Waste Foundry Sand in Asphalt Concrete

SAYEED JAVED, C. W. LOVELL, AND LEONARD E. WOOD

Sands, binders, and additives are used to form molds and cores of metal castings. The sands are reused a number of times but ultimately are sufficiently altered to require being discarded. A laboratory study of a variety of waste sands from Indiana foundries is reported. Most of the wastes were generated from a green sand molding of gray iron products. Other sands were from chemically bonded and shell molding processes. The suitability of waste sands for use as a fine aggregate in asphalt concrete has been examined by replacing some portions of conventional aggregates with a particular waste foundry sand. A replacement level of 15 percent was found to be suitable for this case.

Waste foundry sand (WFS) is a by-product of the casting industry that results from the molding and core-making processes. The mold forms the outside of the castings, and the core forms the internal shape. When the part to be made has deep recesses or hollow portions, sand cores must be provided in the mold.

The annual generation of WFS in Indiana is about 1.78 MN (200,000 tons) (*1*). The bulk of this WFS is nonhazardous and is currently deposited in landfills. The scarcity of landfill space and increase in tipping fees have stimulated the pursuit of disposal other than in landfill or beneficial reuse. A project was undertaken with the cooperation of Indiana Cast Metals Association (INCMA) to evaluate different beneficial reuses of WFS in highway construction. The different applications of WFS, which include geotechnical fill material, fine aggregate supplement in asphalt concrete, and fine aggregate in controlled low strength material (CLSM), are being evaluated. Previous work in geotechnical fill has shown that these materials have good shear strength properties and slightly higher compressibilities and are of low permeability as compared with conventional materials (*2*). The suitability of using WFS as a fine aggregate supplement in asphalt concrete is discussed.

Three types of WFS were tested. Seven were from green sand processes, which means that the metal is poured into the molds when the sand is damp, as it is when the mold is made (*3*). Two types were from chemically bonded processes and one was from the shell-molding process. Samples from green sand are designated G; chemically bonded, C; and shell molding, S. In the green sand process, bentonite is typically added as a binding agent with other additives like seacoal. Chemically bonded sands are those that use furan, phenolic urethane, and acid-cured no-bake systems (*4*). Shell molding uses a mixture of sand and thermosetting resin (usually phenol-formaldehyde) to form the mold. When it touches a heated pattern, the sand-resin mixture forms a thin shell due to the polymerization of the resin, which binds the sand particles (*5*).

Initially, characterization tests were performed to determine if the materials would meet basic requirements for mineral aggregates intended for use in asphalt concrete mixtures. On the basis of the characterization tests, G1 (the first sample of the green sand process) was then selected to compare physical and mechanical properties of a control asphalt mixture with a mixture containing different proportions of G1.

MATERIAL CHARACTERISTICS OF WFS

The suitability of aggregates for use in asphalt concrete was determined by evaluating the following material characteristics:

1. Gradation,
2. Cleanliness and deleterious materials,
3. Clay lumps and friable particles,
4. Durability and soundness,
5. Particle shape and surface texture, and
6. Affinity for asphalt.

Gradation

Aggregate gradation is the distribution of particle sizes expressed as a percent of the total weight. Gradation is one of the most important characteristics of an aggregate. It affects almost all the important properties of an asphaltic mixture, including stiffness, stability, durability, permeability, workability, fatigue resistance, skid resistance, and resistance to moisture damage (*6*). The particle size distributions of the 10 samples are shown in Figure 1. The foundry sands were found to be uniformly graded.

Deleterious Materials

Deleterious substances may include vegetation, clay coating on aggregate particles, iron oxides, gypsum, water-soluble salts, and other particles that affect proper bonding with asphalt. Deleterious materials may also increase the moisture susceptibility of an asphalt mixture. Aggregates with deleterious substances are undesirable and should not be used unless the amount of foreign matter is reduced by washing or other means. The plasticity index (PI) is used to identify and measure the quantity of deleterious materials. ASTM D1073 limits the PI to a value of 4 or less. Most of the WFSs tested were found to be nonplastic. Only G3 and G5 were found to be have a PI greater than 4.

