Abrasive Selection: Performance and Quality Considerations

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The selection of abrasive media for blast cleaning steel is based primarily on two broad objectives, quality and economics. Quality is defined in terms of appearance after cleaning (SSPC-SP 7, 6, 10, and 5), profile depth and contour, and chemical cleanliness. The economics of an abrasive is determined by its initial cost and by the production rate that can be achieved when it is used.

This article reviews the properties of abrasive that affect quality and productivity of surface preparation by abrasive blasting. Also described is a test program including laboratory evaluation of abrasive properties and blasting trials with various silica and slag abrasives.

■ Fig. 1
Mohs Hardness Scale

Softest	1. *Talc*
	2. *Gypsum*
	3. *Calcite*
	4. *Fluorite*
	5. *Apatite*
	6. *Microcline*
	7. *Quartz*
	8. *Topaz*
	9. *Corundum*
Hardest	10. *Diamond*

Visual Cleanliness Requirements (SP 7, 6, 10, and 5)

The degree of cleaning is dependent on several factors. Generally, the amount of time spent blasting an area will affect how much residue is removed; however, the abrasive size or number of hits per square inch also affects the removal of the residue. Blasting with very large particle sizes is similar to throwing buckshot against a surface with few particles of the abrasive hitting the surface, thus leaving large amounts of surface area with no surface contact between each particle hit. Therefore, bigger is not always better.

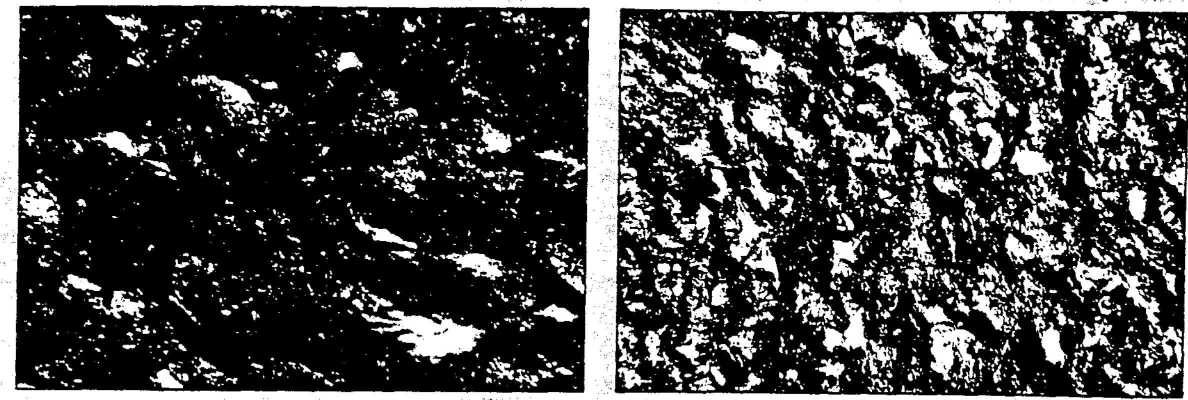
The general rule of thumb is to choose the smallest grain size that can remove the contaminant on the surface. Generally, abrasive particles larger than the 16 or 18 mesh size (1180 or 1000 µ diameter) gouge the surface and have slow cleaning rates, compared to finer particles. Particles of 80 mesh size (180 µ diameter) and smaller cannot generally produce profiles of 1 1/2 mils or more.

The hardness of the abrasive will affect the rate as well as the effectiveness of cleaning. Hard abrasives will cut more effectively and efficiently than soft or brittle abrasives. Hardness is measured by the Mohs Scale, which ranges from 1 to 10, with 1 being low or the softness of talc to 10 being high or the hardness of a diamond (Fig. 1).

Most mineral and slag type abrasives range from a hardness of six to eight, with a recommended minimum hardness of six on the Mohs Scale. Currently, the SSPC Abrasive Committee is developing an abrasive specification that will define the procedure for determining Mohs hardness (SSPC-XAB1X, "Mineral and Slag Abrasives").

