) image of a coal fly ash paper waste aggregate, which is showing the rigid CFA particles are enmeshed into the fibrous paper waste matrix by the binder.

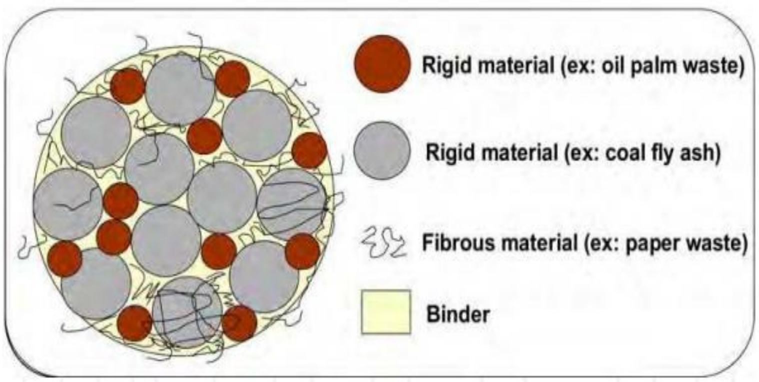

Fig. 1. Schematic diagram of the synthetic aggregate

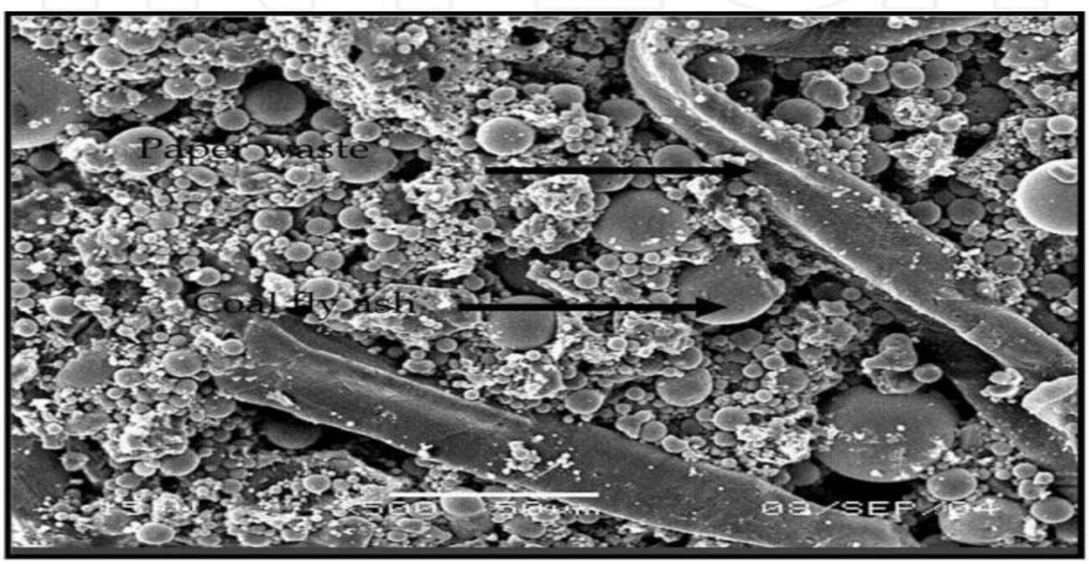

Fig. 2. Scanning electron micrograph of a coal fly ash-paper waste synthetic aggregate.

2.2 Fibrous materials

The formation of aggregate requires a matrix to adhere the rigid particles. Then this matrix can form the aggregate structure by binding the rigid particles into the matrix by the binder. Paper waste, coco fiber, wheat and rice straw and oil palm fiber can be used as the fibrous materials. Figure 2 shows the porous paper waste matrix, which provides the binding sites to the CFA particles. Porous spaces can be observed within the aggregate, which can improve the aeration and the water holding capacity of the aggregates as a growth substrate (Jayasinghe et al., 2007). Fibrous materials in the aggregates also assist to increase the micro pores in the aggregate-soil amendment mixtures during the humification of aggregates by microbes after mixing them into the soil as an amendment.