Clay Lumps and Friable Particles

Clay lumps are composed of clay and silt that remains cohesive during processing. Friable particles are characterized by a poor bond between the grains; hence they break down easily into many smaller pieces. These lumps and friable particles in the finished hot-mix asphalt mixture can break down from freezing and thaw-

---

School of Civil Engineering, 1284 Civil Building, Purdue University, West Lafayette, Ind. 47907.

ing or wetting and drying and cause stripping or ravelling or otherwise affect the durability of the asphalt mixture. Specifications normally limit the amount of clay lumps and friable particles to a maximum of 1 percent. The quantities of clay lumps and friable particles for the 10 WFSs are summarized in Table 1. Since eight of them exceeded the recommended value of 1 percent, it appears that processing of these materials is required before their use.

Durability and Soundness

The soundness test, ASTM C 88, is an empirical screening test that is intended to provide an indication of durability. According to Indiana specifications for fine aggregates, weighted percent loss should not exceed 10 percent by weight after being subjected to five cycles of the sodium sulfate soundness test (*7*). Soundness values for the 10 samples are reported in Table 1. Six of the samples failed this requirement. The high soundness loss may be due to the agglomeration of fine particles during the mulling process of sand with binder and additives in the foundry operation. These agglomerates then tend to break down during the severe action of sodium and magnesium sulfate.

The soundness test has been widely criticized for its inability to accurately predict field performance for specific aggregates. Since in hot mixes there is low moisture in the aggregate, it is expected that freezing and thawing should not be a significant problem. Moreover, the aggregates are coated with a film of asphalt binder that would prevent the aggregates from absorbing a significant amount of moisture during the life of the mixture (*6*).

Particle Shape and Surface Texture

For mixes containing fine and coarse aggregates, the angularity of the fine aggregate is more important to mixture stability than is the angularity of the coarse aggregate (*8*). Angular aggregates are