The color and type of the abrasive can affect the appearance of the blasted surface. Steel blasted with sand will have a different color than steel blasted with slag, even though both surfaces are cleaned to white metal (SSPC-SP 5). Surfaces blasted with slags generally have a grey-white color; white sands generally produce a whitish-white color. It is also evident that color can vary within an abrasive family. For example, white or light colored sands generally produce a whiter white metal blast than brown or darker sands, which produce a darker white metal blast. The Visual Standards Committee of SSPC is in the process of developing a color range for white metal blast.

The uniformity of the particle sizes of the abrasive may also affect the degree of blast. Tests have shown that products with a wider spread grain-size distribution produce a white blast more efficiently than an abrasive with a narrow grain-size distribution. In some cases, particularly in the coarser grades, very uniformly sized products were unable to produce a white metal blast because of the lack of fines or very small particles to polish the surface.



■ Fig. 2
Sample A (left), blasted with a relatively round 20/40 silica sand abrasive, with a roundness of 0.8 and sphericity of 0.75; Sample B (right), blasted with a semi-angular 20/40 silica sand abrasive, with a roundness of 0.6 and sphericity of 0.6

Courtesy of Gay-lynne Snyder

Profile Depth and Contour

The profile, or depth that the abrasive digs into the surface, is affected by the abrasive size, hardness, and shape, and by the distance from the blast nozzle to the surface. Large sized abrasives cut deeper and produce deeper profiles than smaller sized particles of the same composition and shape. Hard abrasives will also cut deeper than softer abrasives, but the hard abrasives are brittle and tend to shatter upon impact, reducing the particle velocity. This results in lower cleaning speeds and profile depths.

Angular shaped particles, such as grit, produce a jagged finish that exposes more surface area for coatings to adhere to. From a production standpoint, angular products are generally preferred for removing the softer surface contaminants such as rust, dirt, and coatings. The round shaped abrasives, such as shot, produce a peening effect, or a wavy shaped profile that is used in applications where one does not want to change the form of the surface. Sands and slags fall in between the angular and round classifications, and are usually classified as semi-angular. Specifying the generic name or even the family name does not always guarantee the shape of the abrasive, because these classifications are very broad. For instance, silica sand used for hydraulically stimulating oil wells are relatively round, while other silica sands used for different purposes can be quite angular.

A method used to evaluate the roundness and sphericity of particles is the chart developed by W.C. Krumbein and L.L. Sloss in *Stratigraphy and Sedimentation* (2nd Ed., W.H. Freeman & Co., San Francisco, CA, 1963, p. 111). Many people believe that round and spherical are one and the same; however, this chart depicts roundness as the "lack of corners or edges" and sphericity as the "degree of a circular ball shape." When using this method, the examiner compares the sphericity and roundness of each grain, and determines the average sphericity and roundness of the sample. Figure 2 shows two steel panels blasted with 20/40 silica sand grades of abrasives. Sample A abrasive has a roundness of 0.8 and a sphericity of 0.75, while Sample B abrasive has a roundness of 0.6 and a sphericity of 0.6. The more semi-angular abrasive, Sample B, produced a more jagged surface, whereas the rounder abrasive, Sample A, produced a wavy surface. The desired profile contour should be considered when selecting the abrasive type.

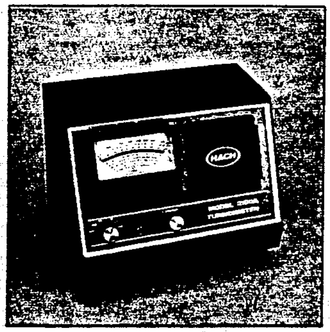
Abrasive Contamination Remaining In Or On The Surface