2.3 Binder

The formation of aggregate requires both physical rearrangement of particles and the stabilization of the new arrangement. Therefore, effective binder should be added in order to obtain stable aggregates. Several binding mechanisms exist between organic polymers and mineral surfaces to provide stable aggregates. Organic polymers have been used quite effectively to stabilize soil structure in recent years. Many researchers have shown that the application of polyacrylamide maintained high infiltration rate during rainfall and reduced soil surface sealing and runoff soil losses (Ben-Hur & Keren, 1997; Sojka et al., 1998; Green et al., 2000). Polysaccharides added to soil as soil conditioners improve soil's physical properties that are important for plant growth and increase soil's resistance against disruptive forces and erosion. Organic polymers have been used quite effectively to stabilize soil structure in recent years. Polysaccharides stabilize soil aggregates because of their contribution as cements and glues. (Taskin etal., 2002). There is a considerable amount of starch which is a polysaccharide coming out as waste material from Okinawa flour industry (Okinawa, Seifun ltd). Utilization of the starch waste is currently under the potential capacity. Therefore, the starch waste was utilized as an organic binder for the synthetic aggregate production. In addition, several inorganic binders can be used to produce synthetic aggregates. Acryl resin emulsion binder EMN-coat /21 and Calcium hydroxide with calcium sulfate can also be used as the binder to produce aggregates.

2.4 Production of synthetic aggregates

Production process of aggregates is given in Figure3. EIRICH mixer, Ploughshare mixer or Pelleger machine can be used for the production of heterogeneous aggregates. Heterogeneous aggregates mean the aggregates containing different particle sizes. Pelleter machine can be utilized to produce homogenous (same size) aggregates. EIRICH mixer was used for small scale aggregate production and pelleger machine and pelleter was used in major scale aggregates production. Different proportions of raw materials were mixed in the pelleger or EIRICH mixer for 1-3 minutes. Then binder was added and mixed for another 1-2 minutes. Finally, whole mixture was mixed for another 2-5 minutes in high speed rotation to form aggregates. Raw materials with binder mixture were inserted to the pelleter machine for the production of homogenous aggregates. Moreover, diameter and the length of the aggregates can be adjusted according to the requirement.

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2.5 Different types of aggregates with various types of wastes.

Different types of aggregates can be developed with the available waste in the site or area. Some of the developed aggregates from different wastes are described below (Figure 4). Basically, aggregates can be divided into two types.

2.5.1. Heterogeneous aggregates

These aggregates contain different sized aggregates. Following are some of the heterogeneous aggregates developed from various materials.

