Properties of Municipal Solid Waste Ash-Cement Composite

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Incineration, which is a viable alternative for processing of municipal solid waste (MSW), reduces the volume of the waste destined for landfills. Results from a recent study on physical, chemical, and engineering properties of MSW mixed with top and bottom ash are presented. These results can be used to assess the possibility of using MSW incinerator ash for certain construction purposes and soil stabilization applications. Some of the test results are compared with those of fly ash (coal burning) cement composites for assessment of their potential use. The MSW ash-cement composite was investigated for strength characteristics at various stages of maturity. The independent variables considered were MSW ash content, sand content, and water cementitious ratio. The ash-cement ratio was varied from 10 to 20. Water-cementitious ratios of 0.45 and 0.6 were investigated. The response variables in this study included compressive strength and splitting tensile strength. Strength tests were conducted at 3, 7, and 28 days of maturity. Tests were also performed to determine the maximum density and optimum moisture content of the MSW ash as needed for field applications.

In the past few years, a number of studies have been done on municipal solid waste (MSW) incinerator ash—generally to investigate toxic waste properties, resource recovery equipment and techniques, and relative costs for hazardous waste incineration. Little, if any, research has been carried out on the construction properties of MSW ash, mainly because of the potential toxicity of the fly ash portions. Although the resulting top (fly) and bottom mixture of MSW ash is usually nontoxic, the bottom ash still contains deleterious materials that might reduce strengths over time. For these reasons, most of the research done on construction applications of ashes has focused on nontoxic coal fly ash, which currently is used in a wide variety of concrete mixes as a pozzolan.

The bulk of the research on MSW solid waste in the 1970s and the early 1980s pursued the feasibility of converting the solid waste materials to power and energy sources or supplementary fuels. Additional studies during this period investigated various resource recovery techniques and processing equipment (*1*).

In the mid-1970s, it became evident that hazardous waste incineration was the most practical method of hazardous waste disposal. The volume reduction achieved made incineration more attractive than landfill disposal, ocean dumping, and deep-well injections. By the early 1980s, the incineration of MSW was more prevalent, and concern was rising about the toxic condition of the incinerated MSW. The incoming amount of MSW was increasing rapidly, and various studies were done on hazardous waste incineration costs (*2*).

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Recently, the projected quantities of MSW ash have been substantial enough to warrant further studies to determine disposal methods. In New Jersey, for example, landfill area is diminishing; and disposal of MSW in these landfills must be monitored because of the effects of heavy metals' leaching into the subsurface groundwater.

Research for recovery of lead, cadmium, and chromium has recently been done at Rutgers University (*3*), using electrochemical plating techniques. Kinetic studies were done on ashes from two different incinerators to determine the time when the ash extraction reaction could be stopped to remove peak quantities of these heavy metals.

Municipalities have also required analysis of MSW incinerator ash to determine appropriate landfill design. The city of Sheboygan, Wisconsin, prompted this type of study in 1989 (*4*). A characterization was done on the MSW ash produced from that city's fluidized-bed furnace by obtaining numerous samples from the bottom ash and the incinerator's sludge lagoon on various dates. Individual and composite samples were taken of the bottom, sludge, and fly ashes; and comparisons were made with the bottom and fly ashes produced the same day. Although the resulting chemical testing done indicated a possible groundwater impact requiring a designed landfill, physical tests were also performed on the bottom ash and extremely low specific gravities and high organic contents were noted.

Further work has been done at Rutgers University (*5*) on the chemical and some physical properties of MSW ash obtained from various types of incinerators in Massachusetts, New Jersey, and Canada. The Canadian bottom ash had over half of the total specimen over 2.01 mm in size. This portion of the sample contained such materials as broken glass, slag, metal fragments, and pebbles as the principal components. An analysis of the metal distribution of these ashes showed that the largest concentrations of lead, cadmium, and chromium appeared on the smallest fly ash particles. Other parameters determined from this analysis were particle surface areas, morphology, and densities.

