Recycled Foundry Sand In the Mix

This is the second article of a two-part series on the use of recycled foundry sand (RFS) in Hot Mix Asphalt (HMA) pavements. Part one focused on the availability and processing of RFS. This article addresses the properties of unprocessed and processed RFS as well as a mix using RFS and economics.

Close-up of Recycled Found Sand stockpile (quarter used for reference)

Photo Courtesy: Chuck Hughes

By Chuck Hughes, P.E.

There are several material characteristics that are important for fine aggregate to perform its function in HMA. These are gradation; cleanliness; deleterious materials; soundness; and particle shape and surface texture.

Gradation affects many properties of a mixture. A study of 13 Wisconsin foundries measured the gradation of the spent foundry sand. The results from seven foundries are shown in Figure 1 and are typical of many.[1]

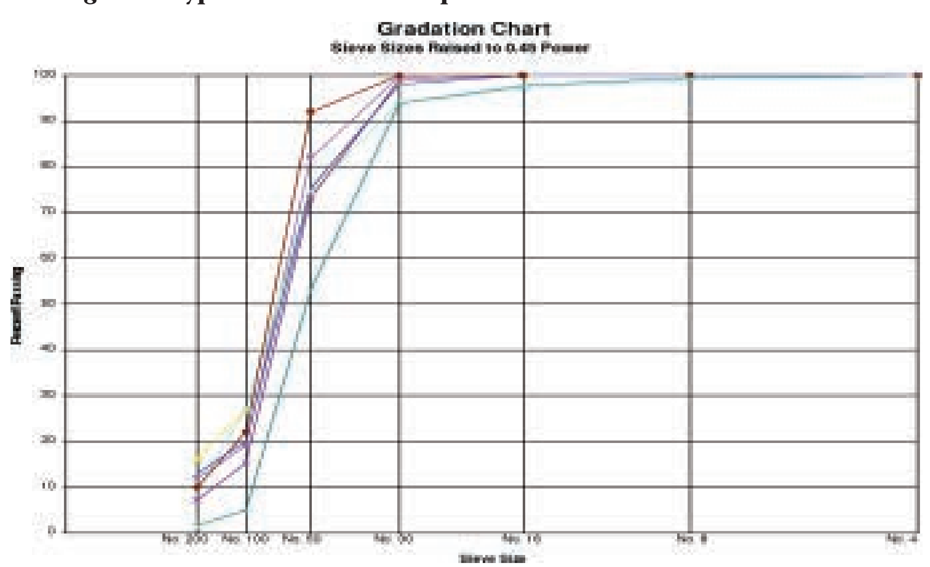
As seen in Figure 1, the spent sands tend to be uniformly graded from the #30 (600 µm) sieve through the #200 (75 µm) sieve with between 2 percent and 16 percent passing the #200 (75 µm) sieve. Few of these sands meet AASHTO M 29 Fine Aggregate for Bituminous Paving Mixtures Standards without blending with other fine aggregate. Depending on the grading, AASHTO M 29 allows a maximum of 5 percent to 10 percent passing the #200 (75 µm) sieve. Thus, those sands with the higher fines content may need to be processed to remove the excess fines.

The removal of excess clay from green sand is one of the important steps for the foundry, the independent aggregate processor, or the HMA producer to undertake to prepare the sand for use in HMA.

Cleanliness and **deleterious materials** are sometimes considered together. Here they are considered separately due to the possibility that the unprocessed spent sand may have an excess clay coating. The sand equivalent value and plasticity index (PI) tests can be used for specifying the required cleanliness. A minimum sand equivalent value of 45 (ASTM D 2419) and/or a non-plastic (NP) classification from the PI (AASHTO T 90) are considered necessary.

Spent sand may contain deleterious materials such as clay lumps, metal, and rubbish that may get in the spent sand stream. The clay can be removed by screening and/or washing when necessary or

Figure 1: Typical Gradations of Spent Sands from Wisconsin Foundries



by the use of a baghouse. Iron can usually be removed by magnets and/or hand separation. Any rubbish present must also be eliminated by screening and/or hand separation.

Fine aggregate should be sound and durable. Although the **soundness** test was developed for aggregates used in portland concrete cement (PCC) mixes, most state highway agencies also require HMA aggregates to meet soundness requirements. The requirements for fine aggregate soundness characteristics, when used, are shown in Table 1. For RFS, this characteristic is usually easily met.