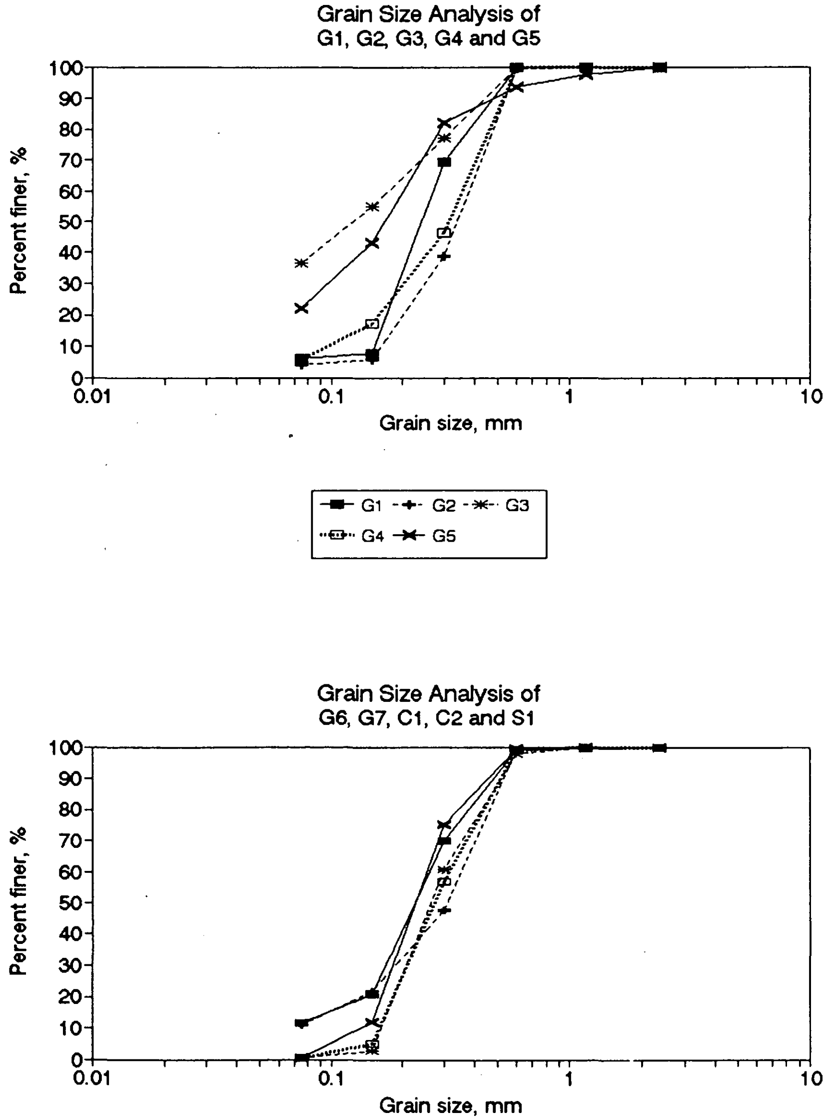

FIGURE 1 **Grain size analysis of 10 samples tested.**

desirable, as opposed to mixtures containing rounded particles, because they result in better workability and require less compactive effort to obtain the required density. This ease of compaction is not necessarily an advantage, however, since mixtures that are easy to compact during construction may continue to densify under traffic, ultimately leading to rutting due to low voids and plastic flow (*6*).

Smooth-textured aggregate is easy to coat with an asphalt film but offers little adhesion to hold the film in place. Thus the rougher the surface texture, generally the higher the stability and durability of the bituminous mixture.

The combined effect of particle shape and texture was determined from the National Aggregates Association uncompacted voids test (*9*) with the following exceptions: apparent specific gravity values according to ASTM D 854 were used to calculate the void content, and the right cylinder to be filled with fine aggregate was 7.6 cm (3 in.) in diameter and 8.9 cm (3.5 in.) high. The results are summarized in Table 1. An increase in void content indicates greater angularity or rougher texture or both. Lower void content results are associated with more rounded, smooth-surfaced fine aggregate. The uncompacted void content for a virgin foundry sand was found to be 43.7 percent. This suggests that WFSs were a little rougher. This roughness may be due to agglomeration of sand with binder and additives.

Affinity for Asphalt

It is known that WFS contains a large portion of silica. Silicates are acidic in nature and generally have a greater affinity for water than for bituminous material, and bituminous films may be more or less easily displaced from them by water. However, affinity for asphalt of the combined aggregates in an asphalt concrete mixture is more significant than for this fraction alone.

PHYSICAL AND MECHANICAL PROPERTIES OF CONTROL AND BLENDED MIXTURES

On the basis of the characterization test results, G1 was selected for detailed testing. The physical and mechanical tests included in this category were bulk specific gravity and theoretical maximum specific gravity as physical tests and Marshall stability and flow as mechanical tests.

The experimental mixture of conventional aggregates and WFS was blended to produce final products with 15, 20, and 30 percent WFS by weight of total aggregates. The total weight of aggregates for a typical mix was 1200 g (2.65 lb). Thus 15 percent blending means 156.5 g (0.35 lb) of WFS and 1043.5 g (2.30 lb) of conventional aggregates and so on for increased percentages of blending. The gradations of the control (aggregates with no WFS) and the samples prepared by blending 15, 20, and 30 percent of WFS with respect to control are shown in Figure 2. The upper and lower limits of No. 12 mix according to Indiana specifications are also included. Instead of the fines being scalped from the normal fine aggregate, blending was carried out as a partial replacement keeping in mind that a scalping procedure would be expensive and nonproductive.

The control contained crushed angular limestone aggregates down to the No. 16 sieve. The balance consisted of natural sands. These aggregates were combined with asphalt in accordance with procedures outlined by the Marshall method of mixture design (*10*), using 75 blows per side of each specimen. Tests of bulk specific gravity and Marshall stability and flow were carried out

TABLE 1 Characterization of Test Results on 10 Samples Tested

Sample #	Soundness %	Clay Lumps & Friable Particles, %	Uncompacted Voids, %
G1	9	1.35	48.6
G2	6	1.72	45.1
G3	25	44.33	58.3
G4	45	2.59	47.8
G5	9	0.62	49.9
G6	17	2.26	51.3
G7	47	23.22	51.1
C1	12	100.00	45.2
C2	21	0.00	47.0
S1	10	10.64	47.2

on the compacted mixtures in accordance with ASTM D2726 and D1559. Results of this work produced mixtures with the properties shown in Figure 3. The design criteria according to the Asphalt Institute (*10*) are shown in Table 2.