Although MSW incineration is probably the most feasible method of disposal, the process has drawbacks. Certain materials are not easily incinerable and will not sustain combustion. Organic materials, especially those containing chlorine, yield products of incomplete combustion (PICs) that can evidence toxicity (*6*). Insufficient turbulence during combustion can result in the development of inclusions, which results in various materials' escaping incineration. Certain substances also require that the incinerator be supplied with supplementary fuels to maintain combustion temperatures. These cir-

cumstances have generated a number of articles that describe the combustion and incineration process (*7*).

As previously mentioned, most of the research done on incinerator ashes for use in the construction industry has incorporated coal fly ash into concrete and grout mixes. Prior work has been accomplished, however, on the use of coal fly ash as structural fill (*8*). This investigation determined the engineering properties of New Jersey fly ash and found it to function satisfactorily as a structural fill with a design pressure of 5 tons/ft^2.

Further research for incinerator ashes for construction purposes has resulted in the use of a wastewater sludge ash and clay mixture to produce construction bricks. (Coal fly ash has also been used for this purpose.) The maximum sludge percentage used to produce the bricks was 40 percent (*9*).

Sludge ash was also experimented with in Singapore for use as an aggregate in lightweight concrete (*9*). The sludge was incinerated at temperatures exceeding 1,000°C and the ash was then crushed and graded, which resulted in a porous (66 percent) aggregate with a specific gravity of 2.90 and a pH value of 9.0. When used in a lightweight concrete mix, the 28-day strengths were comparable to those of other aggregates.

So far, there has been little research accomplished on MSW ash for construction use. The studies that have been done are generally chemical analyses or characteristic determinations for specific landfill designs. The concept of compressive and tensile strength testing of an MSW ash-cement composite is a new approach to a possible solution for incinerator ash disposal.

OBJECTIVE

Physical properties and strength characteristics of MSW ash cement-sand composites are described. The test results presented are compared to those of coal fly ash cement composites for the purpose of assessing the potential use of MSW incinerator ash in applications such as soil stabilization, structural and nonstructural fills, etc.

EXPERIMENTAL PROGRAM

Materials Tested

The MSW incinerator ash used in this study was obtained from a mass-burn MSW incinerator in New Jersey. The schematic diagram of this type of incinerator is shown in Figure 1. The furnace or the combustion chamber of these incinerators generally burns within a temperature range of 600°C to 1,000°C (1,100°F to 1,800°F), while maintaining turbulence to ensure maximum incineration. The ash used in this study was a combination of top and bottom ash after the top, or fly ash, had been previously sprayed with lime. This mixture is generally the end product of most incinerators and carries a high pH value as a result. The chemical composition of the ash is presented in Table 1. The principal metal constituents are aluminum and zinc.

In addition to MSW ash, ASTM Type 1 portland cement and concrete sand were used for preparation of the composite mixes. The particle size distribution of the concrete sand is shown in Figure 2.

Mixture Proportions

A summary of the mix designations and proportions is presented in Table 2. The first 10 mixes use a constant portion of cement while varying the ash, sand, and water-cementitious ratio. This ratio is the fraction of the water content to cement, plus the ash content, and was kept at 0.6 for Mixes 1 through