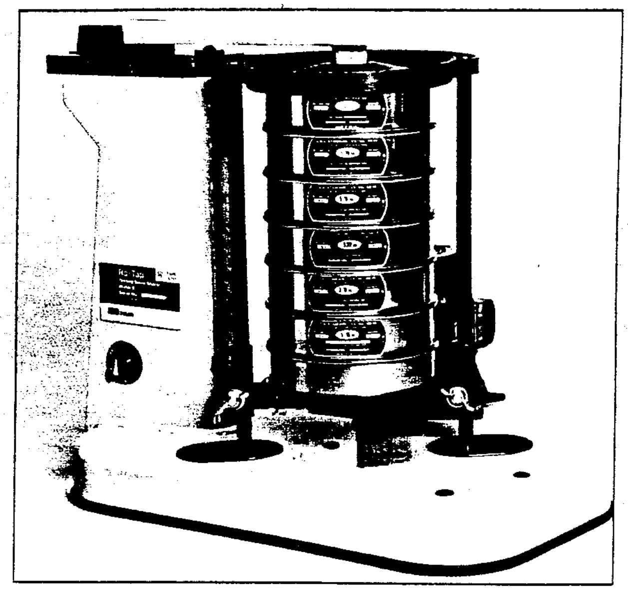
Abrasive contamination on the surface is of concern to the structure owner, but there is a question about what level of contamination affects coating adhesion. Abrasive contamination ranges from product embedment to residues remaining on the surface after blasting, such as chlorides, ferrous ions, and dust.

Product Embedment—All abrasives embed to some extent. The abrasive shape and hardness have an effect on the amount of embedment, as well as the softness or hardness of the surface being blasted. The general consensus is that minimal amounts of embedment are best, and will lead to fewer coating failures. Common questions about embedment include the following. How much embedment is acceptable (particles per

■ Fig. 3
Turbidimeter

Courtesy of HACH Company





■ Fig. 4
Equipment used for conducting sieve analysis

Ro-Tap® Sieve Shaker, Courtesy of W.S. Tyler, Inc.

square inch)? Do the composition and size of the embedded abrasive particle affect the adhesion characteristics? These types of questions do not have a single answer, because there are so many different types of coatings and environmental conditions that also affect the coating adhesion.

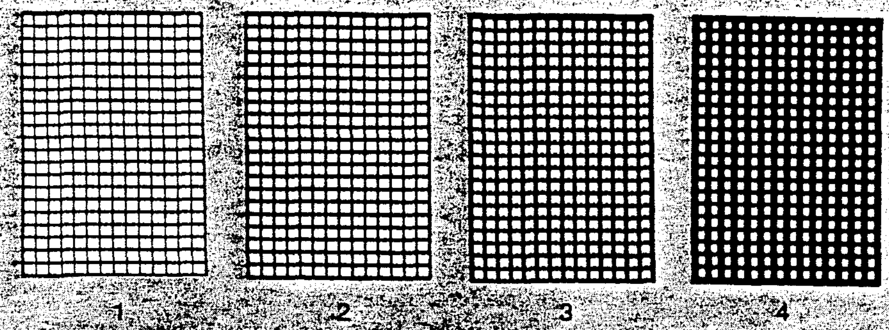
Abrasive Dust Remaining On The Surface—Coating adhesion may be reduced by dust remaining on the surface. Different generic types of abrasives have different breakdown levels. The original abrasive size, as well as characteristics within a generic abrasive type, will also affect the breakdown and dust levels. Obviously, the greater the amount of breakdown and dust level, the higher the probability of dust remaining on the surface prior to coating application. The breakdown characteristics of an abrasive can be determined with a blast cabinet test, which evaluates the particle size before and after blasting. The tape test is one method used to determine levels of dust remaining on the surface after blasting.

Turbidity: Evaluation Of The Cleanliness Of The Abrasive—One measure of the cleanliness of the abrasive and the particulates remaining on the abrasive grains is the turbidity test from the American Petroleum Institute (API). The turbidity level is a direct indication of particulates remaining on the surface, which, together with the abrasive breakdown, will affect the amount of dust generated during the blasting process.

