Uses of Waste Foundry Sands in Civil Engineering

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Molds and cores for metal castings are normally sands with chemical or clay binders and other additives. After the casting is complete, the sand is disaggregated, and it is judged whether it is suitable for reuse. However, after several uses, the sand is no longer suitable and is designated as a waste foundry sand (WFS). Such waste has been disposed in landfills, public and private. Although some WFSs may contain excessive amounts of harmful heavy metals, those discarded after ferrous castings contain only iron, and this concentration is controlled by magnetic extraction from the waste. At this point, only WFSs from ferrous castings are thought to be environmentally acceptable. Through laboratory study of the mechanical and physical properties of WFSs from the greensand, shell, and chemically bonded processes for ferrous castings, a number of civil engineering uses have been identified: embankment fill, subgrade, flowable fill, and fine aggregate replacement in asphaltic concrete. The index properties of the WFSs and the appropriate test parameters for its various acceptable uses are described. The next step is to build demonstration and implementation projects to prove the practicality of the use and to provide long-term evidence of the absence of significant environmental effects.

Recent legislation in Indiana has intensified study of the use of industrial and domestic waste products in civil engineering, particularly in highways. The wastes given primary attention are scrap tires, coal combustion byproducts, destructed pavement materials and building demolition products, and spent foundry sands. This paper summarizes properties and potential uses of spent (waste) foundry sand.

The desire of Indiana foundries to reduce disposal costs led to the sponsorship of a 2-year study of waste foundry sand (WFS) in the School of Civil Engineering at Purdue University. The authors of this paper wrote the research report resulting from the study (*1*). The potential uses given greatest attention were WFS as embankment and subgrade material, fine aggregate in controlled low strength material (CLSM), (also called flowable fill), and fine aggregate in asphaltic concrete (*3*).

BACKGROUND

Sands have long been used for metal casting. They are chosen for several important reasons (*3*): they are readily available, inexpensive, highly refractory, and readily bonded by clays or other inorganic and organic material.

There are three types of molding processes: greensand, chemically bonded, and shell molded. In Indiana, the most commonly used process is greensand molding. The greensand mixture contains clay, combustible additives like seacoal, and water. The predominant metal cast is gray iron. After a number of uses, the molding sands lose the desired qualities and are discarded. The foundry may operate a monofill for these wastes or may transport them to a municipal solid waste landfill. In either case, the disposal costs are significant, and the foundries are anxious to reduce them.

The grain size distribution of WFS is uniform, with most sizes within a narrow range between the No. 50 and No. 100 sieves. This means that they are finer than the materials generally specified for fine aggregates.

The greensands, with their additives of clay, demonstrate cohesive type behavior and the chemically bonded and shell-molded sands show cohesionless response. Consequently, greensand compaction curves show a definite dependence on compaction moisture content. The compacted unit weights of others is almost independent of that moisture content.

The results of standard heavy metal leaching tests, like the EPTOX and the Toxicity Characteristics Leaching Procedure (TCLP), depend on the metals cast because the WFSs are commonly contaminated by these metals. Much of the metal cast in Indiana is ferrous, and although limits are seldom exceeded, iron is occasionally present in concentrations above those stated. Chemically bonded and shell-molded WFSs contain chemicals and organics that may require special environmental assessment before routine use.

CHARACTERIZATION OF WFS

Experimental work on WFSs in the School of Civil Engineering, Purdue University, involved seven samples from greensand processes, two from chemically bonded processes, and one from a shell molding process. All of these involved ferrous castings.

Compactability of these sands is of considerable interest for embankment and subgrade applications. The WFSs from chemically bonded and shell-molded processes are cohesionless and respond best to vibratory compaction. The waste greensands are compacted best by impact (Proctor) type processes. Figure 1 shows the moisture-density and moisture–California Bearing Ratio (CBR) relations for the raw sand (R1) that comprises the casting sands. As is common for such materials, density varies little with compaction water content, although it is somewhat higher for a flushed condition. The soaked CBR is also maximized at this higher water content.

The WFSs from greensand casting for sample G1 are illustrated in Figure 2. Unit weight strongly depends on moisture content, and soaked CBR is maximized at about the optimum moisture content. Note that the swell upon soaking is small and that the soaked CBR values compare favorably with compacted natural soils.

Shear strength parameters were determined by performing direct shear tests on dry samples at various densities. The data are sum-

