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undry Sand Facts for Civil Enginee

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2020

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Foundry Sand Facts for Civil Engineers

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16. Abstract

Metal foundries use large amounts of sand as part of the metal casting process. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed "foundry sand." Foundry sand production is nearly 6 to 10 million tons annually. Like many waste products, foundry sand has beneficial applications to other industries.

The purpose of this document is to provide technical information about the potential civil engineering applications of foundry sand. This will provide a means of advancing the uses of foundry sand that are technically sound, commercially competitive and environmentally safe.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 10001 shall be shown in m^3				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE		
^{0}F	Fahrenheit temperature	5(F-32)/9 or (F-32)/.18	Celsius temperature	^{0}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSION FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
NOTE: Volumes greater than 10001 shall be shown in m^3				
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE		
^{0}C	Celsius temperature	1.8C = 32	Fahrenheit temperature	^{0}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units.
Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised September 1993)

Forward

Metal foundries use large amounts of sand as part of the metal casting process. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed "foundry sand." Foundry sand production is nearly 6 to 10 million tons annually. Like many waste products, foundry sand has beneficial applications to other industries.

The purpose of this document is to provide technical information about the potential civil engineering applications of foundry sand. This will provide a means of advancing the uses of foundry sand that are technically sound, commercially competitive and environmentally safe.

This document was developed by Foundry Industry Recycling Starts Today (FIRST), in cooperation with the U. S. Department of Transportation and the U.S. Environmental Protection Agency. The United States Government assumes no liability for its contents or use. Neither FIRST nor the Government endorses specific products or manufacturers.

This publication does not constitute a standard, specification or regulation.

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U.S. Department of Transportation, through the Federal Highway Administration, supports the expanded use of recycled materials in highway construction and provided overall technical review of the document. The authors appreciate the many agency and industry representatives who provided information and technical comments necessary to compile this document.

Foundry Industry Recycling Starts Today (FIRST) is a non-profit 501 (C) (3) research and education organization whose website www.foundryrecycling.org provides access to the technical references used in the preparation of this document. The American Foundry Society (AFS) is a metalcasting industry association which has sponsored research on foundry sand recycling options.

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Chapter 1:

An Introduction to Foundry Sand

Background Information

What is a Foundry? A foundry is a manufacturing facility that produces metal castings by pouring molten metal into a preformed mold to yield the resulting hardened cast. The primary metals cast include iron and steel from the ferrous family and aluminum, copper, brass and bronze from the nonferrous family. There are approximately 3,000 foundries in the U.S.

What is Foundry Sand? Foundry sand is high quality silica sand that is a byproduct from the production of both ferrous and nonferrous metal castings. The physical and chemical characteristics of foundry sand will depend in great part on the type of casting process and the industry sector from which it originates.

Where Does it Come From? Foundries purchase high quality size-specific silica sands for use in their molding and casting operations. The raw sand is normally of a higher quality than the typical bank run or natural sands used in fill construction sites.

The sands form the outer shape of the mold cavity. These sands normally rely upon a small amount of bentonite clay to act as the binder material. Chemical binders are also used to create sand “cores”. Depending upon the geometry of the casting, sands cores are inserted into the mold cavity to form internal passages for the molten metal (Figure 1). Once the metal has solidified, the casting is separated from the molding and core sands in the shakeout process.

In the casting process, molding sands are recycled and reused multiple times. Eventually, however, the recycled sand degrades to the point that it can no longer be reused in the casting process. At that point, the old sand is displaced from the cycle as byproduct, new sand is introduced, and the cycle begins again. A schematic of the flow of sands through a typical foundry can be found in Figure 2.

Figure 1. Metal casting in a foundry

How is it Produced? Foundry sand is produced by five different foundry classes. The ferrous foundries (gray iron, ductile iron and steel) produce the most sand. Aluminum, copper, brass and bronze produce the rest. The 3,000 foundries in the United States generate 6 million to 10 million tons of foundry sand per year. While the sand is typically used multiple times within the foundry before it becomes a byproduct, only 10 percent of the foundry sand was reused elsewhere outside of the foundry industry in 2001. The sands from the brass, bronze and copper foundries are generally not reused. While exact numbers are not available, the best estimate is that approximately 10 million tons of foundry sand can beneficially be used annually.

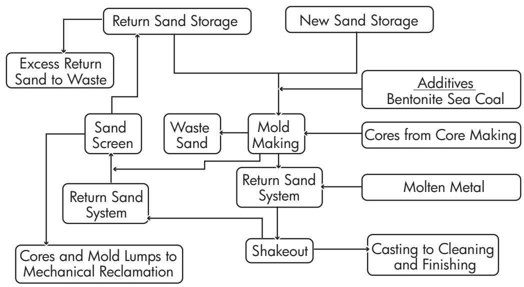


Figure 2. How sand is reused and becomes foundry sand

Foundry Sand Uses and Availability

What Makes it Useful? Foundry sand is basically fine aggregate. It can be used in many of the same ways as natural or manufactured sands. This includes many civil engineering applications such as embankments, flowable fill, hot mix asphalt (HMA) and portland cement concrete (PCC). Foundry sands have also been used extensively agriculturally as topsoil.

What is Being Done With It? Currently, approximately 500,000 to 700,000 tons of foundry sand are used annually in engineering applications. The largest volume of foundry sand is used in geotechnical applications, such as embankments, site development fills and road bases.

Where is it Available? Foundries are located throughout the United States in all 50 states. However, they tend to be concentrated in the Great Lakes region, with strong foundry presence also found in Texas and Alabama (Figure 3).

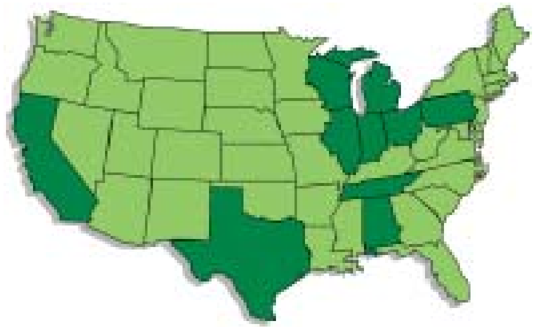


Figure 3. Top ten foundry production states in the U.S.

How Does the Foundry Sand Industry Operate? Historically, individual foundries have typically developed their own customer base. But over time, foundries have joined together to create regional foundry consortia to pool resources and to develop the recycled foundry sand industry. FIRST (Foundry Industry Recycling Starts Today) is a national coalition of member foundries. FIRST focuses on market development of sustainable options for beneficial reuse of foundry industry byproducts.

Types of Foundry Sand

How Many Types of Foundry Sand Are There? There are two basic types of foundry sand available, green sand (often referred to as molding sand) that uses clay as the binder material, and chemically bonded sand that uses polymers to bind the sand grains together.

Green sand consists of 85-95% silica, 0-12% clay, 2-10% carbonaceous additives, such as seacoal, and 2-5% water. Green sand is the most commonly used molding media by foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. The water adds plasticity. The carbonaceous additives prevent the “burn-on” or fusing of sand onto the casting surface. Green sands also contain trace chemicals such as MgO, K_2O, and TiO_2.

Chemically bonded sand consists of 93-99% silica and 1-3% chemical binder. Silica sand is thoroughly mixed with the chemicals; a catalyst initiates the reaction that cures and hardens the mass. There are various chemical binder systems used in the foundry industry. The most common chemical binder systems used are phenolic-urethanes, epoxy-resins, furfyl alcohol, and sodium silicates.

Foundry Sand Physical Characteristics

What is the Typical Particle Size and Shape?
Foundry sand is typically subangular to rounded in shape. After being used in the foundry process, a significant number of sand agglomerations form (Figure 4). When these are broken down, the shape of the individual sand grains is apparent.