Particle shape and surface texture are also considered important. Natural sand is often used in HMA. In the past, the natural sand content has been limited to 15 percent by mass of the aggregate blend to minimize the potential for rounded natural sands acting like ball bearings in the mix. But more recent Superpave mixture requirements have focused on the angularity of the sand as a measure of particle shape as opposed to trying to define whether it is manufactured or natural. The fine aggregate angularity (FAA) test, as measured by the uncompacted void content (AASHTO T 33), has been demonstrated to be a measure of the angularity and is preferred over the descriptive terms of "natural" or "manufactured" sands. The requirements for FAA, as well as sand equivalent and soundness, are shown in Table 1.

Studies of Spent Sand Properties

In addition to the University of Wisconsin study mentioned previously, Purdue University conducted a study of Indiana foundries.[2] Both of these laboratory studies provide test results related to properties of the spent foundry sand.

Related to clay content, the Indiana study reported, for eight of the 10 foundry sands (green sands) tested, the PI was less than a value of 4, the maximum PI allowed in AASHTO M 29. Using this requirement, sands that have a PI value that exceeds 4 must be processed to reduce the plasticity. The Indiana study also reported that eight unprocessed foundry sands had clay lumps that exceeded the recommended maximum value of 1 percent, another indication of the need to process the spent foundry sand prior to use in HMA.

The Wisconsin study reported several sand properties used to qualify fine aggregates in Superpave mixture design. This study used the Superpave test array to determine the sand equivalent value and to measure the FAA. These results are shown in Figures 2 and 3. Additionally, the Wisconsin study measured the absorption of the sands using AASHTO 84 and these values are shown in Figure 4.

Of the 17 foundry sands and one virgin sand tested in the Wisconsin study, only three unprocessed foundry sands and the virgin sand met the minimum Superpave sand equivalent value for cleanliness. This again indicates the need for reducing the clay content.

All but one unprocessed spent foundry sand tested met the lowest particle shape FAA requirement without blending, and most met the highest Superpave requirement.

Processed RFS Properties

As stated previously, one of the main focuses of processing the RFS green sand is to remove sufficient fines, usually clay, to make the sand usable in HMA. Recycled foundry sand gradations from four different sources

**Table 1:
Desirable Fine Aggregate Characteristic Requirements**

Test	Test Method	Typical Specification Range
Sand Equivalent Value*	AASHTO T176	40 – 50 minimum
Fine Aggregate Angularity, percent	AASHTO TP33	40 – 45 minimum
Soundness, Loss percent	AASHTO T104	
Sodium Sulfate		15 maximum
Magnesium Sulfate		20 maximum

*Required value depends on traffic level

Figure 2: Sand Equivalent of Unprocessed Foundry Sand

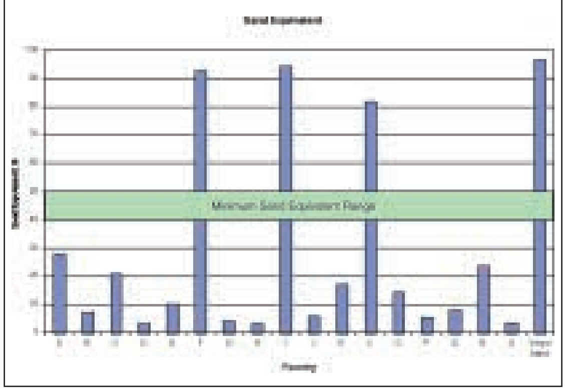
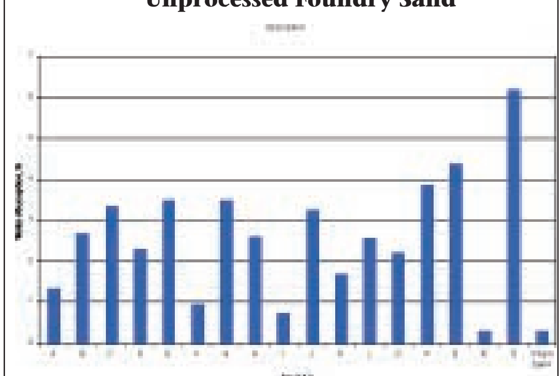


Figure 3: Fine Aggregate Angularity of Unprocessed Foundry Sand

Figure 4: Absorption of Unprocessed Foundry Sand



are shown in Figure 5. These gradations show that the percent passing the #200 sieve (75 µm) is typically very low and is an indication that either the excess clay has been removed, if it was a green sand, or that it was a chemically-bound sand with a typically lower fines percentage.