The test is conducted as follows. Twenty ml of the dry abrasive is mixed with 100 ml of demineralized water, and allowed to stand for 30 minutes. The sample is shaken vigorously approximately 45-60 times in 30 seconds and allowed to stand five minutes. Twenty-five ml of water-silt suspension is extracted with a syringe from near the center of the water sample. The water-silt suspension is placed in a test vial, which is then placed in the calibrated turbidimeter (Fig. 3). The sample turbidity is determined in Formazin Turbidity Units (FTU). API sets a limit of 250 FTU or less. While the abrasive industry does not use this method as a standard test, it is one method that may be used to monitor production cleanliness.

Oil Contaminants On The Surface—Oils that may be sprayed on the abrasive to minimize dusting can be transferred to the substrate during the blasting process, and affect coating adhesion failures. Recycled abrasives may also pick up oil residues from contaminated pieces or from the steel surface, which results in redepositing the oil onto other abrasive pieces. The proposed SSPC abrasive specification test procedure states that the test abrasive is added to deionized or distilled water for a recommended amount of time. Upon examination, there should not be any presence of oil, either on the surface of the water or as an emulsion in the water.

Chloride Contamination of the Surface—Chlorides coming from the abrasive itself may be transferred to the structure surface. Over a period of time, moisture drawn through the coating to the area containing the chloride may produce blistering and premature coating failures. Tests performed by an independent testing agency show that blasted panels containing chloride levels of 10 or more micrograms per square centimeter ($\mu g/cm^2$) produced blistering on panels tested in a humidity cabinet, whereas blasted panels containing chloride levels of five or fewer $\mu g/cm^2$ did not produce blistering on the panels tested in a humidity cabinet (Weldon, Bochan, and Schleiden, *JPCL*, June 1987, pp. 46-58). The proposed SSPC abrasive specification has a test for water-soluble contaminants in which abrasive is placed in deionized or distilled water for a recommended amount of time. Abrasives meeting the specification will not show



■ Fig. 5
Ringelmann Scale

an increase in the conductivity of the solution of more than 200 microhms per cm. A more complete discussion of the effect of contaminant levels on coatings performance can be found in Appleman, *JPCL*, October 1987, pp. 68-82.

Moisture Contamination of Bulk Abrasive

Moisture content is a concern from the standpoint of both production and quality. Abrasive with moisture content that exceeds the recommended levels tends not to have a uniform flow rate. In addition, flash rusting can result from the damp particles hitting the substrate. The proposed SSPC abrasive specification recommends that maximum moisture content be 0.5 percent by weight when tested in accordance with ASTM C-566. In this test method, the abrasive is weighed prior to and after subjecting it to a heat source capable of maintaining the temperature surrounding the sample at 110 C ± 5 C (230 F ±9 F) until the sample is thoroughly dry.

Economics Of Abrasives

Product Size

An important property affecting the surface quality and job production is the particle size. Abrasive suppliers can control product sizing of their original material by changing screen sizes and production feed rates. Depending on the complexity of the screening operation, products can be screened into various sized products and different grain distributions.

Abrasive sizes are measured by a sieve analysis, usually a percentage retained on the designated sieve. In general terms, the sieve number indicates the number of wires per linear inch of sieve cloth; therefore, the higher the sieve number, the more wires per inch, and thus, the smaller the openings between the wires. Sieve sizes normally used to determine the particle size of abrasives are the #8, #12, #16, #20, #30, #40, #50, #70, #100, #140, #200, #270, and the pan. Generally, a "typical" sieve analysis is listed and possibly a range for each sieve. If a range is listed, it is generally the abrasive supplier who provides the range, the minimum and maximum percent retained on each sieve, based on past production data.