Figure 3 when compared with design criteria indicates that control specimens prepared at 5.75 percent asphalt were at or near optimum. WFS was then blended in different proportions at 5.75 percent asphalt and the above properties were again determined. Figure 4 shows these properties when WFS was blended at 15, 20, and 30 percent of the total aggregates. However, it would be more interesting to compare these properties at optimum asphalt content for each percentage of blending.

MOISTURE SUSCEPTIBILITY

The control and mixtures containing 15 percent WFS and 30 percent WFS were then evaluated to determine their indirect tensile strength under normal conditions and soaked conditions to determine the effect of moisture susceptibility. Six specimens at 5.75 percent asphalt content using 75 blows at each side were prepared for each type of three mixtures, including two WFS mixes (15 percent WFS and 30 percent WFS) and one control mix. Thus a total of 18 specimens were prepared. Each mixture of six specimens was then sorted into two groups so that both the groups yielded similar average bulk specific gravity. The first group of three samples was then tested after an air bath of 5 hr at 25°C temperature. The second group of another three samples was tested after first immersing the samples in water at 60°C for 24 hr and then later submerging them at 25°C for 2 hr. The results are shown in Table 3.

DISCUSSION OF TEST RESULTS

The uncompacted void content (UVC) for the sand used in the control mix was found to be 43.3, and that of the virgin sand for WFS was 43.7. Thus, in terms of particle shape and texture, both sands were similar. However, the UVC for all the WFSs was higher than 43.6. The G1 sand used in this study had a UVC of