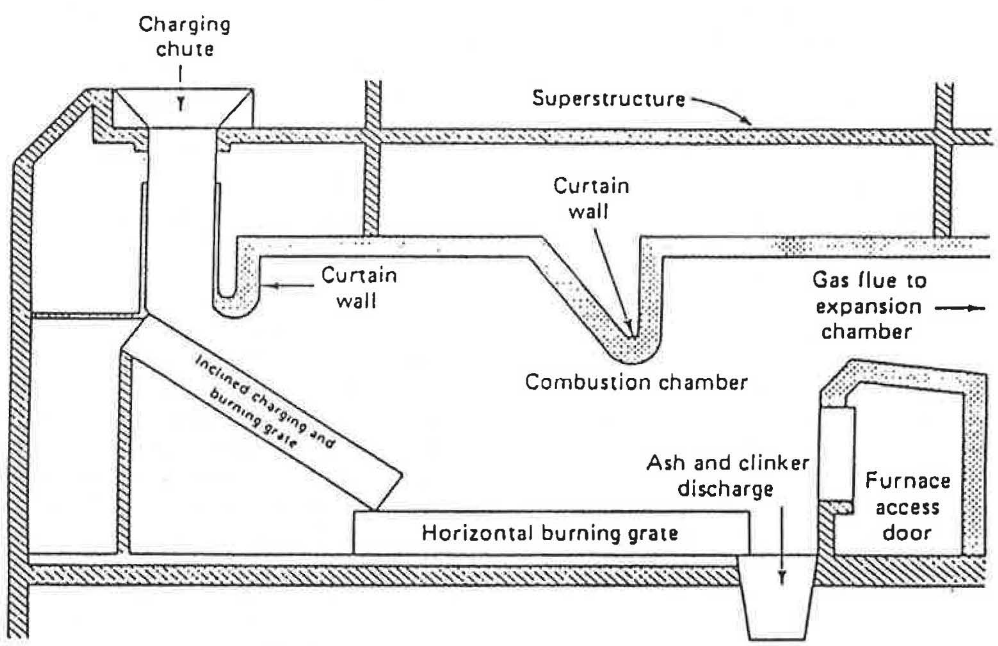

FIGURE 1 Typical municipal incinerator (*1*).

TABLE 1 CHEMICAL COMPOSITION OF NEW JERSEY MSW INCINERATOR ASH

Chemical Composition	mg/kg	Blank[1] (control)	MDL[2] mg/kg
Aluminum	10354.00	N.D[3]	0.1
Antimony	6.9	N.D	0.1
Arsenic	13.73	N.D	0.1
Barium	61.26	N.D	0.1
Cadmium	39.30	N.D	0.1
Chromium	23.78	N.D	0.1
Copper	315.00	N.D	0.1
Lead	701.4	N.D	0.1
Mercury	0.81	N.D	0.02
Molybdenum	14.10	N.D	0.1
Nickel	21.76	N.D	0.1
Selenium	1.2	N.D	0.1
Silver	0.68	N.D	0.1
Zinc	2238.00	N.D	0.1
Total Residue	735000.0	N.D	N/A
Volatile Residue on Total Residue	6500	N/A	N/A

1 Water blank, indicating the initial element amount in the solution prior to testing the ash.

2 Minimum Detection Limit

3 No Detection

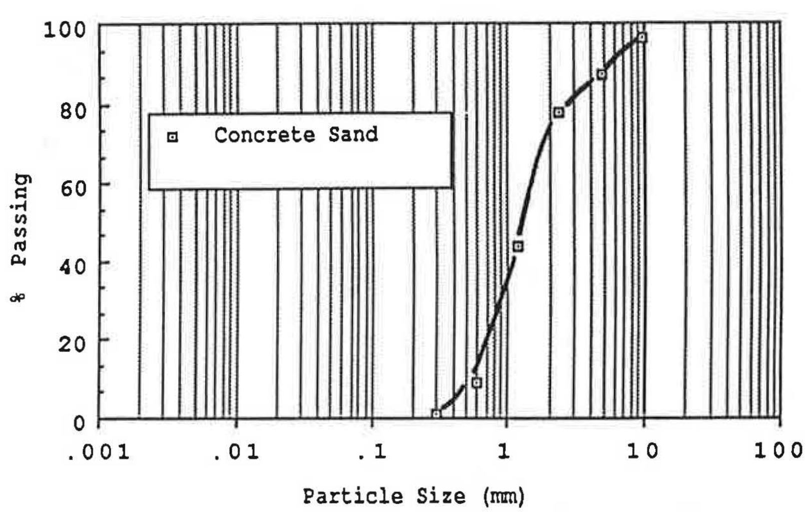

FIGURE 2 Grain size distribution of concrete sand.