The abrasive industry does not have a standard method of applying product names according to abrasive sizes. Generally, each supplier calls his product whatever number he desires; therefore, two suppliers may call their products by the same

Table 1 Five Examples of 20/40 Grade Abrasive

US Sieve #	Microns	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
#16	1180	2.3	.1	—	.9	11.2
#20	850	15.5	5.0	.8	4.3	31.8
#30	600	38.2	29.4	21.2	51.7	49.1
#40	425	27.2	42.9	35.7	42.9	6.9
#50	300	11.1	20.1	31.1	.2	.9
#70	212	3.9	1.4	8.0	---	.1
#100	150	.9	.9	2.1	---	---
#140	106	.3	.2	1.0	---	---
#200	75	---	---	.1	---	---
#270	53	---	---	---	---	---
Pan	---	---	---	---	---	---

Table 2 **Sample of a Range Specification for Abrasive**

US Sieve #	Required Range of Percent Retained	Actual Percent Retained		
		Sample 1	Sample 2	Sample 3
#16	0-1	.5	.2	.1
#20	.5-3	2.7	2.1	1.1
#30	35-48	41.2	47.5	38.9
#40	48-57	51.6	49.1	56.1
#50	2-4	3.8	.9	3.7
Passing #50	0-.5	.2	.2	.1

Effect of Tolerances in a #40 Mesh Sieve on Sieve Analysis

Table 3 **(Nominal, 425 mm; Tolerance Range, 406-444 mm)**

Sample #	Percent Retained at Specified Openings			
	406 mm	428 mm	437 mm	450 mm
1	5.73	7.85	8.63	10.78
2	6.52	7.57	9.23	11.78
3	8.02	9.13	10.36	13.70

number, even though they are not the same size.

Typically, abrasive specifications or quotations state only a common grade name, such as 20/40. Without a standard industry specification or a product range, all of the potential suppliers could call their product 20/40, and all produce a very different product. Table 1 lists five different grades of 20/40; all have the major percentage retained between the 20 and 40 mesh sieves.

An example of a standard numbering system used by another industry is the API's sizing specification, which states that a minimum of 90 percent must be retained between the two designated sieves. To the oil and gas industry, a 20/40 grade means that a minimum of 90 percent will be retained between the 20 and 40 mesh sieves. Our company believes that the API specifications are still very broad, and do not guarantee consistent products from two different suppliers.

Utilizing product ranges for each sieve, as indicated previously, would help ensure product consistency from one load to the next, and from one abrasive producer to another. Table 2 gives an example of a range specification, which results in consistent products.

Sieve manufacturers have (+) and (-) tolerances set by ASTM, which means that a sieve can have various size openings. Each sieve has a centerline, with a (+) or (-) range from the centerline; therefore, a sieve can be slightly more open than another, which allows more product to pass through the sieve than the standard centerline sieve; or a sieve can be tighter, which allows more product to be retained on the sieve than the standard centerline sieve.

For example, a 40-mesh sieve has a nominal opening of 0.425 mm with an ASTM variance of ±4.5 percent. Therefore, sieves with openings of 0.406 mm to 0.444 mm are allowable. However, when tight specification ranges are set, sieves that are on the outer extremes of being open or tight from the centerline affect the sieve analysis results, as shown in Table 3.

This example points out how the same sand sample can produce different percentage results due to sieves being tight or open. The basic concept is that sieves should be calibrated, and as close to the centerline as possible.

For sieve analysis, the representative sample is obtained and split down to a suitable testing size, usually 100 grams. The test sample is then placed into a sieve (sieves are stacked largest opening to smallest opening), covered, and placed in a testing sieve shaker for ten minutes (Fig. 4). Each sieve is then emptied, brushed, and weighed for the weight retained on each sieve, and calculated into a percentage retained on each sieve.

Testing

The criteria for abrasive selection discussed above were combined in a test conducted by our firm to develop an overall impression of product quality. The test had the following parts.