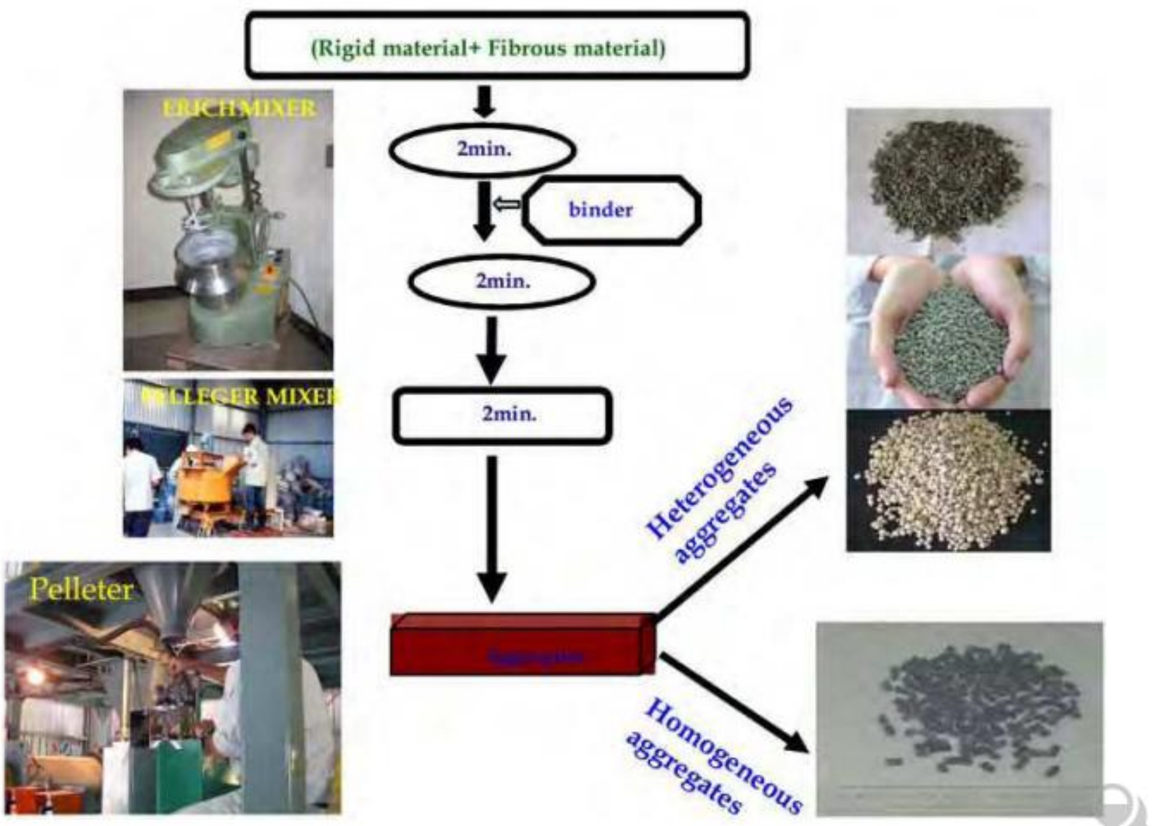

Fig. 3. Production process of different types of aggregates

i. **Coal fly ash based aggregates**

   These aggregates were developed from CFA, paper waste or oil palm waste with organic or inorganic binders (Figure 4a).

ii. **Soil aggregates**

   These were developed from low productive acidic red soil with paper waste, coco fiber, or oil palm waste (Figure 4b) with organic or inorganic binders.

iii. **Acid soil-coal fly ash aggregates**

   These were developed by acid soil and the coal fly ash with paper waste, sewage sludge (SS), CFA with organic or inorganic binder. (Figure 4 c)

iv. Sewage sludge based aggregates

These aggregates were developed from sewage sludge and zeolite with an inorganic binder. (Figure 4d)

v. Compost based aggregates

These were produced from different types of composts and soil with organic or inorganic binders (Figure 4e)

2.5.2. Homogenous aggregates

These aggregates have same sized aggregates and pelleter machine was used for the production of these aggregates. These aggregates are called as synthetic pellet aggregates. Coal fly ash (CFA), soil, compost, paper waste, coco fiber, oil palm waste, sewage sludge and organic or inorganic binders can be utilized as raw materials for these types of aggregates. (Figure 4f)

(a) coal fly ash paper waste aggregates,

(b) soil aggregates,

(c) acid soil coal fly ash aggregates,

(d) sewage sludge based aggregates,

(e) compost based aggregates,

(f) pellet aggregates (homogeneous aggregates)

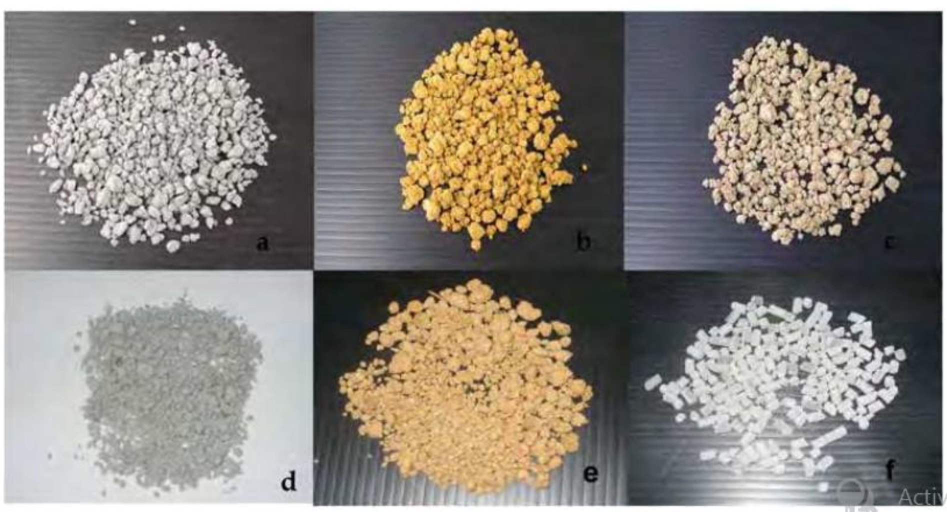

Fig. 4. Different types of aggregates produced from different materials.