Figure 4. Unprocessed foundry sand (Courtesy Lifco Industries)

What are Some of the Physical Properties?
Foundry sand has many of the same properties as natural sands. While one foundry sand will differ statistically from another, recently published properties from Pennsylvania provide fairly typical values. Pennsylvania foundry sands are classified in two categories:

- Foundry sand with clay (5%) – FS #1
- Foundry sand without clay – FS #2

Table 1 shows the results for bulk density, moisture content, specific gravity, dry density, optimum moisture content and permeability measured using the applicable ASTM standard.

Property	ASTM Standard	Foundry Sand with Clay (5%) FS#1	Foundry Sand without Clay FS#2
Bulk density (pcf)	C29	60-70	80-90
Moisture content (%)	D2216	3-5	0.5-2%
Specific gravity	D854	2.5-2.7	2.6-2.8
Dry density (pcf)	D698 Standard Proctor	110-115	100-110
Optimum moisture content (%)	D69	8-12	8-10
Permeability coefficient (cm/s)	D2434	10^{-3}-10^{-7}	10^{-2}-10^{-6}

Table 1. Typical physical properties of foundry sand

Figure 5 compares the gradations of these materials to the ASTM C33 upper and lower limits (See Chapter 6). Foundry sand is commonly found to be a uniform fine sand, with 0 to 12% bentonite or minor additives. The quantity of bentonite or minor additives depends on how the green sand has been processed.

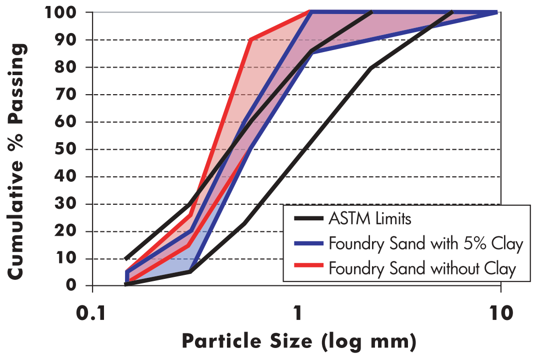


Figure 5. Foundry sand gradation, as compared to ASTM C33

What Color is Foundry Sand? Green sands are typically black, or gray, not green! (Figure 6). Chemically bonded sand is typically a medium tan or off-white color.

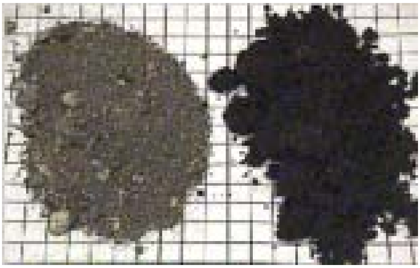


Figure 6. Green sands from a gray iron foundry (after processing and screening)

Foundry Sand Quality

What Determines Foundry Sand Quality?
The quality of foundry sand can be quantified by its durability and soundness, chemical composition, and variability. These three characteristics are influenced by various aspects of foundry sand production.

Durability/Soundness of foundry sand is important to ensure the long-term performance of civil engineering applications. Durability of the foundry sand depends on how the sand was used at the foundry. Successive molding can cause the foundry sand to weaken due to temperature shock. At later stages of mold use, this can lead to the accelerated deterioration of the original sand particles. However, in civil engineering uses, the foundry sand will not normally be subjected to such severe conditions. In geotechnical applications, foundry sand often demonstrates high durability.

Chemical Composition of the foundry sand relates directly to the metal molded at the foundry. This determines the binder that was used, as well as the combustible additives. Typically, there is some variation in the foundry sand chemical composition from foundry to foundry. Sands produced by a single foundry, however, will not likely show significant variation over time. Moreover, blended sands produced by consortia of foundries often produce consistent sands. The chemical composition of the foundry sand can impact its performance.

Variability. Reducing the variability of the foundry sand is critical if consistently good engineering products are to be produced. Foundry sand suppliers should understand and control foundry sand variability so that they can provide customers with a consistent product.

How can I know I'm getting good quality? Methods to ensure foundry sands conform to specifications vary from State to State and source to source. Some States require testing and approval before use. Others maintain lists of approved sources and accept project suppliers' certifications of foundry sand quality. More and more, foundry sand generators are determining the engineering properties of their sands.

The degree of quality control necessary depends on experience with the specific foundry sand and its history of variability. Many purchasers require source testing and a certification document to accompany the shipment.

How should foundry sand be handled? Foundry sand is most often collected and stockpiled outside of the foundries, exposed to the environment. Prior to use in an engineering application, the majority of foundry sand is:

- Collected in closed trucks and transported to a central collection facility;
- Processed, screened, and sometimes crushed to reduce the size of residual core sand pieces. Other objectionable material, such as metals, are removed.

Foundry Sand Economics

The success of using foundry sand depends upon economics. The bottom line issues are cost, availability of the foundry sand and availability of similar natural aggregates in the region. If these issues can be successfully resolved, the competitiveness of using foundry sand will increase for the foundries and for the end users of the sand. This is true of any recycled material.

Foundry Sand Engineering Characteristics

What are the key engineering properties of foundry sand? Since foundry sand has nearly all the properties of natural or manufactured sands, it can normally be used as a sand replacement. It can be used directly as a fill material in embankments. It can be used as a sand replacement in hot mix asphalt, flowable fills, and portland cement concrete. It can also be blended with either coarse or fine aggregates and used as a road base or subbase material. Table 2 shows the relative ranking of foundry sand uses by volume.

Ranking	Application
1	Embankments/Structural Fills
2	Road base/Subbase
3	Hot Mix Asphalt (HMA)
4	Flowable Fills
5	Soil/Horticultural
6	Cement and Concrete Products
7	Traction Control
8	Other Applications

Table 2. Foundry sand applications by volume

According to a recent survey of 10 states, foundry sand has been approved for use by various agencies within the state in the following engineered applications (listed in Table 3). It is expected that more states will be supplementing these uses as they become more familiar with the material.

	IA	IL	IN	MI	MN	NJ	NY	OH	PA	WI
Landfill daily cover				X			X	X		X
Highway embankment				X				X		X
Roadway subbase	X		X	X	X	X		X		X
Parking lot subbase				X	X	X		X		X
Concrete and asphalt		X	X	X	X		X	X	X	X
Foundation subgrade fill	X							X		X
Flowable fill							X	X		X
Generate fill		X	X	X				X		
Other		X	X					X		X

Table 3. Engineered uses of foundry sand

Foundry Sand Environmental Characteristics

What about trace elements in foundry sand? Trace element concentrations present in most clay-bonded iron and aluminum foundry sands are similar to those found in naturally occurring soils. The leachate from these sands may contain trace element concentrations that exceed water quality standards; but the concentrations are no different than those from other construction materials such as native soils or fly ashes. Environmental regulatory agencies will guide both the foundry sand supplier and the user through applicable test procedures and water quality standards. If additional protection from leachate is desired, mechanical methods such as compacting and grading can prevent and further minimize leachate development.

In summary, foundry sand suppliers will work with all potential users to ensure that the product meets environmental requirements for the engineering application under consideration.

Closing

Do I need to know more about this technology to use it confidently? Foundry sand can be used to produce a quality product at a competitive cost under normal circumstances. The remaining chapters of this publication provide a general overview of foundry sand use in various civil engineering applications. It will familiarize highway engineers and inspectors with this technology. This publication is also designed to assist those individuals who have little or no previous experience using foundry sand or no experience in a particular application of foundry sand.

Chapter 2:

Foundry Sand in Structural Fills and Embankments

Engineering Properties For Embankments

How are embankment materials generally classified? Embankment materials used in construction (Figure 7) are generally classified on the basis of soil type, grain size distribution, Atterberg limits, shear strength (friction angle), compactability, specific gravity, permeability and frost susceptibility.

Figure 7. Embankment with foundry sand subbase (Ohio Turnpike, sand from Ford Motor Company supplied by Kurtz Bros. Inc.)