- Blasting mild steel plates to determine production rates (area blasted per 100 pounds of abrasive), profile depths, degree of cleaning, density of the abrasive dust coming off the surface while blasting (Ringelmann Scale), and field comments on the blasted plates using 5X magnification
- Using a blast cabinet test to determine breakdown rate by comparing sieve analysis of the abrasive before and after blasting
- Lab testing to detect chlorides and ferrous ions, measure pH, and evaluate the cleanliness of the abrasive (turbidity)
- Using photography to determine profile contours, blast patterns, and embedded particles

The abrasive media tested fell into the following generic product categories:

- Sands
    - Silica Sands
        - Very Coarse
        - Coarse

- Medium Coarse
- Medium Fine
- Fine
- Very Fine
- River Sands
  - Very Coarse
  - Coarse
  - Medium Fine
  - Fine
- Flint Sands
  - Coarse
- Slags
  - Coal/Coke Slags
  - Nickel Slags
  - Copper Slags

Size categories were determined by sieve analysis prior to blasting with a minimum of 95 percent retained between designated sieves. Sizes were as follows:

- Very Coarse—12/20
- Coarse—12/40, 16/30, 16/40
- Medium Coarse—16/50, 20/40
- Medium Fine—20/50
- Fine—30/70
- Very Fine—30/100, 40/140, and finer

Open Abrasive Blast Test

In Part I of our test, one person performed the blasting and tried to blast as much surface area as possible on the mild steel plates with intact mill scale to a near-white blast with 25 pounds of an unknown abrasive. The equipment included a 600-pound sandblast pot with a 175-cfm compressor, and a number 5 Venturi nozzle. Air pressure at the nozzle was 100 psi, and was measured with a hypodermic needle gauge. The distance from the nozzle to the surface ranged from 18 to 20 inches, and the blasting angle was 75 to 90 degrees. Average profile was measured with the replica tape and optical comparator. Square footages were measured, and the degree of cleaning was evaluated. Dust levels coming off the blasted surface were evaluated using the Ringelmann Scale (Fig. 5), which is a set of four charts depicting a grid of black lines of varying widths on a white background. The grids give different appearances of density levels of dust coming off the surface, ranging from one (low) to four (high).

Comments from the field blasting are shown below.

Very coarse silica sands produced uniform rounded profile contours with slight iron oxide staining. Coarse silica sands produced uniform rounded profile contours with very slight iron oxide staining. Medium coarse silica (rounded frac sand products) produced uniform rounded profile contours; semi-angular frac sand produced a uniform sub-angular profile contour. Other high silica products produced rounded profile contours with some iron oxide staining on the surface and traces of white embedded particles. Medium fine silica produced uniform rounded profile contours, and fine silica produced uniform rounded profile contours with no visible signs of contaminant staining. Very fine silica produced a uniform rounded profile contour with no visible signs of contaminant staining; however, products were somewhat dusty while blasting.

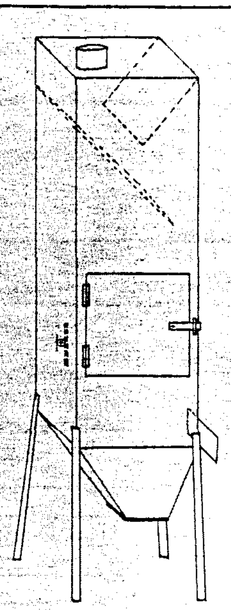
Very coarse river sands produced a very irregular blast pattern, with a somewhat rounded contour profile. Iron oxide staining appeared on the plates. Coarse river sands produced a very uneven blast pattern, with a slightly jagged, contoured profile; large amounts of iron oxide embedment; and dustiness during blasting. Medium fine river sands produced a fairly even blast pattern with a somewhat jagged, contoured profile; extensive amounts of white and black embedded particles; and iron-oxide embedment. Fine river sands produced an even blast pattern with a slightly jagged, contoured profile; an extreme amount of iron oxide staining; other colored contaminants embedded in the surface; and extreme dustiness.

Coarse flint sands produced a uniform blast pattern with a long valley-shaped contour profile. The blast appeared white; however, occasional white particles were embedded in the surface. The product was dusty during blasting.