III PHYSICAL AND CHEMICAL PROPERTIES OF SYNTHETIC AGGREGATES

3.1. Physical properties

Particle size distributions of synthetic aggregates developed by different materials are given in the Table 1. Particle size distribution of a substrate is important because it determine spore space, air and water holding capacities (Raviv et al., 1986). Mean distribution of the aggregate media showed that fraction between 5.60 and 2.00 mm was the most abundant fraction in all types of synthetic aggregates (Table 1). An excess of fines in a substrate clogs pores,

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increases non-plant-available water holding capacity and decreases air filled porosity (Spiers &Fietje, 2000). Therefore, these synthetic aggregates which are having higher percentage of larger- sized particles can be utilized to enhance the properties of problematic soils having higher finer particles to improve its porosity and hydraulic conductivity.

Synthetic aggregates developed from low productive acid soil and paper waste addition to the problematic grey soil in Okinawa, Japan significantly enhanced the particles >2.00 mm and hence the hydraulic conductivity and porosity were significantly increased (Jayasinghe et al., 2009d). All of synthetic aggregates shown in the Table 1 are heterogeneous which are having different sized aggregates. Synthetic pellet aggregates can be developed with single particle sized diameter which are called as homogenous aggregates. These pellet aggregates can be produced with the required diameter as a tailor-made production. In addition, aggregate diameter of heterogeneous aggregates depends upon the material type and quantity, binder type and quantity and the mixing time. Therefore, suitable particle sizes of heterogeneous synthetic aggregates can be designed according to the requirement. Synthetic aggregates particle sizes are varying with the required situation. For an example particle sizes for a potting medium are different from particle sizes required as a soil ameliorant. As a potting medium relatively, higher percentage of smaller sized-diameter particles should be utilized to improve the potting media characteristics.

A: coal fly ash paper waste aggregates with starch binder (Jayasinghe et al., 2009b),

B: acid soil aggregates with starch binder (Jayasinghe et al., 2008),

C: acid soil coal fly ash aggregates with starch binder, (Jayasinghe et al., 2008),

D: acid soil compost aggregates with inorganic binder,

E: coal fly ash aggregates with inorganic binder (Jayasinghe et al., 2009a),

F: sewage sludge aggregates with inorganic binder.

Table 1. Particle size distribution of synthetic aggregates

Aggregate type	>5.60 mm	5.60-3.35 mm	3.35-2.00 mm	2.00-1.00 mm	1.00-0.50 mm	>0.50 mm
A	25.61	30.19	28.32	8.54	5.20	2.14
B	10.77	19.85	36.98	13.15	7.91	11.34
C	23.86	28.14	25.74	9.44	8.09	4.73
D	6.34	16.92	16.98	19.44	21.23	19.09
E	26.20	30.28	27.54	8.73	5.02	2.23
F	7.10	15.21	18.77	15.91	22.87	20.14

Bulk density, particle density, hydraulic conductivity, water holding capacity and aggregate strength of the synthetic aggregates are given in the Table2. Bulk density of a substrate gives a good indication of porosity, which determines the rate at which air and oxygen can move through the substrate. Bulk density values of all substrate given in the table showed low values compared to red soil (1.26 gcm-3) in Okinawa Japan. These low values are due to the coal fly ash, paper waste, and sewage sludge in the developed synthetic aggregates. It is also evident that there were significant differences between bulk density values of aggregates produced with different coal fly ash additions to red soil (Jayasinghe et al., 2005). The particle density of the synthetic aggregates was also low compared to the red soil. Red soil gave a particle density of 2.61 gcm-3. Hydraulic conductivity of a substrate is a measure of the ability of air and water to move through it. Hydraulic conductivity is influenced by the size, shape and continuity of the pore spaces, which in turn depend on the bulk density, structure and the texture. Hydraulic conductivity of the aggregates showed higher values compared to the red soil and grey soil studied in Okinawa, Japan. The red soil and grey soils showed hydraulic conductivity values of 6.62 x10-5 and 6.67 x10-5, respectively. The water holding capacity of the synthetic aggregates given in the table varied between 0.59 and 0.68 kgkg-1, which are increased values compared to the red soil (0.48 kgkg-1) in Okinawa Japan (Jayasinghe et al., 2009e). Aggregate strength of the produced aggregates varied between 2.58-4.01 kgcm-2. Synthetic aggregates developed by using coal fly ash, paper waste, and starch waste gave an average aggregate strength in the range of 2.05-3.58 kgcm-2, which can be considered as higher aggregate strengths (Jayasinghe et al., 2005, 2006, 2008). Higher aggregate strengths indicate resistance of the aggregate to the erosion. Therefore, these synthetic aggregates can withstand to erosion compared to soil particles.