TABLE 2 MIX DESIGNATION AND PROPORTIONS

MIX DESIGNATION	CEMENT:MSW-ASH:SAND	WATER/CEMENTITIOUS
1	1-6-10	0.6
2	1-8-10	0.6
3	1-10-10	0.6
4	1-6-15	0.6
5	1-8-15	0.6
6	1-10-15	0.6
7	1-6-20	0.6
8	1-8-20	0.6
9	1-10-20	0.6
10	1-6-10	0.45
11	1-1-2	0.6
12	4-1-5	0.6

9. Mix 10 was prepared using a water-cementitious ratio of 0.45. These mix proportions were specially chosen for comparison of the test results with data obtained from a study on the properties of high volume coal fly ash cement composite (flowable mixtures).

Mixes 11 and 12 (low-volume ash content) were prepared with lower ash and higher cement contents to investigate the possibilities of using the ash for various grouts (such as driller's grout) and soil stabilization applications.

TEST RESULTS AND DISCUSSION

Index Properties of MSW Incinerator Ash

Numerous physical tests were conducted on the ash to determine its index properties. A summary of the results for particle size distribution, Atterberg limits, and maximum dry density–optimum moisture content tests is given in Table 3. The particle size distribution for MSW ash and that of a coal

TABLE 3 COMPARISON OF PHYSICAL PROPERTIES OF NEW JERSEY MSW INCINERATOR ASH AND COAL FLY ASH

Properties	NJ MSW Ash	NJ Coal Fly Ash
Specific Gravity	2.39	2.54
Max. Dry Density (pcf)	104.6	103.2
Opt. Moist. Content	13.2	13.6
Uniformity Coeff.	> 10	2.5
Liquid Limit	35.10	16.8
Plastic Limit	34	-
Average pH Value	12.07	-

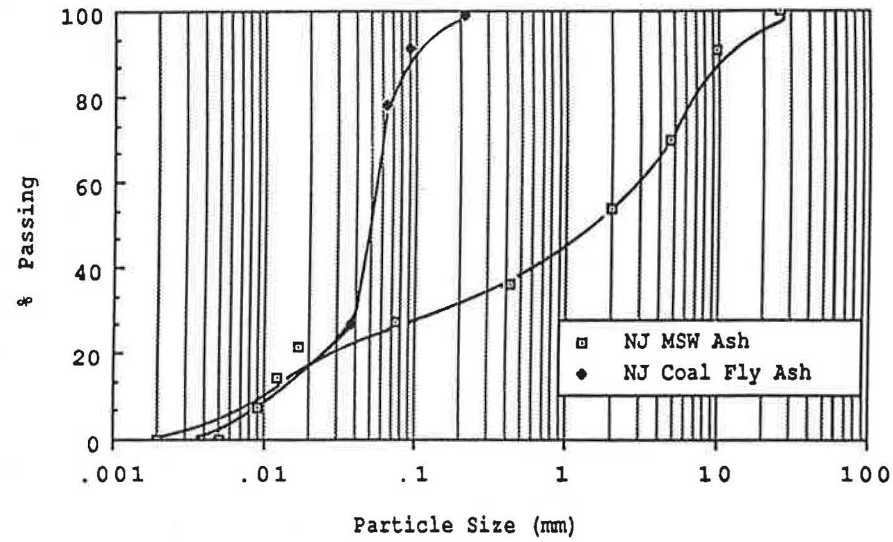

FIGURE 3 Grain size distribution, New Jersey MSW ash and New Jersey coal fly ash.

fly ash for comparison are presented in Figure 3. A significant difference is observed between the gradation of these two types of ash. Because of its heterogeneity, MSW ash is far less uniform in size than coal fly ash.

The maximum dry density and optimum moisture content were determined using ASTM-1557-C, a modified Proctor compaction test. The results of compaction tests for the New Jersey MSW ash as well as those for coal fly ash from New Jersey and other regions are shown in Figure 4.