Coarse coal/coke slags produced a uniform blast pattern with jagged, contour profile, and a number of embedded particles.

Medium coarse nickel slag produced a uniform blast pattern with slightly angular contour profile. The surface had a very large number of embedded particles.

Coarse copper slags produced an irregular blast pattern with jagged, contour profiles. The surfaces had much product embedment.



Dimensions

Cabinet:	1' x 1' square 3' tall—rubber lined
Baffle Plate:	(2) 45° from vertical— mounted in opposition to each other
Coupon Holder:	3" x 5"—mounted to articulate to allow 45° and 90° blasting angle
Blast Nozzle Inlet:	Mounted opposite coupon holder at 45° angle intersection, allowing for distance adjustment of nozzle
Access Door:	Construct large enough to allow for removal and insertion of coupons
Air Outlet:	3" diameter to allow attachment of dust collector

Source: *Materials Protection*, Vol. 3, No. 7, July 1964, pp. 76-80; reprinted with permission from the National Association of Corrosion Engineers.

■ Fig. 6
Blast cabinet for abrasive testing

Table 4 Product Breakdown Formula

$$\text{Breakdown Rate} = \frac{\text{percent spent abrasive retained x average sieve opening}}{\text{percent as-received abrasive retained x average sieve opening}}$$

	As Received	After Breakdown
.05345 x percent retained on 8 sieve		
.08620 x percent retained on 10 sieve		
.07240 x percent retained on 12 sieve		
.06080 x percent retained on 14 sieve		
.04745 x percent retained on 18 sieve		
.03625 x percent retained on 20 sieve		
.02825 x percent retained on 30 sieve		
.01995 x percent retained on 40 sieve		
.01410 x percent retained on 50 sieve		
.01000 x percent retained on 70 sieve		
.00710 x percent retained on 100 sieve		
.00500 x percent retained on 140 sieve		
.00350 x percent retained on 200 sieve		
.00250 x percent retained on 270 sieve		
.00130 x percent retained on pan		
Totals		

Breakdown factors range from 1.0 for an abrasive showing no reduction from original size after blasting to approximately zero for large grains that are reduced to dust.

Table 6 Results of Abrasive Contaminant Test

Abrasive Type	Ferrous Ions Detected	Chloride Ions Detected	pH	Turbidity Level-FTU	Presence of Oils
SANDS					
SILICA SANDS					
Very Coarse	No	No	7.1	60	No
Coarse	Yes	No	7.1	56-92	No
Med Coarse	Yes	Frac—No	7.1-7.2	Frac—36-92	No
		Others—Yes	7.2	Others—15-33	No
Med Fine	No	No	7.2-7.3	47-80	No
Fine	Yes	No	7.1-7.2	27-115	No
Very Fine	Yes	No	7.1-7.2	41-45	No
RIVER SANDS					
Very Coarse	Yes	No	7.2	68	No
Coarse	No	No	7.2	96	No
Med Fine	No	No	7.2	40	No
Fine	No	No	7.2	106	No
FLINT					
Coarse	Yes	No	7.0	190	No
SLAGS					
COAL/COKE					
Coarse	Yes	No	7.0-7.3	25-38	Yes
NICKEL					
Med Coarse	Yes	No	7.1	35	Yes
COPPER					
Coarse	Yes	Yes	7.3	14-37	Yes

Blast Cabinet Test

In Part II of our test, a four-inch by five-inch piece of mild steel plate was mounted inside an enclosed blast cabinet (Fig. 6), 4 in. from a number five Venturi nozzle. A 300-pound blast pot with a 175 cfm compressor was used for the blasting. Air pressure at the nozzle was 100 psi, and was measured with a hypodermic needle gauge. Ten pounds of the abrasive was blasted at the steel plate, and then collected to perform a sieve analysis. A representative abrasive sample was taken before and after blasting, followed by sieve analysis on each sample. The before and after sieve analysis results were calculated for the product breakdown factor (Table 4). Breakdown factors range from 1.0 for an abrasive showing no reduction from the original size after blasting to approximately 0 for large grains that are reduced to dust.