Because the clay has been removed by screening, washing, or the use of a baghouse, the material meets DOT cleanliness requirements.

The deleterious materials may be removed by hand separation and/or by screening. This property is typically monitored by inspection. However, there may be a concern that the RFS contains an appreciable percentage of metal. As mentioned several times, it is in the best interest of the RFS processor to remove as much of the metal as possible because of the economic benefits of this by-product. There are reports that typically less than 0.1 percent metal remains in the RFS after processing.

The Wisconsin laboratory study found that the FAA did not change after washing. Thus, the FAA of the RFS should be essentially the same as the unprocessed sand. As discussed previously, all but one sand met the FAA requirement for Superpave.

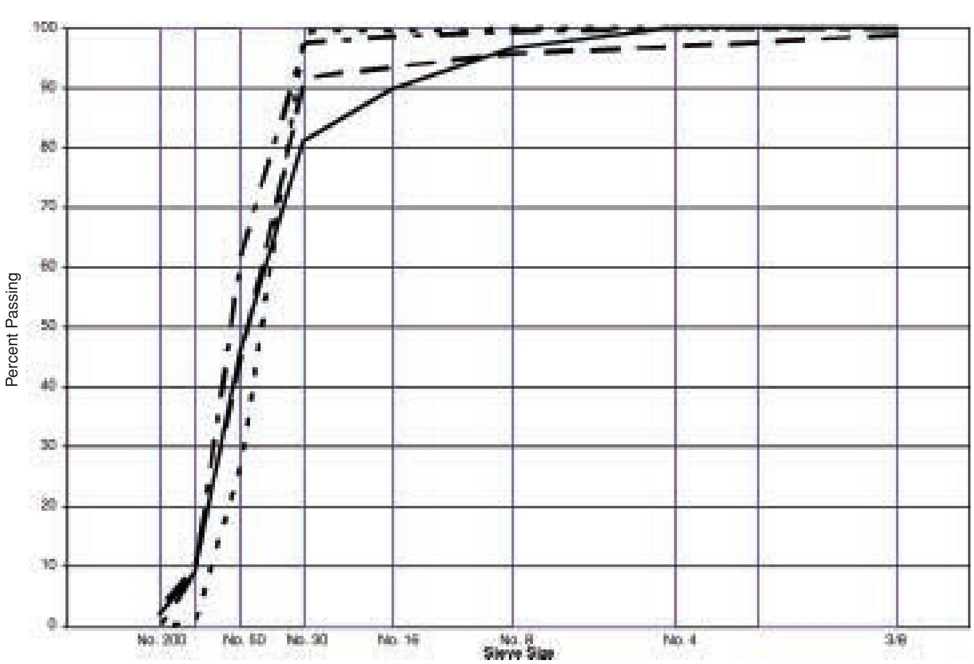
Percentages of RFS Used in HMA

The percentages of RFS that are used in HMA tend to vary, as expected, considering the variety of aggregates with which they are blended.

The Wisconsin study developed a blend optimization program to determine the proportion of each stockpile, including the RFS, to use in the aggregate blend. For the unprocessed sands, they found the percent of foundry sand that could be used varied from about 14 percent to about 19 percent.

The Indiana study concluded that replacing some portion of conventional aggregate with foundry sand could be accomplished at a level of 15 percent.[2] In practice, the typical usage rate is similar to what the laboratory studies indicate is appropriate and ranges from 8 percent to 25 percent. However, specialty HMA mixes, such as those for tennis courts, may use as much as 35 percent RFS.[3]

Figure 5: Typical Gradations of Processed RFS



One of the main focuses of processing the RFS green sand is to remove sufficient fines, usually clay, to make the sand usable in HMA.

Laboratory Properties of HMA Using RFS

The two laboratory studies conducted by the University of Wisconsin and Purdue University concluded that using RFS in amounts up to about 15 percent produced mixture results comparable to those using a like percentage of conventional sands.