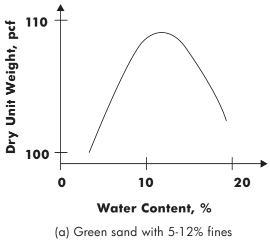
Soil Classification. Foundry sand would normally be classified under the Unified Soil Classification System (USCS) as SP, SM or SP-SM and under AASHTO as A-3, A-2, or A-2-4. It is a nonplastic or low plasticity sand with little or no fines. Some foundries or foundry sand suppliers will process the sand to remove the majority of silts or clays that may be present. The silt or clay content can range from 0 to 12%.

Grain Size Distribution. Foundry sand consists of a uniform sand, with a coarse appearance. Typical gradations are provided in Chapter 1.

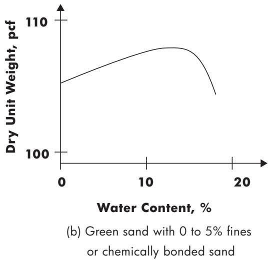
Atterberg Limits (Liquid and Plastic). Typically foundry sand without fines is nonplastic. The plastic behavior can depend on the clay content. For foundry sand with 6 to 10% clay, a liquid limit LL greater than 20 and a plastic index PI greater than 2 are typical.

Shear Strength (Friction Angle). Foundry sands have good shear strength. For foundry sands without clay, the direct shear test is used to measure its friction angle. It ranges from 30^0-36^0, which is comparable to conventional sands. Its shear strength is superior to silts, clays or dirty sands, showing that foundry sand is acceptable for use as an embankment material. The triaxial shear strength test can be used to measure the drained shear strength, friction angle and cohesion of foundry sands that contain clay. A typical value of the friction angle and cohesion for these sands is 28^0 and 3700 psf, respectively. But these properties can vary. Foundry sand used on the Ohio Turnpike had a friction angle of 35^0 and cohesion of 6100 psf.

Compaction. Compaction of foundry sand is needed to increase its density during embankment construction. Moisture-density relationships have been developed for green sands with 0 to 5% fines, green sands with 5 to 12% fines, and chemically bonded sands. They show the optimal moisture content for maximum dry density for a specified level of compaction. In Figure 8, there is a definite peak in the moisture-density curve for green sands with fines between 5 and 12%. The green sands with few fines and the chemically bonded sands produce a flatter curve. The influence of water is not as significant for them. However, both curves are relatively flat, when compared to plastic soils.



(a) Green sand with 5-12% fines



(b) Green sand with 0 to 5% fines or chemically bonded sand

Figure 8. Moisture density relationships for green sand and chemically bonded sand

Specific Gravity. Foundry sands will normally have a specific gravity of 2.50 to 2.80.

Permeability. Green sands with fines less than 6% and chemically bonded sands have permeability values in the range of $6x10^{-4}$ to $5x10^{-3}$ cm/sec. However, when fines such as bentonite clay are present and greater than 6%, permeability can be lower, between $1x10^{-7}$ and $3x10^{-6}$ cm/sec.

Frost Susceptibility. Soils that are not susceptible to frost and that do not produce heave are gravel and clean sands. Fine-grained soils are generally classified as frost susceptible. The fine content of the foundry sand determines its frost susceptibility. Foundry sand without fines can have low to negligible frost susceptibility.

CBR (California Bearing Ratio). In foundry sand, a CBR between 11 and 30 is typical. The resistance to penetration of a 3 in^2 piston in a compacted sample of foundry sand is compared to its resistance in a standard sample of compacted crushed rock. CBR is high when the water content is dry of optimum, and then drops after the optimum water content is reached. The CBR for foundry sand with fines is generally higher than it is for granular sands.

Construction Practices

General. Many contractors have found that working with foundry sand is similar to working with conventional construction materials. Foundry sand has been used effectively in normal embankment construction with and without permeability and leachate control. Foundry sands have also been used in conjunction with geogrid systems and with reinforced earth retaining walls that use straps or grids as horizontal tiebacks.

Standard construction procedures can be adjusted to account for using foundry sand. Many procedures have been developed as the result of the experience gained using foundry sand in trial embankment and construction projects.

Stockpiling. Foundry sand can be stockpiled in a climate-controlled environment or exposed to the elements. The foundry sand stored under controlled climatic conditions can be delivered to meet narrow limitations on moisture content. Conversely, the moisture content of the foundry sand stored outside will vary, depending on its location within the stockpile. It is recommended that foundry sand stockpiled outside be tested at various locations within the stockpile.

Site Preparation. The site should be prepared for foundry sand placement in the same way it is prepared for similar soil fill materials. It should be cleared and grubbed, and the topsoil should be retained for final cover. The normal precautions for draining the site to prevent seeps, pools or springs from contacting the foundry sand should be followed. Also, environmental restrictions may require that the foundry sand be encapsulated in layers of clay.

Delivery and On-Site Storage. As with any fill, foundry sand is hauled to the site in covered dump trucks (Figure 9). The water content of the foundry sand is adjusted to prevent dusting and to enhance compaction. Foundry sand can be stockpiled on-site if the sand is kept moist and if the sand is covered.

Figure 9. Foundry sand delivery (sand supplied by Kurtz Bros., Inc., construction by Trumbull Corp.)

Spreading. Foundry sand is spread using normal construction equipment, such as dozers. Lifts are usually 6 to 12 inches thick. Many contractors then track the dozer for initial compaction. Ideally, the sand is at or near optimal moisture when placed; if not, water should be added.

Compaction. Compaction should begin as soon as the material has been spread (Figure 10) and is at the proper moisture content. Ohio experience has shown it to be preferable to place the foundry sand as close to the optimum moisture content as possible, within 1-2%. Too dry of optimum requires significantly more compactive effort than when the sand is properly moisture-conditioned. However, the required compaction can eventually be achieved. Foundry sands are not normally sensitive to over-rolling and can tolerate a wider range of moisture contents than natural sands.

Figure 10. Spreading foundry sand (Ohio turnpike, sand supplied by Kurtz Bros. Inc.)

Vibratory smooth drum rollers, pneumatic-tired rollers, and vibrating plates have all been used successfully. It is important to properly screen the foundry sand and to remove residual core pieces. In most cases cores are not a problem if they are less than 3 to 4” long. The compaction process will slow down if they are larger.

The lift thickness, the weight and speed of the compaction equipment and the number of passes should be determined for optimal compaction (Figure 11). Many contractors run test strips and relate construction practices to the foundry sand's degree of compaction. When vibratory compaction equipment is used, lifts of 12 inches are acceptable. In fact, thicker lifts may be preferred. They provide greater confinement. If the lift is too thin, the sand may dry out too fast. Also, it will not offer enough confinement for proper compaction.

Figure 11. Grading foundry sand

In a recent project, dynamic compaction was used successfully to compact foundry sand. The moisture-conditioned foundry sand was placed in 10 to 15 foot lifts, and then dynamically compacted by a 12 ton weight dropped from 40 to 60 feet. This height can be adjusted for the required level of compaction and thickness of the sand layer.

In some foundry sand embankment construction, a foundation of coarser material such as rock or shale is placed. The foundry sand is placed on top in uniform horizontal lifts not more than 8 inches deep. It is then compacted according to normal density specifications.

Moisture Control. As with any fill material, controlling its moisture is an important consideration in compaction. Be sure to compare hauling foundry sand that has been moistened to the desired water content at the plant to adding water at the site. Hauling moist foundry sand translates to higher transportation costs, while adding water on-site sacrifices productivity in field placement.

Erosion and Dust Control. To prevent wind and water erosion of the surface of the foundry sand embankment, contractors use the same sediment and erosion control techniques commonly used on other earthwork operations. On a project in Ohio, the contractor installed organic filter socks or berms around the construction area.