3.2. Chemical properties

Chemical properties of the different types of synthetic aggregates are given in the Table 3. It is evident that pH of aggregates were varied in a wide range from 4.57 to 10.72. A, C, E and G aggregates having higher pH values were produced by using CFA as a material in the aggregates. The original pH of the CFA used to produce synthetic aggregates was varied in the range of 11.36-11.80. Therefore, CFA aggregates gave alkaline pH values. The hydroxide and carbonate salts in CFA gave one of its principle beneficial chemical characteristics, the ability to neutralize acidity in soils (Pathan et al., 2003). Therefore, these alkaline synthetic aggregates can be used as a buffer material to neutralize the acidic problematic soils. Jayasinghe et al., (2006) reported that 25% of synthetic CFA based aggregates addition increased the acidic pH (4.62) of red soil into 6.25. Type B aggregates were developed from acidic red soil with paper wastes showed acidic pH of 4.57 due to acidic soil. Type D aggregates were produced from acidic red soil with cattle manure compost which neutralized the acidic pH of the red soil and gave a pH of 6.40. Type F aggregates gave a pH of 7.58 due to the alkaline sewage sludge (pH=7.72) in the aggregates.

It is evident that the pH of the aggregates depends on the materials which were used to form the aggregates. Aggregates showed high electrical conductivity (EC) except type B due to high essential and non- essential elements in the aggregates. Type B aggregates produced from red soil and paper waste, which did not contain much element concentrations, gave the lowest EC. But coal fly ash had high concentrations of different elements, which subsequently raised the EC of the CFA based aggregates. The EC and metal content of soil increases with increasing amount of CFA application (Sikka & Kansal, 1994). Aggregates developed from sewage sludge (SS) also showed high EC due to the presence of high concentrations of elements in the sewage sludge (SS). Gil et al., (2008) reported that SS was characterized by higher EC. The High EC in SS may be due to presence of high concentrations of different types of elements

Table 2. bulk density, particle density, hydraulic conductivity, water holding capacity and aggregates strength of the synthetic aggregates.

Aggregate type	Bulk density (gcm^{-3})	Particle density (gcm^{-3})	Hydraulic conductivity(cms^{-1})	Water holding capacity ($kgkg^{-1}$)	Aggregate strength ($kgcm^{-2}$)
A	0.56	2.48	$2.8*10^{-2}$	0.62	3.91
B	0.87	2.44	$1.87*10^{-2}$	0.63	2.58
C	0.80	2.20	$3.74*10^{-2}$	0.68	3.06
D	0.64	2.48	$2.80*10^{-2}$	0.67	3.76
E	0.64	2.31	$1.87*10^{-2}$	0.59	3.88
F	0.54	2.08	$2.24*10^{-2}$	0.61	4.01
G	0.52	2.20	$2.80*10^{-2}$	0.60	3.92

A: coal fly ash paper waste aggregates with starch binder,
B: acid soil aggregates with starch binder,
C: acid soil coal fly ash aggregates with starch binder,
D: acid soil compost aggregates with inorganic binder,
E: coal fly ash aggregates with inorganic binder,
F: sewage sludge aggregates with inorganic binder,
G: synthetic pellet aggregates (diameter is 10 mm).

Table 3. Chemical properties of synthetic aggregates

	A	B	C	D	E	F	G
pH	9.82	4.57	9.71	6.40	10.72	7.58	9.28
EC(mSm-1)	96.16	6.36	57.50	48.76	90.40	156.26	80.76
C (g kg-1)	120.82	85.40	66.21	101.12	55.22	291.80	113.61
N (g kg-1)	0.71	0.40	0.40	1.06	0.42	29.10	0.62
P (g kg-1)	0.11	0.08	0.05	0.46	0.06	14.65	0.20
Na (g kg-1)	0.87	0.24	0.44	0.71	0.78	0.54	0.88
K (g kg-1)	1.51	0.18	0.76	2.34	1.56	0.62	1.61
Mg (g kg-1)	0.72	0.38	0.47	0.87	0.73	4.12	0.91
Ca (g kg-1)	3.34	1.10	2.31	2.12	37.25	65.64	3.18
B (mg kg-1)	16.86	0.12	10.33	0.42	19.34	0.51	12.17