It should be kept in mind that the University of Wisconsin study used "delivered spent sand," not processed RFS. The conclusions concerning mixture properties found in the study that used initial Superpave mixture design criteria are as follows:

- The optimum asphalt content for HMA surface mixtures containing various types of foundry sands ranged between 5 percent and 6.25 percent, which is comparable to the control mixture that did not contain foundry sand. Binder mixtures are typically coarser and consequently have a lower optimum asphalt content. Tri-State Sand Co., the largest operation in Tennessee, has produced binder mixtures using RFS with about 4.2 percent asphalt content.[4]
- VMA results ranged between 13.3 percent and 16.8 percent. Minimum VMA Superpave requirements for the 12.5 mm nominal maximum size mix studied is 14 percent. So most of the mixes using the foundry sand met the VMA requirement, but some did not.

- The VFA results for the mixtures satisfied the Superpave mixture design requirements.
- The moisture susceptibility properties of mixtures containing foundry sand and the control sand were low. However, since no anti-strip additive was used in any mixes, this conclusion is not very definitive. The study recommended further research of this property.
- Foundry sand can be used as a replacement for conventional fine aggregate in HMA mixtures.
- The majority of spent foundry sand should be processed before being used in HMA.

The conclusions concerning mixture properties found in the Purdue University study that used Marshall mixture design criteria are as follows:

- When as much as 15 percent of this particular RFS is blended with conventional aggregates, the performance of the HMA is not very different from those using conventional materials.
- The increase in roughness (higher FAA values) with blending of increased quantities of RFS was very insignificant as compared with deviation from dense gradation.
- With a few exceptions, RFS of different Indiana foundries are very similar in gradation and shape and texture.
- Lumps in the RFS may be a problem, requiring some cleaning or washing before use.
- Even with washing, RFS may be viable for only limited blending with conventional aggregates in HMA.

Performance Tests Results

Wisconsin collaborated with the Federal Highway Administration (FHWA) to conduct Superpave performance tests on RFS.[5] This study concluded that many of the sands taken from Wisconsin foundries pass consensus property specifications used currently in HMA design. Some sands were found to improve stability and moisture resistance of mixes, while others had no noticeable effect. Mixes produced with foundry sand were found to be able to pass volumetric criteria. The effect of foundry sands on fundamental performance properties of HMA varies greatly from one sand to another. No results were found that would exclude foundry sands from being used effectively in HMA. Some of the specific conclusions are as follows:

- The RFS have, generally, high angularity characteristics as measured by Superpave uncompacted void criteria.
- Volumetric tests revealed that the addition of RFS required a

minor increase in the required asphalt content of the mixture.

- No significant problems were observed regarding compaction of mixes or reaching the appropriate air voids.
- Stability of mixes made with RFS, as measured by the Gyratory Load-cell Plate Assembly (GLPA), a special device in the gyratory compactor, can be higher than those made with conventional sand.
- With regard to moisture resistance, the Hamburg test results indicate RFS improve the resistance compared to the control mix that used conventional sand.
- The type of RFS is important with regard to the Superpave Shear Tester (SST) results. Some sands appeared to improve the mixture resistance to rutting, while others did not. All sands, however, appear to contribute positively to the resistance to fatigue damage under control strain conditions.
- There appears to be potential positive effects of using RFS on mixture performance.

Quality of HMA Using RFS

The quality of HMA using RFS is essentially no different than the quality of HMA using conventional aggregates. The states of Pennsylvania, Michigan, and Tennessee are examples of departments of transportation (DOT) that allow RFS in Hot Mix Asphalt. The HMA producers determine the optimum percentage of RFS that fits their conventional aggregates.

According to Ed Canters, Quality Control Manager for an HMA plant in Washington County, Tennessee, the mix with 10 percent RFS compacts better and out performs the Tennessee C mix it replaced that used washed river sand. This plant produces about 70,000 tons of HMA per year with much of it using RFS.

Eastern Industries in Pennsylvania typically uses 8 percent to 10 percent RFS in their ID-2 Wearing course that meets all PennDOT requirements. Likewise, the plant of Asphalt Paving Inc. of Muskegon, Michigan produces HMA incorporating from 10 percent to 20 percent RFS in mixes meeting Michigan DOT 1300L, 36A, and 4B specifications.