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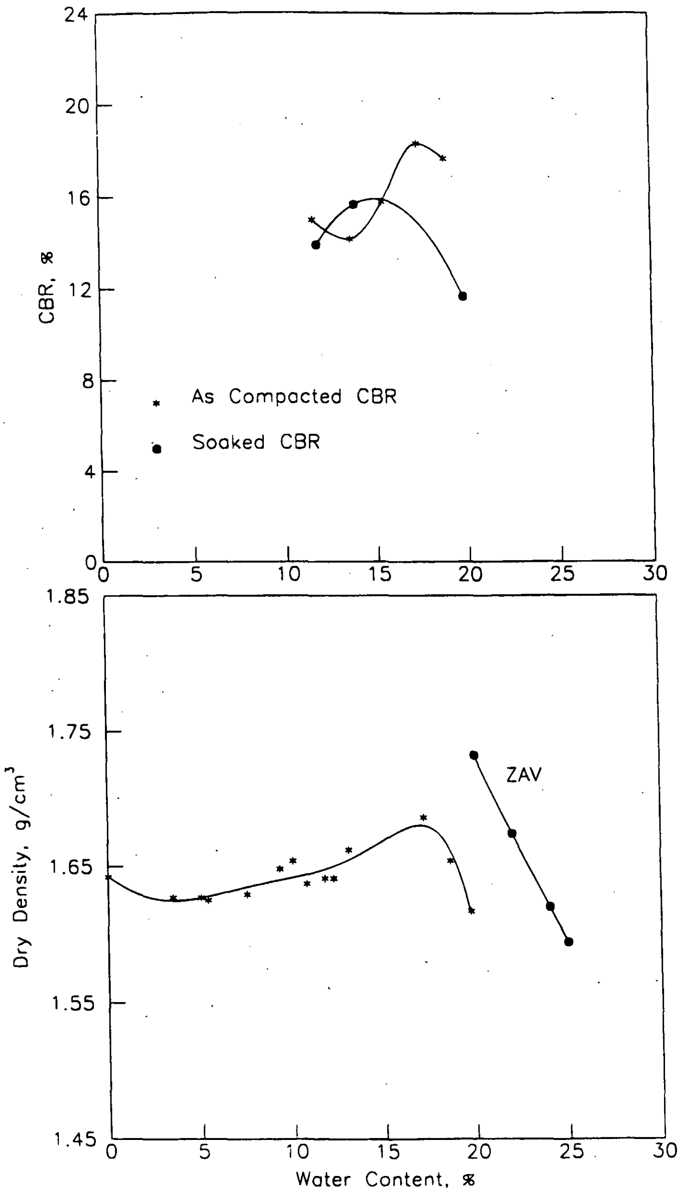

FIGURE 1 Moisture density–CBR relationship of R1.

marized in Table 1, along with typical values for natural sands reported in works by Terzaghi and Peck (*4*) and Peck et al. (*5*). The symbol G represents greensand, C chemically bonded, S shell molded, and R raw sand. The ϕ values represent peak strengths for dense samples and ultimate strengths for loose samples: (D_r) is relative density.

To determine the suitability of WFSs for subgrade, resilient modulus (M_r) tests were conducted. These are reported in detail elsewhere (*1*). It was found that the laboratory-compacted greensands had values comparable with or higher than soils typically used for subgrades in Indiana (*6*).

Use of WFS as a fine aggregate supplement in asphalt concrete has been reported elsewhere (*2*). Based on simple testing, it was determined that as much as 15 percent of the conventional sand content of asphalt concrete could be replaced by WFS.

A promising new engineering material is a mixture called controlled low strength materials (CLSM). These mixtures of cementitious materials, fly ash, sand, and water can flow into hard-to-access locations and, within a few hours, can set up to produce strengths comparable to compacted soils. Because it is often desirable to be able to remove or replace these materials (e.g., in utility cuts), their strengths should be relatively low.

The CLSM mix will then have parameters of flow, rate of strength gain, and final strength, which vary with mix constituents and percentages. In this study, the constituents were Type 1 cement, Class F fly ash, water, and WFSs. The use of WFS in CLSM mixes is relatively new, and therefore comparisons with mixes using conventional sand appeared appropriate. Table 2 shows these comparisons with values reported in works by Amon (*7*) and Nantung (*8*).