Dusting may occur when compacted foundry sand is placed in dry or windy weather, or due to traffic disturbance. During construction, the soil should be kept moist and covered. Clay layers have also been used to cover the face of the embankment to prevent erosion of the foundry sand in a heavy rain. The completed embankment should be covered with topsoil and vegetation.

Three Key Construction Steps. To ensure successful construction of an embankment (Figure 12), with foundry sand and its long-term performance it is important to:

1. *Assess availability.* Contact the local foundry sand supplier and determine whether an adequate supply of foundry sand can be provided in the time frame required.

2. *Investigate site conditions.* As with any embankment project, use standard geotechnical techniques to evaluate subsurface soil and groundwater conditions. The two most important subsurface characteristics affecting embankment construction and performance are shear strength and compressibility of the foundation soils.

3. *Evaluate the physical, engineering, and chemical properties of the foundry sand.* The physical and engineering properties that will determine the behavior of a foundry sand embankment (or any embankment) are grain-size distribution, shear strength, compressibility, permeability and frost susceptibility. Laboratory tests designed for testing soil properties apply equally well to testing foundry sands. Most foundry sand distributors can provide information on the physical, engineering and chemical composition of the foundry sand and can provide details on any possible leachate that must be considered during design and construction.

Figure 12. Stepped embankment
(Ohio turnpike, sand supplied by Kurtz Bros. Inc., construction by Trumbull Corp.)

Environmental Impacts. The trace element concentrations in most clay-bonded and aluminum foundry sands are similar to those found in naturally occurring soils. The vast majority of foundry sands meet water quality standards for leachate. Additionally, State environmental regulatory agencies can guide you through applicable test procedures and water quality standards. The amount of leachate produced can be controlled by assuring adequate compaction, grading to promote surface runoff, and daily proof-rolling of the foundry sand layer to impede infiltration. When construction is finished, a properly seeded soil cover will reduce infiltration. For highway embankments, the pavement itself can be an effective barrier to infiltration.

Chapter 3:

Foundry Sand in Road Bases

Background Information

What is a Road Base? A road base is a foundation layer underlying a flexible or rigid pavement and overlying a subgrade of natural soil or embankment fill material. It can be composed of crushed stone, crushed slag, or some other stabilized material. It protects the underlying soil from the detrimental effects of environment and from the stresses and strains induced by traffic loads.

Flexible Pavement Road Base. For flexible pavements, there are typically two bases underneath the pavement that comprise the road base, a stabilized base and an untreated or granular subbase (Figure 13). The two different base materials are usually used for economy. Local or cheaper materials are used in the subbase, and the more expensive materials are used in the base.

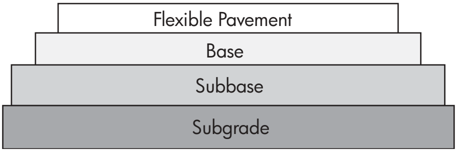


Figure 13. Schematic of a flexible pavement structure

Rigid Pavement Road Base. In contrast to flexible pavements, rigid pavements are typically placed on a single layer of granular or stabilized road base material (Figure 14).

Since there is only one layer under the rigid pavement and above the subgrade, it can be called either a base or a subbase.

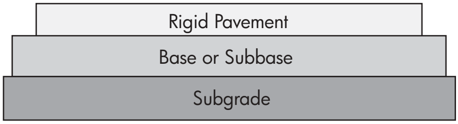


Figure 14. Schematic of a rigid pavement structure

Granular or Stabilized Road Base. The selection of a stabilized base course or a granular base course depends on the traffic loads. Pavements that are subjected to a large number of very heavy wheel loads typically use cement-treated, asphalt-treated, or a pozzolanic stabilized mixture (PSM) base. Granular materials may erode when the heavy traffic induces pumping.

Purpose of the Road Base

Five of the most important reasons for constructing a road base are to:

- Control pumping,
- Control frost action,
- Improve drainage,
- Control shrinkage and swelling of the subgrade, and
- Expedite construction.

Control Pumping. For pumping to occur, three conditions must exist simultaneously. The material under the concrete slab must be saturated with free water, the material must be erodible, and frequent heavy wheel loads must pass over the pavement. These loads create large hydrodynamic pressures that transport untreated granular materials and even some weakly cemented materials to the surface. This loss of fines is termed pumping.

Control Frost Action. Frost action is the combination of frost heave and frost melt. Frost heave causes the pavement to lift up, while frost melt causes the subgrade to soften and the pavement to depress. Both lead to the break up of a pavement. Three factors produce frost action:

1. The soil must be frost susceptible in the depth of frost penetration. These soils generally have more than 3% fines or are uniform sands with more than 10% fines.

2. Water must be available.

3. Temperatures must remain below freezing for a sufficient period of time for water to flow from the water table to where the ice lenses form in the road base.

Improve Drainage. A road base can raise the pavement to a desired elevation above the water table, acting as an internal drainage system.

Control Shrinkage and Swelling of the Subgrade. If the subgrade shrinks and expands, the road base can provide a surcharge load to reduce its movement. Dense graded or stabilized base courses reduce the water entering the subgrade, and act as a waterproofing layer. Open-graded base courses serve as a drainage layer.

Expedite Construction. A road base can serve as a working platform for heavy construction equipment.

Mix Design Evaluation

The road base material should be made of a mixture of crushed rock and enough fine material to hold the rock in place and to provide good compaction. Foundry sand can be used as the fine material in a road base. Engineering properties that characterize foundry sand as a subbase material are plasticity, shear strength, compaction (moisture-density relationship), drainage and durability.

Plasticity (Shrinkage or Swelling). Green foundry sands without fines and chemically bonded sands are typically non-plastic. However, the presence of bentonite clay increases the foundry sand's plasticity. The plasticity index is commonly used to indicate a soil's tendency to undergo volume change (shrinkage or swelling). The plasticity index is typically less than 2 for green sands with no or few fines and chemically bonded sands, and greater than 2 when the clay content increases beyond 6%.

Shear Strength (Friction Angle). A soil's shear strength is its ability to resist deformation. This property is critical when determining a soil's ultimate bearing capacity, which is the largest load that the road base material can support. Shear strength depends on several material properties, such as soil cohesiveness, and the interlocking ability and packing of the particles.

The friction angle of green sands with 6 to 12% clay is higher than it is for chemically bonded foundry sands and green sands without clay. The friction angle ϕ in Table 4 represents the peak strength for dense samples and the ultimate strength for loose ones. The higher friction angle for the green sand with clay is attributed to its fines. Similarly, the cohesive strength of green sands with clay is higher than it is for the chemically bonded sands (Table 5). Green sands without clay are non-plastic. Either ASTM D5311 or ASTM D3080 can be used to measure shear strength.

	ϕ	
	Loose	**Dense**
Green sand with clay (6-12%)	32°-34°	37°-41°
Clean green sand without clay/ Chemically bonded sand	30°	35°
Natural sand	29°-30°	36°-41°

Table 4. Friction angle of foundry sands

	Cohesion (psi)	
	Loose	**Dense**
Green sand with clay (6-12%)	0.60-0.75	1.44-1.82
Chemically bonded sand	0.06	1.04

Table 5. Cohesion of foundry sands

Compaction. The compaction characteristics of a granular base or subbase material depend on the soil's moisture-density relationship. Most specifications require that the granular base be compacted to a specified density that is at least 95% of the Standard Proctor maximum dry density, with the water content near optimum. The Standard Proctor test (ASTM D698 or AASHTO T99) is commonly used to measure compaction. The Modified Proctor test (AASHTO T180) can also be used when the base must have a high shear strength or be dense.

To ensure base stability, angular particles with rough surfaces are preferred over round, smooth particles. Foundry sands are round to subangular in shape, with both smooth and rough surface textures.