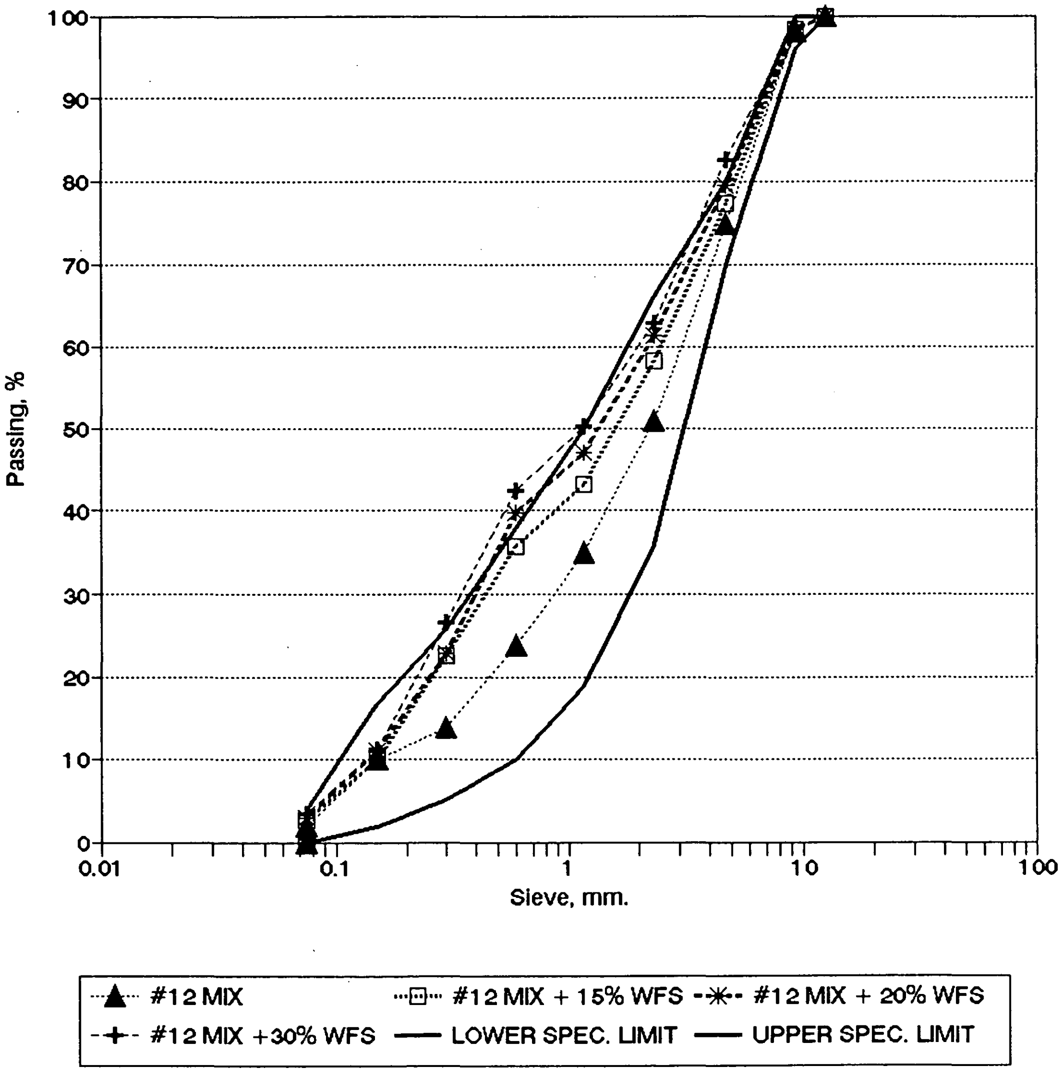

FIGURE 2 Gradation of control, specimens blended with WFS, and boundary limits of No. 12 mix.

48.6 (Table 1). The UVC for the portion of limestone aggregates passing the No. 8 sieve and being retained on the No. 16 sieve was found to be 50.1. The UVC for limestone aggregates above the No. 8 sieve could not be determined because of the limitation of the 1.27-cm (0.5-in.) funnel opening. If the UVC for the aggregates coarser than No. 8 is assumed to be the same as that for limestone aggregates passing the No. 8 and being retained on the No. 16 sieve, the resulting weighted UVC with increased blending of WFS would be calculated as shown in Table 4, which shows that the angularity or roughness, or both, with increased blending of WFS was very insignificant and was almost the same as that of the control mix.

Increasing amounts of WFS in the control mix resulted in a decrease of the unit weight. This was expected because increasing amounts of WFS were replacing the heavier conventional materials. The bulk specific gravity of G1 was 2.50, whereas that of the control mix was 2.66. Moreover, uniformly graded and relatively more rough-textured WFS tends to increase voids, which results in a decrease of unit weight.

Percentage of air voids and voids in the mineral aggregate (VMA) were found to increase with blending of increased quantities of WFS. This was due to deviation from dense gradation. VMA has two components: the volume of the voids that is filled with asphalt and the volume of voids remaining after compaction. The volume of asphalt was same for different replacement levels. However, it was the percentage of air voids that was increasing VMA. A certain percentage of air voids is always desirable to ensure that space will remain for expansion of the bitumen if