Compressive and Tensile Strength of MSW Incinerator Ash Cement-Sand Composite

The cured specimens of MSW ash cement-sand composites were tested for determination of their compressive (ASTM D1633) and tensile (ASTM D3967-86) strength. A summary of the compressive and tensile strength test results (28-day) for high-volume MSW ash cement-sand composites, and those for coal fly ash cement-sand composites (for comparison), is presented in Table 4. Compressive and tensile strengths of MSW ash composites tend to decrease with increasing ash and sand content (all other factors constant). This trend was opposite to that observed for coal fly ash composites. A possible explanation is that the coal fly ash acts as a pozzolan in the cement-sand composites. Thus, increasing its content significantly enhances the composite's strength.

Although the MSW ash strength test results (Table 4) compare well with those of coal fly ash composites, particularly in lower ash content range, the high-volume mix proportions are not recommended for practical use, mainly because of deterioration of the test samples after 28-day tests. Deterioration was caused by excessive cracking caused by expansion and leaching of gel from within the sample. This may be a result of calcium hydroxide (lime) presence in the ash and its effect on the composite durability (*10*). As expected, deterioration was more evident in specimens with high ash content. It was therefore decided to (a) reduce the water-cementitious

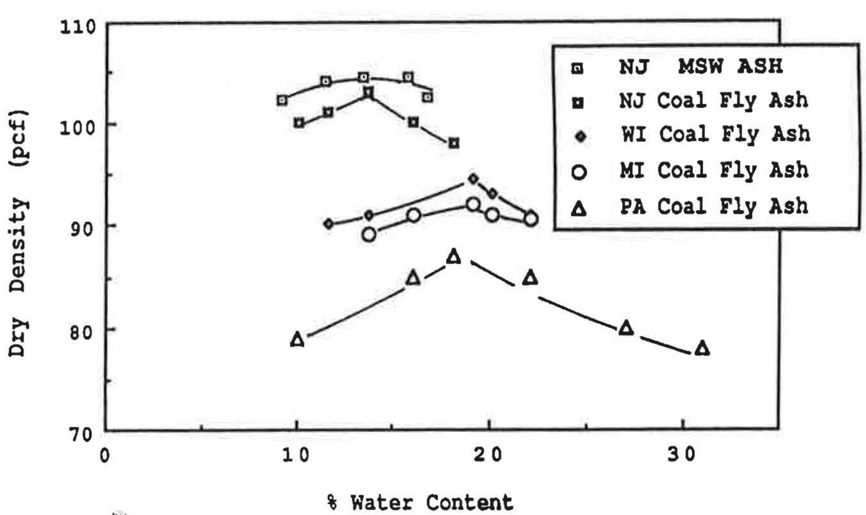

FIGURE 4 Density-moisture relationship.

TABLE 4 COMPRESSIVE AND TENSILE STRENGTH OF ASH CEMENT-SAND COMPOSITES WITH HIGH-VOLUME ASH

Mix Proportions by Parts (Cement-Ash-Sand)	NJ MSW Ash		NJ Coal Fly Ash	
	Compressive Strength (psi)	Tensile Strength (psi)	Compressive Strength (psi)	Tensile Strength (psi)
1-6-10	166	28	198	18
1-8-10	167	28	159	17
1-10-10	106	22	-	-
1-6-15	127	25	255	27
1-8-15	125	24	250	21
1-10-15	110	22	276	18
1-6-20	139	24	212	22
1-8-20	117	22	301	31
1-10-20	93	22	636	30

ratio of the mix or (b) increase the cement content of the mixtures, or both, to determine a suitable mix proportion that gives a stable mix.

Although reduction of the water-cementitious ratio significantly enhanced the strength of high-volume ash composites (Table 5), sample deterioration was still a problem. This problem was greatly reduced by increasing the cement content of the mix. Two mix proportions (one part cement, one part ash, two parts sand, 1-1-2; and the other 4-1-5) were tested for observing the effect of increase in cement content. The results of compressive and tensile strength tests (strength versus curing time) for these mixes are shown in Figure 5. As for mix stability, no long-term deterioration has been observed to date (in 8 months).

The stiffness of the composite was reduced by increase in the ash content. Comparison of the stress-strain relationships for the various mix proportions tested is shown in Figures 6–8.