Drainage. Since a road base should provide drainage as part of a pavement's structure, the base material's permeability is very important. Materials that are free-draining typically have a permeability between 10^{-2} and 10^{-3} cm/sec.

The permeability of green and chemically bonded sands are given in the table below (Table 6). The presence of clay reduces the permeability of the green sands. Higher permeabilities are associated with foundry sands that have fewer fines, such as green sands that have been processed to remove the clay and chemically bonded sands. Permeability of foundry sands can be measured using ASTM D2434, AASHTO T215 or ASTM D5084.

	Permeability k (cm/sec)
Green sand with clay	2.8×10^{-5} to 2.6×10^{-6}
Green sand without clay	3×10^{-3} to 5×10^{-3}
Chemically bonded sand	4.5×10^{-3} to 5.9×10^{-4}
Natural Sands	10^{-3} to 10^{-4}

Table 6. Permeability of foundry sands

Durability. Foundry sand has sufficient strength to resist excess breakdown when placed in road bases (Figure 15). They have good particle strength. Many States will specify minimum requirements for LA abrasion (ASTM C131 or AASHTO T96) and sodium sulfate soundness (ASTM C88 or AASHTO T104). Foundry sand without clay is normally not susceptible to frost, and this should be assessed using AASHTO T103.

Figure 15. Supplying Foundry Sand for a road base

Control of Materials

Handling. No deleterious materials (plastic fines, organic matter, or extraneous debris) should be in the foundry sand. This will reduce its load carrying capacity and ultimately, the expected performance of the road base. Foundry sand should be screened prior to its use in engineering projects.

Aggregate. To meet State specifications for road bases, blending the foundry sand with another aggregate may be necessary. The gradation of the road base materials influences base stability, drainage, and frost susceptibility. Likewise, the aggregate must be sound and able to resist environmental deterioration.

Construction Practices

Blending of Materials. Aggregate used in the construction of road bases should be mixed and processed to produce a uniform blend of material prior to final placement.

Construction Plants. Construction plants should collect and store foundry sand until use. Because of the importance of the fine aggregate moisture content, the foundry sand should have consistent moisture content.

Hauling. Blended mixtures can be hauled to the site in open or covered trucks. The mix in an open truck can dry and dust when hauled long distances.

Spreading. The placement of road base material shall conform to local grading ordinances and agency specifications. The typical road base is a uniform layer of base material that is 6-10 inches thick, without any segregation. The final thickness after compaction is 4-6 inches.

Compaction. Road base material should be rolled to achieve the desired compaction and specified density. It is important that all waste materials be removed from the foundry sand, because it can become entangled in the compaction equipment and delay construction.

Finishing. The final layer of road base shall be finished with equipment capable of shaping and grading the final surface within the tolerances specified by the agency.

What if I can't afford to buy specialized construction equipment? There is no need to! Most plants can be readily adapted to add the foundry sand to the road base mix. For spreading, it can be placed with a jersey spreader.

What advice do you have for a first time user?
Using foundry sand can produce strong durable road bases, but attention should be given to the following precautions:

- **Mix design evaluation.** Proposed mix designs should be evaluated for performance prior to construction. Good quality constituents do not always produce a mix that will perform as desired.
- **Moisture content.** Moisture must be maintained in the mix to ensure optimal compaction. The moisture may be added on site or at the plant.

Marketing Fill

The project specific nature of the fill materials market makes it difficult to quantify the total amount of foundry sand that will be needed on a regular basis. Currently, the rates of foundry sand generation is sufficient to supply construction companies and other related industries with fill material. The marketability of the sand depends on the availability of other fill material at or near the construction site. Transportation costs may quickly offset the low initial cost advantage of foundry sand. Foundry sand use is more advantageous when it is stockpiled close to the construction site.

Chapter 4:

Foundry Sand in Hot Mix Asphalt

Introduction

Asphalt concrete is the most popular paving material used on our highways and roadways in the United States. Over 94% of all pavements in the U. S. are covered with asphalt. This translates to over 2,030,000 miles (Figure 16).

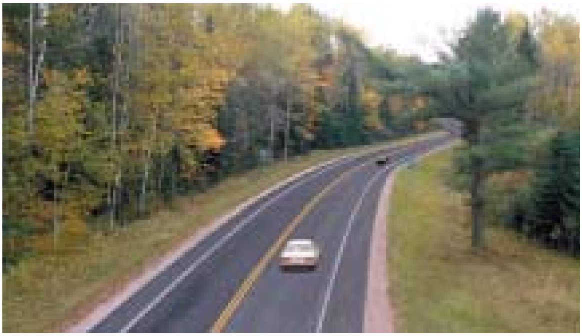


Figure 16. Asphalt pavement (courtesy Asphalt Pavement Alliance)

The most prevalent type of asphalt paving material is hot mixed asphalt (HMA). This consists of a combination of plant-dried coarse and fine aggregates. They are coated with hot asphalt cement, which acts as a binder.

Foundry sand has been used successfully to replace a portion of the fine aggregate used in HMA. Studies have shown that foundry sand can be used to replace between 8 and 25% of the fine aggregate content. When mixes are properly designed using Superpave, Marshall, or Hveem techniques, foundry sand can be an effective sand alternative.

Hot Mix Asphalt Aggregate Requirements

Hot mix asphalt production requires that all constituent products:

- Have inherently good quality characteristics,
- Come from consistent, reputable supply sources,
- Meet all environmental requirements, and
- Are economically competitive with similar materials.

Foundry sand has the potential to be a very high quality material in hot mix applications (Figure 17). However, it is important that the foundry sand be cleaned of clay, dust, and other deleterious materials. Additionally, metals present in the sands should be removed either manually or magnetically. Then, it may be blended with other sands, at 8-25% replacement, to provide equal or possibly better results than normal sands.

Gradation. Fine aggregates in hot mixes generally are required to meet the specifications of AASHTO M29. This specification limits materials passing the No 200 sieve to between 5 and 10%. Many foundry sands have a higher percentage, requiring screening prior to blending or a limit on the maximum amount of foundry sand that can be added to a mix.

Particle Cleanliness. Hot mix asphalt is generally tested by the sand equivalent test (ASTM D-2419) or by the non-plastic index test (AASHTO T-90). These tests detect clay portions, which are very detrimental to aggregate-binder adhesion. It is important that when qualifying foundry sand, the clay content and organic-based additive be quantified and limited in producing an asphalt mix. For many foundry sands, the sand equivalent test is not applicable. According to research done at the University of Wisconsin at Madison, the methylene blue test (AFS 2211-00-S) is a better method for the clay content. The loss on ignition test (AASHTO T 267-86) is a good method for detecting the organic based additives.

Soundness. Nearly all foundry sands meet the loss of soundness specification, AASHTO T104.

Particle Shape and Texture. Many hot mix asphalt specifications now require a fine aggregate angularity test, using AASHTO TP33. Foundry sands typically fall within the specified 40-45% range.

Absorption and Stripping. Foundry sand is generally non-plastic and has low absorption. However, it is primarily silica, which in the past, has been linked to stripping. As with all silica-based hot mix asphalt mixtures, a foundry sand mix should be tested using standard stripping tests. The University of Wisconsin at Madison has tested foundry sand mixes for moisture damage and, depending on the clay content and the extent of organic-based additives used, foundry sands can have positive or negative effects on resistance to moisture damage. The University of Wisconsin at Madison is currently developing better methods to quantify clay and organic-based additives to predict how foundry sands influence moisture damage.

Figure 17. Construction of HMA pavement

Case Studies

Pennsylvania, Michigan and Tennessee Departments of Transportation allow the use of recycled foundry sand in HMA. Pennsylvania DOT allows the use of 8 to 10% of the total aggregate portion to be recycled foundry sand in the asphalt wearing course. One hot mix producer in Michigan consistently supplies HMA with 10-20% recycled foundry sand to replace the conventional aggregate, and it meets Michigan DOT specifications. Another hot mix supplier in Tennessee claims that hot mix with foundry sand replacing 10% of the fine aggregate compacts better and outperforms the HMA containing washed river sand. In addition, a hot mix producer in Ontario, Canada has used foundry sand as a fine aggregate substitute for the past 10 years in both foundation and surface HMA layers.