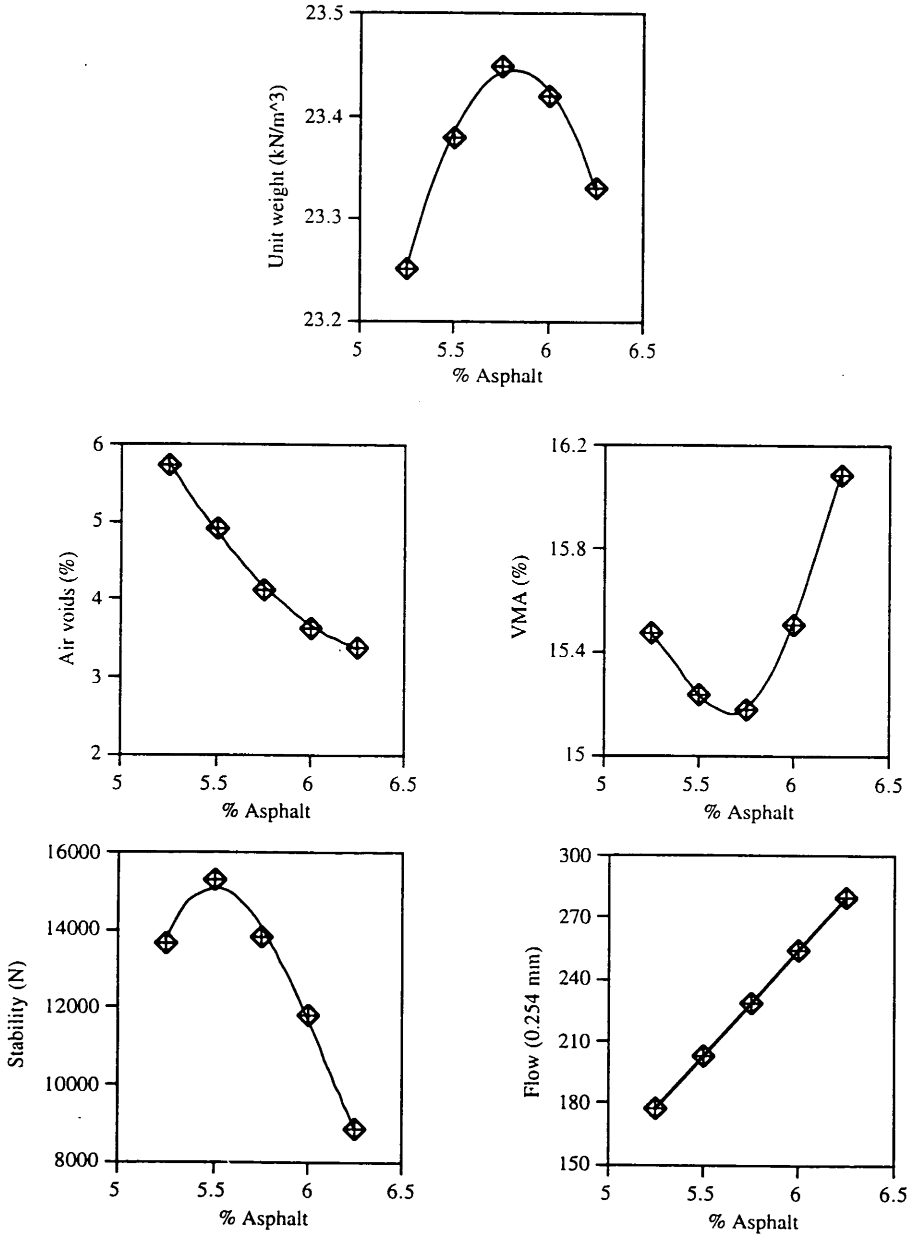

FIGURE 3 Physical and mechanical properties of conventional aggregate mixture at varying asphalt contents.

TABLE 2 Asphalt Institute Criteria

Parameters	Acceptance Range
Marshall Stability, N.	6675 minimum
Flow (0.254 mm)	203-406
Air Voids, %	3-5
VMA, % for 9.53 mm. maximum size	14 minimum

1 lb = 4.45 N

1 inch = 25.4 mm

further densification under traffic or expansion to the asphalt that would occur on a hot summer day is expected. However, if the air void contents are high, there is a possibility that water will get into the mix, penetrate the thin asphalt films within the aggregate and asphalt mass, and lower the resistance of the mix to the action of water.

Marshall stability is defined as the maximum load carried by a compacted specimen tested at 60°C at a loading rate of 5 cm/min (2 in./min). This stability is generally a measure of the mass viscosity of the aggregate-asphalt cement mixture and is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement at 60°C. Stability values are also influenced by the aggregate gradation. The aggregate that has