CONCLUSIONS

1. MSW incinerator ash used in this study is a relatively light and nonuniform (high-C_u) material with a specific gravity slightly lower than that of New Jersey coal fly ash.
2. MSW incinerator ash used in this study has somewhat lower optimum moisture content and higher maximum dry density than those of New Jersey coal fly ash.
3. Compressive and tensile strengths of high-volume MSW ash (>40 percent ash by weight) low cement (<6 percent by weight)-sand composites are in general lower than those of coal fly ash mixes and decrease significantly with increasing ash or sand content. High-volume MSW ash mixes are not recommended for practical use because of the deterioration of the composite.
4. Compressive and tensile strengths of low-volume MSW ash (<40 percent ash), relatively high-volume (25 percent by

TABLE 5 EFFECT OF WATER-CEMENT RATIO ON THE STRENGTH OF MSW INCINERATOR CEMENT-SAND COMPOSITE

Water-Cement Ratio	Compressive Strength (psi)	Tensile Strength (psi)
0.6	166	28
0.45	276	51.3

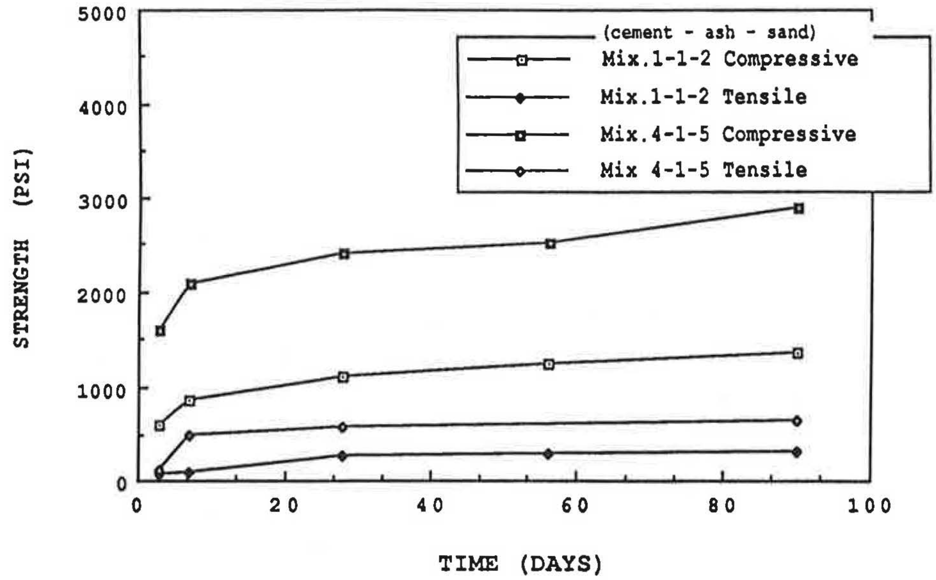

FIGURE 5 Strength of low-volume MSW ash, high-cement-content–sand composites.

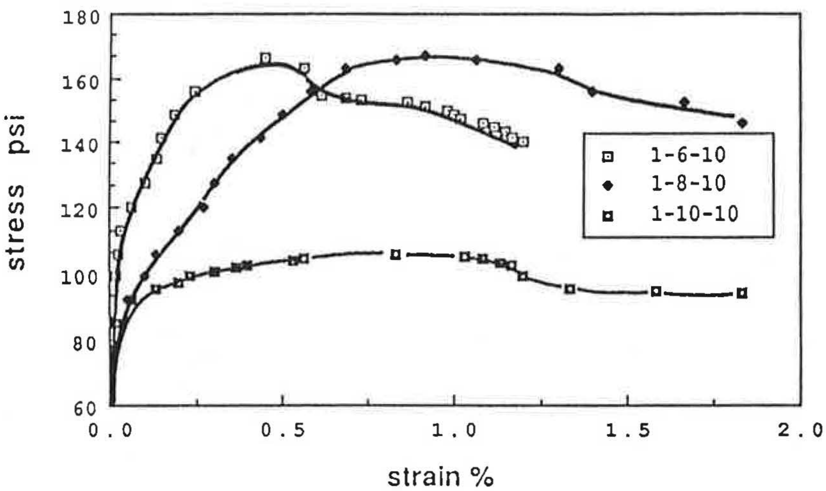

FIGURE 6 Variation in the stress-strain relationship of the composites as a function of MSW ash content (1 part cement and 10 parts sand).