In Pennsylvania, 10 million tons of asphalt pavement are produced each year. Two million tons of fine aggregate are needed. Although foundry sand cannot be used to replace the total fine aggregate quantity, it can be used to replace up to 15%. This would allow a significant amount of foundry sand to be used each year in Pennsylvania.

Concerns of the Hot Mix Industry

To be used by the hot mix industry, foundry sand has to be a consistent product with adequate supply. The engineering characteristics of the foundry sand have to be relatively similar from batch to batch, especially in gradation, so that the resulting hot mix asphalt is also consistent. Once a proper hot mix asphalt design has been developed and calibrated with the foundry sand, it is not cost effective to change the mix design. This will result in additional costs. If the foundry sand supply changes during the construction season, the hot mix supplier will be responsible for any out-of-specification material, and will incur any consequent penalties.

Economics

Use of foundry sands can be cost effective for both the foundries and the HMA industry. Highway agencies and contractors could switch to the recycled material when it is geographically and economically competitive.

Chapter 5:

Foundry Sand in Flowable Fills

Introduction

Flowable fill has several names, but each is essentially the same material:

- Controlled density fill (CDF),
- Controlled low strength material (CLSM),
- Fly ash slurry,
- Lean mix backfill,
- Unshrinkable fill, and
- Soil cement.

Flowable mixtures make up a class of engineering materials having characteristics and uses that overlap those of a broad range of traditional materials including compacted soil, soil-cement, and concrete. Flowable mixtures consist of sand, water, cement and sometimes fly ash. The mixtures are proportioned, mixed and delivered in a very fluid consistency to facilitate placement; they provide an in-place product that is equivalent to a high-quality compacted soil but without the expensive compaction equipment and related labor. ACI defines flowable fill as a cementitious material that is in a flowable state at the time of placement and has a specified compressive strength of 1200 psi or less at 28 days.

Flowable fills have been used as backfill for bridge structures including abutments, culverts, and trenches. It has been used for embankments, bases, and subbases. It is commonly used as bedding for slabs and pipes. It has also been used to economically fill caissons and piles, abandoned storage tanks, sink holes, shafts and tunnels.

Flowable fill materials usually offer an economic advantage over the cost of placing and compacting earthen backfill materials. Depending on the job conditions and costs involved, significant savings are possible. The closer the project location to the source of the flowable fill, the greater the potential cost savings.

Most foundry sands can be used in flowable fill mixtures. The foundry sand does not have to meet ASTM C33 gradation specification requirements as a concrete fine aggregate to be suitable for use in flowable fill mixes. ACI 229R reports that foundry sand with up to 20% fines produced successful flowable fill mixtures. Because low strength development is desirable in flowable fill, even foundry sand with organic binders may be suitable. Foundry sand for flowable fill can be used in a dry or moisture conditioned form.

Mix Design and Specification Requirements

Flowable fills typically contain portland cement, fly ash, sand and water. Foundry sand can be the major ingredient in flowable fills. The flowable character derives from its distribution of spherical and irregular particle shapes and sizes. When mixed with enough water, the fly ash and sand surfaces are lubricated, so that it flows.

Water requirements for mixture fluidity will depend on the surface characteristics of all solids in the mixture. A range of 50 to 200 gallons per cubic yard would satisfy most materials combinations. As with most flowable fill applications, the wetter it is the better. The water acts as a means of conveyance for the solid particles in the mixture. Portland cement is added, typically in quantities from 50 to 200 pounds per cubic yard, to provide a minimal (weak) cementitious matrix. Table 7 shows mix proportions recommended in ACI 229R. However, contractors familiar with flowable fill and foundry sand have reported using lower quantities of foundry sand, approximately 1500 pounds per cubic yard.

Component	Typical Mix Design (lb/yd^3)	Range (lb/yd^3)
Fine Aggregate/ Foundry Sand	2850	1850-2910
Cement	100	50-200
Fly Ash	250	0-300
Water	500	325-580

Table 7. Foundry sand mixes (adapted from ACI 229R)

According to the ACI definition, flowable fill should have an upper compressive strength limit of 1200 psi, but strengths can be designated as low as 50 psi. Most flowable fill mixes are designed to achieve a 28-day maximum unconfined compressive strength of 100 to 200 psi. The goal is to have the flowable fill support early loads without settling, and yet still be readily excavated at a later date. Flowable mixtures can be designed to allow for hand excavation as well.

It is important to remember that flowable fill mixtures with a low ultimate strength in the 50 to 70 psi range have at least two to three times the bearing capacity of well-compacted earthen backfill material.

Mixture Proportioning Concepts For Flowable Fills With Foundry Sand

The following are the most important physical characteristics of flowable fill mixtures:

- Compressive strength development,
- Flowability,
- Time of set, and
- Bleeding and shrinkage.

Strength Development in flowable fill mixtures is directly related to its water-to-cement ratio. Water is added to achieve a desired flowability or slump. Just like normal concrete mixes with a given cement content, increasing the water content will usually result in a decrease in compressive strength. The coarser the sand, whether natural or foundry, the higher the bearing capacity is of the hardened flowable fill.

Flowability is primarily a function of the water content and aggregate gradation. The higher the water content and the more uniform and spherical the sand, the more flowable the mixture. It is usually desirable to make the mix as flowable as possible in order to take advantage of the self-compacting qualities of the flowable fill.

Time of Set is directly related to the cementitious materials content and type, sand content, water content and weather conditions at the time of placement. Within 24 hours, construction equipment is usually expected to move across the surface of the flowable fill without any apparent damage. The time of set has been found to depend on the type of foundry sand incorporated into the flowable fill. Green foundry sands with low clay content and chemically bonded foundry sands normally require less water in the mixture. The flowable fill also takes less time to harden.

Bleeding and Settlement are possible in high water content flowable fill mixtures, since evaporation of the bleed water often results in settlement. As with any cementitious material, plastic shrinkage cracks on the surface of the fill can occur in high water content mixtures as well. The main concern with plastic shrinkage cracking is that water can infiltrate at a later date. Flowable fill mixtures should be checked for settlement and plastic shrinkage.

Structural design procedures with flowable fill materials containing foundry sand are no different than standard geotechnical design procedures for conventional earth backfill materials. The design procedure uses the unit weight and shear strength of the flowable fill to calculate bearing capacity and lateral pressure of the material for given site conditions.

Closing Comments

Although most foundry sands will meet ASTM C33 gradation requirements, it is not a controlling factor in the flowable fill mix design. If the flowable fill meets the general ASTM test requirements shown in Table 8, the flowable fill should be fine for most applications.

ASTM	Title
C39	Standard test method for compressive strength of cylindrical concrete specimens
C88	Standard test method for soundness of agregates by use of sodium sulfate or magnesium sulfate
C138	Standard test method for density (unit weight), yield, and air content (gravimetric) of concrete
C232	Standard test methods for bleeding of concrete
C403	Time of setting of concrete mixtures by penetration resistance
C827	Change in height at early-ages of cylindrical specimens from cementitious mixtures
D2166	Unconfined compressive strength of cohesive soils, used where minimal or no cement is added to the blend
D4219	Highly fluid grout-like mixes
D4832	Standard test method for preparation and testing of controlled low strength material (CLSM) test cylinders
D5971	Standard practice for sampling freshly mixed CLSM
D6023	Standard test method for unit weight, yield, cement content and air content (gravimetric) of CLSM
D60624	Standard test method for ball drop on CLSM to determine suitability for load application
D6103	Standard test method for flow consistency of CLSM

Table 8. Recommended test methods for flowable fills

Chapter 6:

Foundry Sand in Portland Cement Concrete

Introduction

Portland cement concrete (PCC) is a mixture of approximately 25% fine aggregate, 45% coarse aggregate, 20% cement and 10% water. Foundry sand can be used beneficially in concrete production as a fine aggregate replacement.