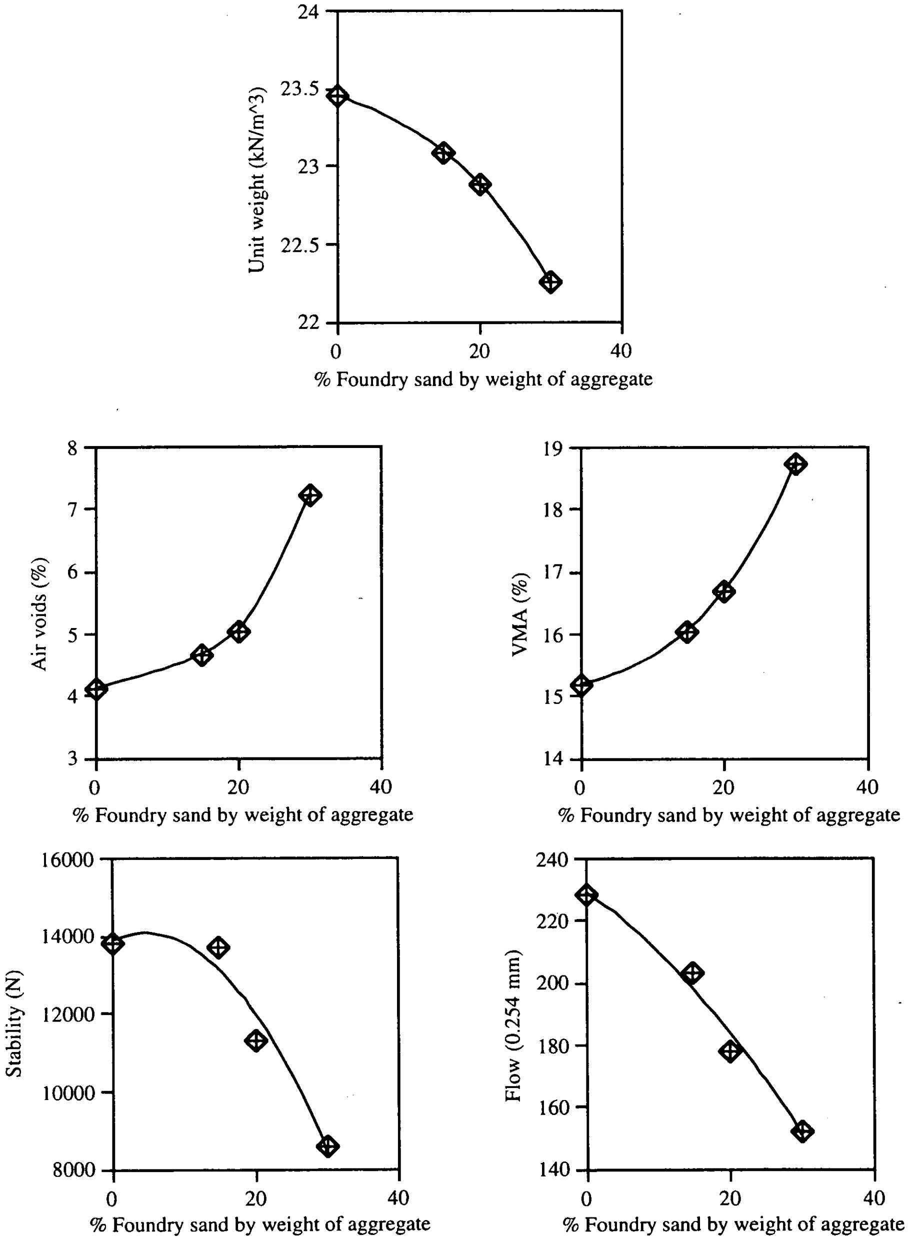

FIGURE 4 Physical and mechanical properties using different percentages of WFS at 5.75 percent asphalt content.

TABLE 3 Results of Indirect Tension Before and After Immersion

Before Immersion

Sample #	CF0	CF15	CF30
Foundry sand, %	0	15	30
Bulk specific gravity	2.393	2.341	2.281
Tensile strength, kPa	1424.58	1341.28	814.33

After immersion

Sample #	CF0	CF15	CF30
Foundry sand, %	0	15	30
Bulk specific gravity	2.395	2.345	2.280
Tensile strength, kPa	1504.64	1451.86	682.59

1 psi = 6.89 kPa

TABLE 4 Weighted Uncompacted Void Content with Blending of Increased Quantities of WFS

Type of Sample	Weighted Uncompacted Void Content[1]
Control mix	47.7
Control mix + 15% WFS	47.8
Control mix + 20% WFS	47.9
Control mix + 30% WFS	47.9

[1] Weighted UVC = $(W1 \times U1 + W2 \times U2 + W3 \times U3)/W$

W1 = Weight of limestone aggregates

U1 = UVC of limestone aggregates

W2 = Weight of natural sand used in the control mix

U2 = UVC of natural sand

W3 = Weight of WFS

U3 = UVC of WFS

W = Total weight of aggregates

maximum density provides increased stability through increased interparticle contacts and reduced VMA (*6*). Stability values obtained by blending 15 percent WFS were found to be essentially the same as those of the control mix. However by blending more WFS, stability was found to decrease as compared with the control mix. The increase in roughness due to increased blending of WFS was very insignificant as compared with deviation from dense gradation, which ultimately resulted in decrease of stability.