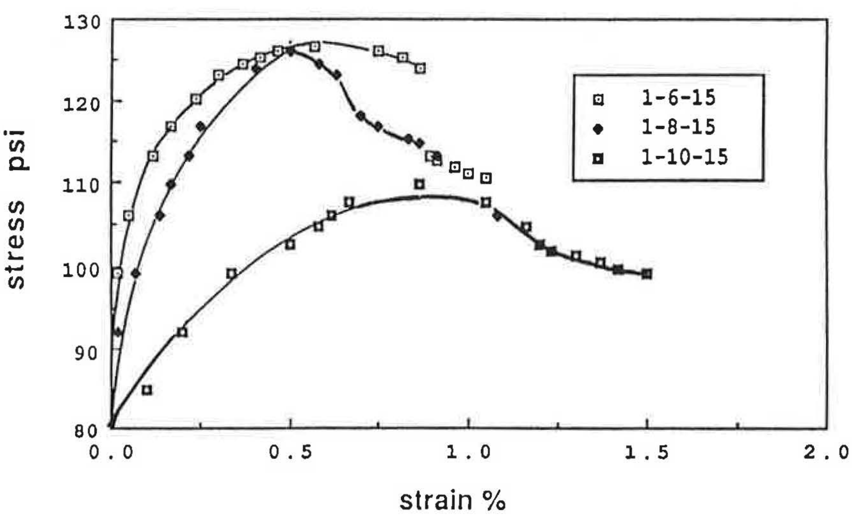

FIGURE 7 Variation in the stress-strain relationship of the composites as a function of MSW ash content (1 part cement and 15 parts sand).

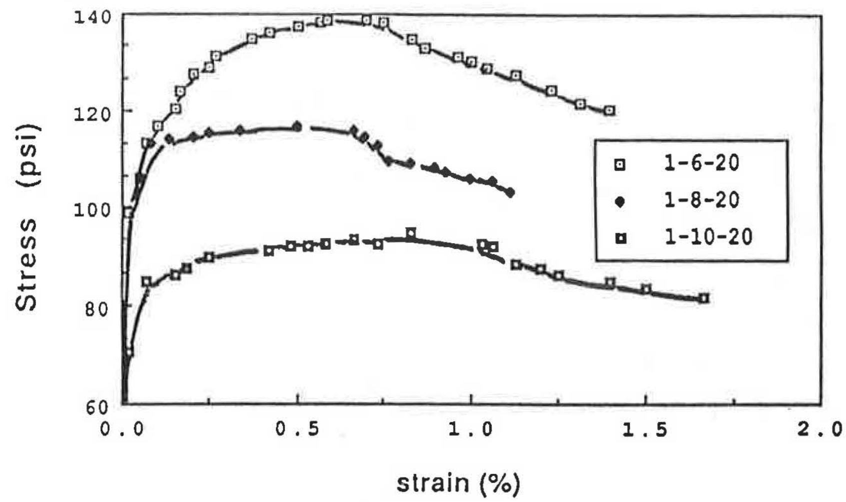

FIGURE 8 Variation in the stress-strain relationship of the composites as a function of MSW ash content (1 part cement and 20 parts sand).

weight) cement-sand composites compare well with those of typical soil-cement mixtures and are in general higher than those of strongly cemented soils. The mix proportion 1-1-2, which corresponds to 25 percent cement, 25 percent ash, and 50 percent sand, is a stable mix with no deterioration.

5. Use of MSW incinerator ash for construction will require a proper specification for mix proportion. To design optimum mix proportions for a particular application, two factors should be considered: first, mix proportions, particularly the cement content, should be such that no deterioration shall take place; and second, mix proportions should meet the requirements for compressive and tensile strength.

6. Stiffness of the composite decreases with increase in ash content irrespective of the mixture proportions.

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