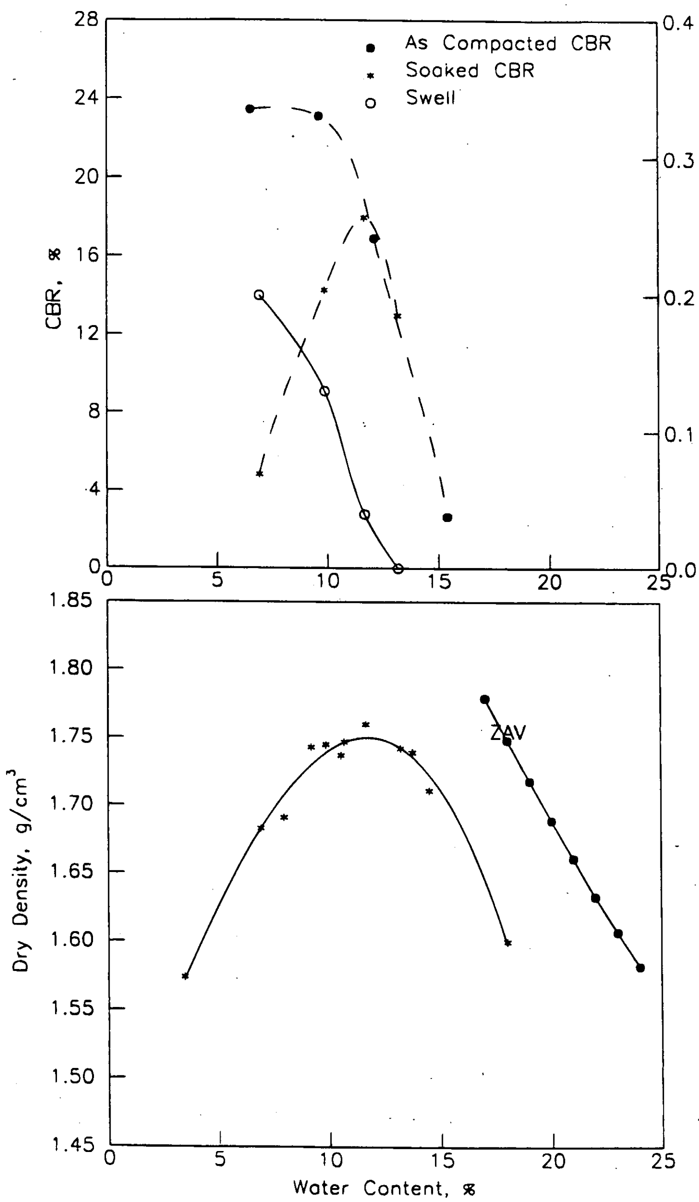

FIGURE 2 Moisture density–CBR relationship of G1.

The WFSs are assumed to be free of charge and, within a short distance of source, produce CLSMs that are economical. Mix 3 is preferred within this set, but the use of WFS raises questions of porosity and permeability, as well as setting rate. These issues are being addressed in current research (*9*).

ENVIRONMENTAL CONCERNS

All of the WFSs tested in this study were from ferrous castings. Therefore, one would expect that the only elements present in the waste sand would be the additives and a small amount of iron. Because the principal additives in greensand are clay and seacoal, these materials would be expected to pass all reasonable environmental tests. The greensands pass the various leaching tests. Bioassay testing (a waste water technique) is also planned for these materials, but they are expected to pass.

There is no specific environmental testing for the chemicals and other inorganic or organic substances used in chemically bonded and shell-molded WFSs; therefore, more potential risk is involved. One also expects that greensand casting of other metals (e.g., aluminum), will yield a nonhazardous waste. Conversely, other castings, like brass, would be highly suspect.

Two use scenarios appear well-suited for demonstrating the use of greensand from ferrous casting:

- Well-drained situations like subgrades and embankments—leachate in such situations is small and is further minimized by clay-encasing layers on the sides. Some sort of growing layer would need to be placed at the sides, even without the encasement requirement.

TABLE 1 Results of Direct Shear Tests

Sample #	D_r	Loose c (kPa)	Loose ø (deg)	D_r	Dense c (kPa)	Dense ø (deg)
G1	29	4.13	32.4	90	9.92	36.6
G3	34	5.17	34.2	98	12.54	40.9
C2	22	0.41	30.4	94	7.17	34.9
S1	31	0.41	30.8	94	4.75	36.5
R1	32	0.21	30.4	88	1.17	33.8
Uniform medium sand[a]	Moderately dense		32-34	Very dense		35-38
Sand[b]	Loose		29-30	Dense		36-41

1.0 psi = 6.89 kPa
[a] *(4)*
[b] *(5)*

TABLE 2 Spread, Density, and Compressive Strength for Different Mixes

Mix No.	1	2	3	4	5	1A[a]	ES-1[b]
Cement (kg/m³)	78	74	59	33	45	47	37
Fly ash (kg/m³)	259	246	94	109	82	249	190
Water (kg/m³)	414	442	439	438	454	333	293
WFS or Sand (kg/m³)	1140	1080	1265	1262	1261	1503	1645
Spread (mm)	190.5	228.6	208.3	205.7	208.3	-[c]	127-152
Density (kg/m³)	1890	1842	1858	1842	1842	-[c]	2147
Compressive strength (kPa)							
3 - Day	296	282	248	59	165	-[c]	138
7 - Day	462	372	303	62	214	310	207
28 - Day	710	551	482	55	379	827	551

1.0 pcy = 0.593 kg/m³, 1.0 in = 25.4 mm, 1.0 pcf = 16.02 kg/m³ , 1.0 psi = 6.89 kPa
[a] *(7)*
[b] *(8)*
[c] Data not available

• Stabilized mixtures like CLSMs—although these are wet and poorly drained situations (trenches, around pipes and tanks), the WFSs are reasonably well fixed in the mix. Porosity and permeability of the CLSM need to be given greater attention to increase confidence in this usage.

CONCLUSIONS

• The WFSs passed all environmental tests and demonstrated good physical and mechanical properties.

• Greensands from ferrous castings appear likely to pose very low environmental risk.

• Shell-molded and chemically bonded WFSs pass all existing leaching tests but warrant further study with respect to chemical and organic additives before use.

• Uses most favored for demonstration projects are (a) well-drained embankments and subgrades and (b) a fine aggregate in CLSMs.

• The WFSs are likely to be economically competitive when the project is close to a disposal source.

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