The flow is equal to the vertical deformation of the sample (measured from the start of loading to the point at which stability begins to decrease) in 0.254 mm (0.01 in.). High flow values generally indicate a plastic mix that will experience permanent deformation under traffic, whereas low flow values may indicate a mix with higher-than-normal voids and insufficient asphalt for durability. Such a mix may experience premature cracking due to mixture brittleness during the life of the pavement (*6*). It was found that flow values decreased with increased amounts of WFS. The low flow values were associated with increasing air voids caused mainly by increase in uniformly graded WFS.

The indirect tensile strength also decreased with blending of increased amounts of WFS. Both the control sample and the sample containing 15 percent WFS showed an increase in strength after immersion in water (Table 3). This might have occurred because of asphalt hardening. However, the sample containing 30 percent WFS showed a decrease in strength after immersion. This was due to a significant increase in the percentage of air voids. High air voids resulted in stripping caused by the introduction of water between the asphalt and the aggregate particles.

CONCLUSIONS

A number of conclusions may be drawn from the testing program reported here:

1. When as much as 15 percent of this particular WFS is blended with conventional aggregates, the performance of the asphalt concrete mixture is not very different from that using conventional materials. However, using more than 15 percent WFS in the conventional aggregates resulted in low flow values and high air voids, which may lead to mixture brittleness and consequently premature cracking.
2. The increase in roughness with blending of increased quantities of WFS was very insignificant as compared with deviation from dense gradation.
3. With a few exceptions, WFSs of different Indiana foundries are very similar in gradation (Figure 2) and shape and texture (Table 1). Thus, conclusion 1 may be generally applicable.
4. Lumps in the WFS may be a problem, requiring some cleaning or washing before use.
5. Even with the washing requirements, WFS will be viable for limited blending with conventional aggregates in asphaltic concrete mixtures.

ACKNOWLEDGMENTS

The authors wish to extend their appreciation to the Indiana Cast Metals Association, which provided funding for this research. In addition, Shabbir Alam deserves thanks for his assistance in the laboratory work.

REFERENCES

1. Javed, S. *Use of Waste Foundry Sand in Highway Construction—Interim Report.* Report JHRP-92/12. School of Civil Engineering, Purdue University, West Lafayette, Ind., May 1992.
2. Javed, S., and C. W. Lovell. Use of Waste Foundry Sand in Highway Construction. In *Proc., 44th Highway Geology Symposium*, Tampa, Florida, May 1993.
3. Wendt, R. E. *Foundry Work.* McGraw-Hill, New York, 1942.
4. Hayes, R. A. Reclaiming Chemically Bonded Sands: A Technology Review. *Modern Casting*, May 1993, p. 37.
5. Cannon, W. A. *How to Cast Small Metal and Rubber Parts*, 2nd ed. TAB Books, Inc., Blue Summit, Pa., 1986, p. 10.
6. Roberts, F. L., P. S. Kandhal, E. R. Brown, D. Y. Lee, and T. W. Kennedy. *Hot Mix Asphalt Materials, Mixture, Design, and Construction.* NAPA Education Foundation, Lanham, Md., 1991.
7. Indiana Department of Highways. *Standard Specifications.* Indianapolis, 1988.
8. Herrin, M., and W. H. Goetz. Effect of Aggregate Shape on Stability of Bituminous Mixes. *HRB Proc.*, Vol. 33, 1954.
9. Meininger, R. C. *Proposed Method of Test for Particle Shape and Texture of Fine Aggregate Using Uncompacted Void Content.* National Aggregates Association, Md., March 1989.
10. Asphalt Institute. *Mix Design Methods for Asphalt Concrete and Other Hot Mix Types.* Manual Series No. 2, MS-2. College Park, Md., 1988.