Table 5 shows our test results from Parts I and II.

Contaminant Test

Part III of our test consisted of evaluating the parts per million (ppm) of chlorides using Quantab test strips, and ppm of ferrous ions using Merkoquant 10004 test strips. Both test procedures involve taking equal amounts of the abrasive and distilled water, and swirling the mixture for one minute. The test strips were inserted in the deionized water mixture; time elapsed until the test strips absorbed the water mixture, and then the test strips were evaluated. The abrasive/distilled water mixture was also evaluated for pH with a pH meter. Cleanliness of the abrasive was determined by conducting a turbidity measurement, which was previously described. The abrasives were also evaluated for the presence of oil, based on the previously described test procedure. Test results are given in Table 6.

Microscopic Evaluation

Part IV of our test evaluated the blasted mild-steel plates under 40X magnification. The surfaces were evaluated for profile contour and uniformity of the blast pattern, and product embedment. Photographs of each blasted surface were taken.

Conclusion

Selecting an abrasive involves more than simply considering price; generic types of products vary in quality; products vary within generic families; and products vary from one supplier to another, as test results show. Abrasive selection should be based on the desired results. After the desired end results have been determined, the abrasive should be selected in accordance with the end requirements. ■

Table 5 Results from Open Blasting and Blast Cabinet Tests

Abrasive Type[a]	Profile (mils) Replica Tape	Profile (mils) Optical Comparator	Area Blasted Sq Ft/100 lb	Degree of Cleaning[b] (for open blast and blast cabinet)	Ringelmann Scale	Breakdown Factor
SANDS						
SILICA SANDS						
Very Coarse (1)	3.4	3-4	31.6	35% SP 10 65% SP 6	1	.66
Coarse (3)	2.6-3.0	2-3	30-38	90% SP 5 10% SP 10	1	.67-.75
Medium Coarse (5)						
—Frac Sands	2.2-2.6	2-3	32-40	75% SP 5 25% SP 10	1	.72-80
—Non-frac Sands	2.2-2.6	2-3	32-40	90% SP 5 10% SP 10	2-3	.48-.58
Medium Fine (2)	2.1-2.4	2-3	33-39	75% SP 5 25% SP 10 90% SP 5 10% SP 10	1	.76-.77
Fine (4)	1.7-1.9	1-2	33-47	75% SP 5 25% SP 10 90% SP 5 10% SP 10	1-2	.65-.79
Very Fine (5)	1.5-1.8	1-2	26-36	95% SP 5 5% SP 10 100% SP 5	1-3	.78-.87
RIVER SANDS						
Very Coarse (1)	3.4	3-4	24.4	20% SP 10 80% SP 6	2+	.52
Coarse (1)	2.2	2-3	27.2	85% SP 5 15% SP 10	2+	.62
Medium Fine (1)	2.4	2-3	35.6	10% SP 5 90% SP 10	3	.63
Fine (1)	2.1	2-3	44.8	80% SP 10 20% SP 6	3	.79
FLINT						
Coarse (1)	2.6	2-3	38.0	85% SP 5 15% SP 10	3	.48
SLAGS						
COAL/COKE						
Coarse (2)	3.5-3.8	3-4	22-25.6	75% SP 10 25% SP 6 50% SP 10 50% SP 6	2-4	.52-.59
NICKEL						
Medium Coarse (1)	2.9	3-4	25.3	80% SP 10 20% SP 6	2	.60
COPPER						
Coarse (2)	3.0-3.1	3-4	16.8-22.4	10% SP 10 90% SP 6 40% SP 10 60% SP 6	2+	.48-.55

[a] The number in parentheses indicates the number of product samples of either different product sizes or different suppliers' products.
[b] Where more than one product sample was used, two different degrees of cleaning sometimes resulted, depending on the various producers and grades of products.