Mixture Design and Specification Requirements

Aggregates are classified based on particle size. Fine aggregates consist of natural sand or crushed stone with particle diameters smaller than 3/8 inch. Coarse aggregates are gravel or crushed stone with particle diameters ranging between 3/8 inch and 2 inches.

The selection of aggregate used in concrete is of great importance. Aggregate properties strongly influence the concrete's freshly mixed and hardened properties. Aggregate must be:

- Clean and free of objectionable materials, including organic material, clay and deleterious contaminants, which can affect bonding of the cement paste to the aggregate,
- Strong, hard and durable, and
- Uniformly graded.

Gradation

Specifications governing the selection and use of aggregates in concrete mixtures generally relate to the particle size distribution or gradation of the aggregates. The recommended gradation for fine aggregate is given in Table 9. This specification is geared towards plain concrete and concrete structures, pavements, sidewalks, and precast products.

Sieve No.	Sieve Size (mm)	Percent Passing by Weight
4	4.75	95-100
8	2.36	80-10
16	1.18	50-85
30	0.600	25-60
50	0.600	10-30
100	0.150	2-10

Table 9. Fine aggregate gradation (from ASTM C33)

Generally foundry sand is too fine to permit full substitution. The percentage of materials passing the No. 30, 50 and 100 sieves is too high. To meet the specification, it is necessary to remove the fines or to blend the spent foundry sand with coarser sands. The foundry sands will then comply with the specification. In some areas, natural sands lack finer material. Foundry sand can be blended with them as a partial replacement to satisfy the specification.

Effect of Material Characteristics on Foundry Sand Concrete Quality

Various characteristics of foundry sand can significantly affect the quality of concrete produced. The material characteristics of greatest importance and their effects on the product are discussed below. Foundry sand properties vary in samples taken from one foundry, and there is increased variation from foundry to foundry. This necessitates testing the sand every time prior to use to ascertain its quality.

Particle Size Distribution. The fine aggregate particle size distribution can affect cement and water requirements, as well as concrete workability, economy, porosity, shrinkage and durability. Too many fine particles can lower the concrete strength and adversely affect durability. ASTM C33 requires that the fine aggregate used in concrete have a fineness modulus, an index of aggregate fineness, in the range of 2.3 to 3.1. The fineness modulus of foundry sand typically ranges from 0.9 to 1.6. The sand has to be blended with a coarser material to meet this specification.

Dust Content. ASTM C33 allows a maximum of 5% fine aggregate particles to pass the No. 200 sieve. These particles include clay and other dusts. A large dust content can interfere with the bonding of cement to the aggregate surface, and they can also increase water demand. These factors reduce the durability of hardened concrete. This is a concern when using foundry sands.

Density. Density must be a minimum of 75-110 lbs/ft^3 (1.20 to 1.76 g/cm^3), according to ASTM C330 for general fine aggregate. A higher density aggregate is required when the concrete will be subjected to high compressive loads.

Organics Content/Deleterious Materials Content. According to ASTM C33, the maximum amount of clay lumps and friable particles allowed is 3%. Organic content is restricted because it interferes with hydration of the cement and its subsequent strength. The organic content of aggregate can be measured by a color test.

Grain Shape. Round particles need less water and cement to coat their surface, and they produce a mixture that is more workable. Angularity increases water demand and cement content to maintain a workable mix. Foundry sand particles are typically angular to rounded.

Specific Gravity. Although specific gravity does not directly relate to concrete quality, it can be used as a quality control indicator. The specific gravity of foundry sand varies from 2.5 to 2.8, depending on the source. This compares very favorably to natural sands.

Other Constituents

Coarse Aggregate. Coarse aggregates used in the concrete mixture should be appropriately sampled and tested to ensure good quality. Some aggregates of marginal quality have been observed to adversely affect the matrix of hardened concrete.

Cement. Foundry sand can be used in combination with all types of cementitious materials.

Chemical Admixtures. In general, foundry sand can be used with any concrete containing chemical admixtures. Retarders and water reducers are compatible with most foundry sands. As with natural sands, any organic material in the foundry sand may affect the dosage and effectiveness of air entraining agents. Trial mixtures should always be examined for any potential compatibility problems.

Construction Practices

General Considerations. Foundry sand must be processed prior to reuse, i.e. screened, crushed, and magnetic particles should be separated. This will remove waste and deleterious materials, such as tramp metal and core pieces, preventing technical problems at the mix plant.

Plant Operations. A separate bin should be reserved for the foundry sand at the plant, as is done for fly ash. Foundry sand can be handled in typical aggregate holding bins. It is important to keep the bins clean and the foundry sand dry to help eliminate any bulking problems at the gate opening.

Case Study

Laboratory Use of Foundry Sand in Concrete. An American Foundry Society (AFS) study in Illinois investigated foundry sand as a substitute for fine aggregate in concrete. When foundry sands without fines replaced a portion of the fine aggregate, the concrete produced had compressive strengths, tensile strengths and modulus of elasticity values comparable to mixtures composed of natural sand.

On the other hand, when green foundry sands that had not been processed replaced 33% of the fine aggregate, the resulting concrete compressive strengths at 28 days were between 2600 psi and 4000 psi. These low strength concretes can be used in applications not requiring structural grade concrete, such as buried applications like sewer pipe or below grade concrete. The decrease in concrete compressive strength, as well as in tensile strength and modulus of elasticity, were attributed to too many fines and organic materials (clay and dust) in the foundry sand.

Likewise, foundry sand has been used to make paving blocks and bricks. For these applications, foundry sand replaced 35% of the fine aggregate. If the fineness modulus was not exceeded, the concrete product was acceptable provided they met the ASTM specifications for minimum compressive strength, absorption, and bulk density. It is recommended that proper testing be performed to establish the appropriate limits on foundry sand addition prior to using it in commercially produced products.

Applications

Concrete can be used for cast-in-place or pre-cast products such as pipes, ornamental concrete units, load bearing structural units (i.e., beams, girders, etc.), utility structures and concrete blocks. The ultimate use, shape, and size of the product will govern the type and gradation of the aggregate required in the concrete mixture. For example, the final dimensions of the precast block will determine the maximum aggregate size. For this reason, when marketing spent foundry sand to precast producers or to a ready mix plant, the particle size distribution requirements should be requested ahead of time.

When the required concrete compressive strength is between 50 psi and 2500 psi, a 50% fine aggregate substitution with foundry sand has been successful. As with regular concrete, trial mixtures should always be tested prior to production for any potential compatibility problems.

Limitations

Foundry sand is black. In some concretes, this may cause the finished concrete to have a grayish/black tint, which may not be desirable. A 15% fine aggregate replacement with foundry sand produces a minimal color change. Also, the foundry must be able to meet the quantity requirements of the precast manufacturer.

Chapter 7:

Foundry Sand in Other Engineering Applications

Introduction

Other engineering applications of foundry sand will be presented in this chapter. They include using foundry sand in:

- Portland cement manufacturing,
- Mortars,
- Agricultural / soil amendments,
- Traction material on snow and ice,
- Vitrification of hazardous materials,
- Smelting,
- Rock wool manufacturing,
- Fiberglass manufacturing, and
- Landfill cover or hydraulic barriers.

Foundry Sand in Portland Cement Manufacturing

Portland cement reacts chemically with water when hydrating, causing it to set and to harden. When mixed with fine and coarse aggregate, concrete is formed. There are several specifications for portland cement, as designated by ASTM C150 and ASTM C1157.