A Superpave mixture design performed by the University of Wisconsin using RFS is essentially no different than a Superpave mixture design using conventional aggregates.

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Economic Considerations

The use of recycled foundry sand in Hot Mix Asphalt will be feasible only if both the foundry and HMA industries can obtain an economic benefit from the processing and reuse of this material. As has been demonstrated by foundries that supply RFS to HMA producers, the foundry industry benefits by avoiding landfill cost, tipping fees, and other associated costs. And if the foundry is using an external landfill, the economic benefit is even greater by avoiding the tipping fee as well as the transportation costs. As previously mentioned, tipping fees may range from about $15 to $35 per ton or higher in urban areas, and these costs are increasing.

The Process Recovery Corp., an operation in Pennsylvania, estimates that member foundries have saved more than $15 million in tipping fees since the monofill began operation in 1990.

Prior to sending the RFS for beneficial reuse, the Kingsport Tennessee Foundry had been paying about $35 per ton for tipping fees. This money has now been saved and it now pays about $4 per ton to Tri-State Sand for brokering the RFS to Washington County.

From the HMA producer's viewpoint, obtaining a good fine aggregate source at a competitive price can reduce HMA costs. The cost of the RFS is strongly influenced by the cost of competing fine aggregate. For instance, in areas where conventional sands cost $6 to $8 per ton, RFS may be competitive at $5 per ton. In other areas, where conventional sand is more abundant and the cost may be $1 per ton or less, the RFS may cost $2 per ton but have superior properties such as FAA. This may allow the HMA producer to produce a Superpave mix that otherwise would not be possible and may have a beneficial impact on reducing the binder content, resulting in a more economical mix.

One company spends a little more than $1 per ton in haul cost to pick up and transport the RFS to an HMA plant [Personal conversation with Ed Canters, February 18, 2000.] This cost compares to about $4 per ton paid for conventional river sand. An additional savings is found in burner fuel cost. Because the RFS from the foundry has been dried and stored in a silo, it essentially has no moisture. Thus, the HMA plant has a dry source of sand to use. The material tends to shed water and is stockpiled in an area that has positive drainage to maintain the low moisture content.

Conclusion

The foundry and HMA industry have found a joint beneficial reuse for spent foundry sand in limited localities. As an alternate to putting as much as 8 to15 million tons of spent foundry sand in landfills, several companies have developed screening, crushing, and/or fines removal systems to process the spent sand into RFS. This can be a valuable HMA resource potentially used to replace a percentage of the conventional sand. With proper processing, RFS has proven to be a good, economical source of sand to HMA producers. It is clear that, at present, only a small portion of the potential for using spent sand in HMA is being tapped. Hopefully, this series of articles present the economic and performance benefits that may be realized by looking at ways to process RFS for use in HMA. HMAT

Chuck Hughes, P. E., is an engineering consultant. For a copy of the first article in this two-part series, e-mail the HMAT *editor at* mgrove@hotmix.org *and request a copy of* RFS Sources and Properties *from* HMAT*, June 2002, Vol. 7, No. 4.*

Acknowledgements

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[1] Miller, Edna, Arif Khatri, Mark Winter, Dr. Hussain Bahia, and Dr. Craig Benson, "Utilization of Foundry Sand in Hot Mix Asphalt," Final Report, The Asphalt Research Program, Department of Civil and Environmental Engineering, University of Wisconsin – Madison, July 1998.

[2] Javed, Sayeed, C.W. Lovell, and Leonard E. Wood, "Waste Foundry Sand in Asphalt Concrete," *Transportation Research Record 1437*, Transportation Research Board, Washington, DC, 1994.

[3] "1998 Annual Project Update and Progress Report," Resource Recovery Corporation of Western Michigan, 1999.

[4] Personal communication from Brian Gibson, Tri-State Sand, July 24, 2000.

[5] Delange, Kenneth P., Andrew Braham, Hussain U. Bahia, Matius Widjaja, Pedro Romero, and Thomas P. Harman, "Performance Testing of Hot Mix Asphalt Produced with Recycled Foundry Sand," Paper presented at the 2001 Annual Meeting of the Transportation Research Board, January, 2001.