Mn (mg kg-1)	15.82	20.28	18.73	24.14	19.20	109.66	14.88
Cu (mg kg-1)	18.47	13.21	16.22	22.66	18.50	188.02	19.12
Zn (mg kg-1)	34.63	21.35	28.93	32.12	34.60	485.07	31.98
Cr (mg kg-1)	7.62	1.21	5.45	0.98	7.60	34.42	7.02
Cd (mg kg-1)	ND	ND	ND	ND	ND	0.40	ND
Se (mg kg-1)	ND	ND	ND	ND	ND	ND	ND
Pb (mg kg-1)	7.56	3.01	5.88	3.66	7.60	26.33	8.02
As (mg kg-1)	ND	ND	ND	ND	ND	ND	ND

A: coal fly ash paper waste aggregates with starch binder,

B: acid soil aggregates with starch binder,

C: acid soil coal fly ash aggregates with starch binder,

D: acid soil compost aggregates with inorganic binder,

E: coal fly ash aggregates with inorganic binder,

F: sewage sludge aggregates with inorganic binder,

G: synthetic pellet aggregates (diameter is 10 mm).

EC: electrical conductivity, ND: not detected.

Carbon (C) content of aggregates also varied in a greater range and depends on the material type in the aggregate. The N content of the aggregate types of A, B, C, E and G showed low N amount. But D and F gave high N content. Aggregate D contains cattle manure compost while F contains sewage sludge. Moreover, aggregates enriched with N, P and K can be developed by adding respective N, P and K chemical fertilizer as a material to produce aggregates. All of the aggregates gave low phosphorous (P) content except the type E since it is composed with high P containing SS. Aggregates having CFA, compost and SS (A, C, D, E and F) gave high concentrations of Na, K, Mg and Ca in the aggregates. Chemically, 90–99% of CFA is comprised of silicon (Si), aluminum (Al), Ca, Mg, Na and K (Adriano et al., 1980). Aggregates developed from coal fly ash gave high boron (B) content compared to other aggregates. This is due to high B content of the CFA. CFA contains significant levels of B (Lee et al., 2008). Heavy metal concentrations of the different aggregates are given in Table 3. Selenium (Se) and Arsenic (As) were not detected in any aggregates, and Cadmium (Cd) was detected only in F. The copper (Cu), chromium (Cr), manganese (Mn), zinc (Zn) and lead (Pb) concentrations were generally well below the maximum pollutant concentrations of individual metals for land application suggested by the US Environmental Protection Agency (USEPA, 1993). The maximum pollutant concentrations of individual heavy metal content for land application of sewage sludge given by the US Environmental Protection Agency are (all in mg/kg); As 41, Cr 1200, Cu 1500, Zn 2800, Pb 300, Cd 39 and Se 36, respectively (USEPA, 1993). Furthermore, average concentrations of heavy metals reported in uncontaminated soils are (all in mgkg-1); 6 As, 70 Cr, 30 Cu, 90 Zn, 35 Pb and 0.35 Cd, respectively (Adriano, 2001). Though the concentrations of heavy metals were below the uncontaminated soil values and not alarming, there should be routine inspections to ensure that heavy metal concentrations remain within safe limits.

IV CONCLUSIONS

Synthetic aggregates can be developed from wide range of waste types and can be utilized in different ways. Different types of aggregates can be developed according to the required utilization method. Moreover, the sizes of the aggregates can be decided with respect to the requirement. Aggregates can be designed according to the availability of the waste materials in the area or the region. Developed aggregates can be utilized as a soil amendment to problematic soils to enhance their challenged physical and chemical characteristics. Coal fly ash aggregates as a soil amendment to acidic soil improve the soil poor properties and subsequently improved the crop growth parameters. In addition, synthetic aggregates effectively can be used as a potting media component to substitute conventional media.

Aggregates addition to the soil as an amendment improved the microspores due to microbial activities with the assistance of the fibrous materials in the aggregates, which lead to enhance the soil water holding capacity, porosity and permeability. Synthetic aggregate production from different wastes can be recommended as a potential way of waste management. Waste materials contain considerable contents of trace elements that can be detrimental to human and therefore routine investigations should be undertaken to get confirmed the trace element concentrations are below the permissible levels in the waste materials. Future studies should be undertaken to study the potential utilization of these aggregates for different range of crop varieties.

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