Production of Portland Cement. Portland cement is manufactured using materials with the appropriate proportions of calcium oxide, silica, alumina, and iron oxide. These ingredients are found in natural rock, like shale, dolomite, and limestone. It is the chemistry of the foundry sand as a silica source that is more important in cement production than is its grain size or shape. The requirements that must be met for foundry sand to be used in portland cement production are:

- Its silica content equals or exceeds 80%,
- It is a low alkali material,
- A large quantity of sand is available, and
- It has uniform particle sizes.

Foundry sand may be one of the highest quality sources of silica available to the cement industry. The major chemical constituents of raw portland cement available in foundry sand include silica and alumina and iron oxides. By using foundry sands to replace virgin sands, the quantity of mined virgin sands can be reduced.

Blended Cements. Blended hydraulic cements are of particular interest in the beneficial use of foundry sand, since these cements are produced by blending together two or more types of fine materials. Historically, blended cements have included portions of blast furnace slag or fly ash.

Foundry Sand Acceptance by Portland Cement Manufacturers. The cement manufacturer has to evaluate the foundry sand to confirm its compatibility with other raw materials. In addition, cement producers need a chemical oxide analysis, TCLP results, annual volume and a sample. The chemical oxide analysis shows the amount of silica contained in the sand, while the TCLP shows whether or not the sand is hazardous. Also, because limestone, silica and clay are all common materials, the cement manufacturer has to be willing to use foundry sand.

Limitations. Factors that may limit foundry sand use in portland cement manufacturing involve limits on the quantity of foundry sand available and cost issues. Cement manufacturers require significant quantities of silica, 10,000–40,000 tons annually for a plant. It is unlikely that a single foundry can provide that much sand. The sand from several foundries should be pooled at a community storage site to meet the demands of a single cement plant.

Cement manufacturers will pay nominal fees to foundries for the use of their spent sand, but will consider it waste disposal. Additional charges may be levied for handling fees and shipping. However, there is potential for cost savings.

Case Studies

Laboratory Study of Foundry Sand in Cement. The American Foundry Society (AFS) in Illinois studied using green sand from a gray iron foundry in portland cement manufacture. First, a chemical analysis of the sand was performed to see if it met AASHTO specifications. Based on the chemical content, the foundry sand appeared to be an attractive alternative to raw material for cement kiln feed. Four mixtures were designed using 0%, 4.45%, 8.9% and 13.36% of foundry sand. The chemical characteristics of the resulting clinkers showed little difference between those made with and without foundry sand. The cement produced with the foundry sand met all the relevant chemical specifications. The properties of the cement, namely set time and compressive strength, were not affected by the presence of foundry sand. There was even a slight increase in compressive strength.

Commercial Study by Frazer & Jones. In January 1994, a green sand manufacturer (Frazer & Jones) in up-state New York shipped 15,000 tons of foundry sand to a cement manufacturer in Ontario, Canada. It was used successfully as a replacement for excavated silica materials in the manufacture of low-alkali portland cement. The finished product was a high quality portland cement.

Foundry Sand in Grouts and Mortars

Mortars primarily consist of sand, cement and other additives, and are used in masonry construction. Its primary uses are to joint and seal concrete masonry units, to strengthen masonry structures by bonding with steel reinforcing, and to provide architectural quality. Approximately one cubic foot of sand is used to make one cubic foot of mortar. The cement paste occupies the space between the sand particles and makes it workable.

Sand used in masonry mortar mixes is generally specified based on grading. ASTM C144 recommends the following gradation (Table 10). Sands that are deficient in fines make a coarse mix and ones that have too many fines produce a weak mortar.

Sieve No.	Sieve Size (mm)	Percent Passing by Weight
4	4.75	100
8	2.36	95-100
16	1.18	70-85
30	0.600	40-75
50	0.300	20-40
100	0.150	10-25
200	0.075	0-10

Table 10. ASTM C144 sand gradation for mortars

A well-suited aggregate will fall into the middle of this range. Adequate gradation reduces mortar segregation and bleeding and improves mortar water retention and workability. Foundry sand is generally finer than the ASTM gradation requirements, but it can be blended with coarser sands to meet the specification.

In addition to aggregate gradation, the aggregate should be clean and free from wastes, and also have a consistent moisture content. Likewise, the color of the foundry sand can impart a dark tint to the mortar, so it should be deemed acceptable prior to its use in architectural projects.

Foundry Sand in Agricultural/Soil Amendments

Foundry sand can be used as an additive in topsoil and compost materials. It is ideal for topsoil manufacture because of its uniformity, consistency, and dark color. Since a high sand content is required in topsoil, it is an essential ingredient. In composting, foundry sand reduces the formation of clumps and prevents the mix from compacting. This allows air to circulate through the material and to stimulate decomposition. Ohio nurseries have been blending foundry sands with soils and compost for use on ornamentals. Kurtz Bros. of Ohio has also used it successfully as golf green topdressing. For these applications, the presence of clay is beneficial, since it promotes the retention of nutrients.

Regulatory issues for foundry sand use in agricultural applications vary from State to State on a case-by-case basis.

Foundry Sand to Vitrify Hazardous Materials

Because of foundry sand's high silica content, it is an ideal candidate to encapsulate, vitrify or neutralize hazardous materials. Preliminary tests show that this is a feasible option.

Foundry Sand as a Traction Material on Snow and Ice

Another possible use of foundry sand is as an anti-skid material on roads covered with snow and ice. Particularly its angular particles improve traction on highways in the winter. Likewise, its black color (ex. green sand) will hold the heat longer and will melt the ice faster. To be used as an anti-skid material, the foundry sand must meet each State's requirements. Typically, foundry sand is too fine to comply with anti-skid regulations, but when mixed with a coarser material, it does comply. Trial mixes should be formulated and evaluated prior to use. In addition, the foundry sand should be free from glass, metals, or other substances that could be harmful to cars and vehicles.

Foundry Sand for Smelting

Another potential use for foundry sand is as a raw material in zinc and copper smelting. Foundry sand can be used in place of virgin sand. Guidelines for using silica sands in zinc and copper smelting are that the sand should be relatively pure silica (minimum 99.0%), have a maximum particle size of 2 mm and a bulk phenol content of less than 2 mg/kg (ppm).

The foundry should demonstrate to the smelting plant that the foundry sand meets these criteria and will produce quality zinc and copper.

Case Study. A smelter in California has been using recycled foundry sand for some time. All of the foundry sands used in area brass and steel foundries were deemed acceptable due to their high silica content.

Foundry Sand in in Rock Wool Manufacturing

Rock wool fibers are commonly used to reinforce other materials, such as building material insulation, and are similar to fiberglass. Foundry sand can serve as a source of silica in the rock wool production process. They are produced by combining blast furnace slag with silica or alumina in a cupola furnace and then fiberizing the molten material. To be used in production, the foundry sand has to be pre-treated and formed into briquettes.

Foundry Sand in Fiberglass Manufacturing

Foundry sand can be used in the manufacture of fiberglass. Fiberglass is produced by melting silica sand and straining it through a platinum sieve with microscopic holes, thereby forming the desired glass fibers. Manufacturers of fiber-glass, such as Owens-Corning and CertainTeed Corporation, have specifications for silica content and particle size distribution, so to be used in this application, the foundry sand has to have the needed properties.

Foundry Sand for Landfill Cover or Hydraulic Barriers

Foundry sand has been used for some time as a daily cover soil on municipal waste landfills and as a landfill liner. Foundry sand containing clay (> 6%) and the following Atterberg limits (liquid limit greater than 20 and plastic index greater than 3) has a low permeability. It is an ideal material for final or top cover. It is also expected to be resistant to permeation by brines and leachates in the short term.

Each State may have different requirements placed on landfill materials and foundry sand usage should be decided on a case-by-case basis.

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