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FINE ALUMINAS FOR HIGH PERFORMANCE REFRACTORIES

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Abstract

Increasingly severe process environments require further improvements in advancing refractory technology to obtain more cost effective performance. Development of new and improved fine aluminas, made in various controlled crystal sizes which disperse readily, provides the refractory manufacturers with an opportunity to "fine tune" mix designs to optimize technical refractory performance. The unique characteristics of the following new Bayer alumina products are presented for use by the refractories industry: three grades of less costly intermediate sized sintered corundum; three grades of readily dispersible, fully ground, fine calcined aluminas having cost/supply advantages; a special calcium aluminate cement for low cement castables having extended working time; and "brown tabular," an economical sintered grain to satisfy the need for an aggregate intermediate between calcined refractory grade bauxite and the more expensive white fused and white sintered products. Continued close cooperation between raw material producers, refractory manufacturers and users is required to properly appraise the true cost effectiveness of these new products and to provide a basis for further modification, improvement, and development of new products in the future.

1. Introduction

The advent of technical refractories began in the late 1950s with the development of new and improved refractory binders and aggregates for use in controlled grain size distributions. High-purity calcium aluminate cement (CAC) and phosphate-bonded refractory shapes and monoliths made with tabular alumina, refractory grade bauxite, synthetic mullite and chamotte formed the basis for many of the technical developments by refractory companies. They still do today.

Available high purity Bayer alumina, specially calcined and ground to pass 325 mesh, and crushed tabular alumina, sized to various screen fractions, were used for alumina enrichment in refractories made with lower purity aggregates and as the prominent alpha alumina source in 90–99+% Al_2O_3 refractories. Increasingly severe environments in new iron and steel, petrochemical, non-ferrous metal, and energy conservation processes during the interim have provided the need and motivation for developing more cost effective, high performance refractories. Tabular alumina slide gates, plates and nozzles, shrouds, etc, and applications utilizing CAC and phosphate-bonded dry vibratables, low cement and/or low moisture castables and other specialty plastics and ramming mixes are a few examples of products developed to fit those needs.

Monolithic refractory technology has accelerated during the past several years and is well documented.[1-10] As noted by Yamamoto,[11] there have been extensive research and developments on deflocculants, chemical-bonding additives for alumina cement, silicate or phosphate bonding of cement-free castables, and clay bonding to modify and improve strength, porosity, hot modulus of rupture, and hot volume stability in the microstructure of castable refractories.

With every advance in technology there is a recognized need to develop new and improved refractory materials that are more consistent and cost effective. As a result, a renewed effort has been placed on developing innovative raw materials for use by the refractories industry. This paper highlights some of these developments which we have historically based on high alumina products such as tabular alumina, high purity CA cement and phosphate bonding.

2. Maximum Density Particle Size Distributions

The design of refractory mixes for maximum density using the principles of particle packing provides a basis for the extraordinary advances in refractory technology.

Means for achieving compaction in mortar and concrete mixes were reported in a joint theoretical study by Furnas[12] and Anderegg[13] in 1931. Furnas developed the mathematical relationship for two types of grading. One involves intermittent or gap grading based on mixing two, three or four sizes of material to achieve good packing. Poor workability is the main disadvantage of this system. Furnas' second system of continuous grading size distributions has the advantages of improved workability, low water requirement, and good compactness with resultant low shrinkage and high strength. Continuous grading was first applied successfully by Anderegg to mortars and cast stone mixes. He noted that it was necessary to separate the system into a number of closely sized screened fractions to approximate Furnas' "ideal" distribution on recombining. This ideal distribution can be matched at one less than the number of sized fractions used in batching and be more closely matched when increasing the number of sized components.

A calculated Furnas distribution for obtaining maximum density by optimizing packing of 4760 µm (Tyler* 4 mesh) to 0.2 µm particles is shown in Fig. 1. This distribution is based on the assumption that particle packing of narrow size fractions of component materials is constant at 50% voids. The amount of material required to match the ideal distribution is obtained by dropping a vertical line from the specified particle diameter to the theoretical curve and substracting the percentage obtained by the horizontal intersection from the adjacent larger particle interval percent undersize. The percentage required for each $\sqrt[4]{2}$ sieve interval is shown between the vertical lines corresponding to the specific intervals. The curve represents either a weight or volume distribution when using a single material. It is on a volume basis when using multicomponent materials to make up the size distribution. The density of each component can be used for converting to a weight distribution.

Fig. 2 shows five calculated Furnas curves for maximum density with the top size ranging from 4 to 48 mesh (4760 to 298 µm). It is apparent from these curves that as the top size of a refractory composition designed for maximum packing becomes smaller, the subsieve portion increases significantly from 32%

*See Appendix.

for the coarse distribution to over 50% for the minus 48 mesh composition. The submicron requirement essentially doubles.

Fig. 1 Continuous Particle Size Distribution Curve for Maximum Density after Furnas

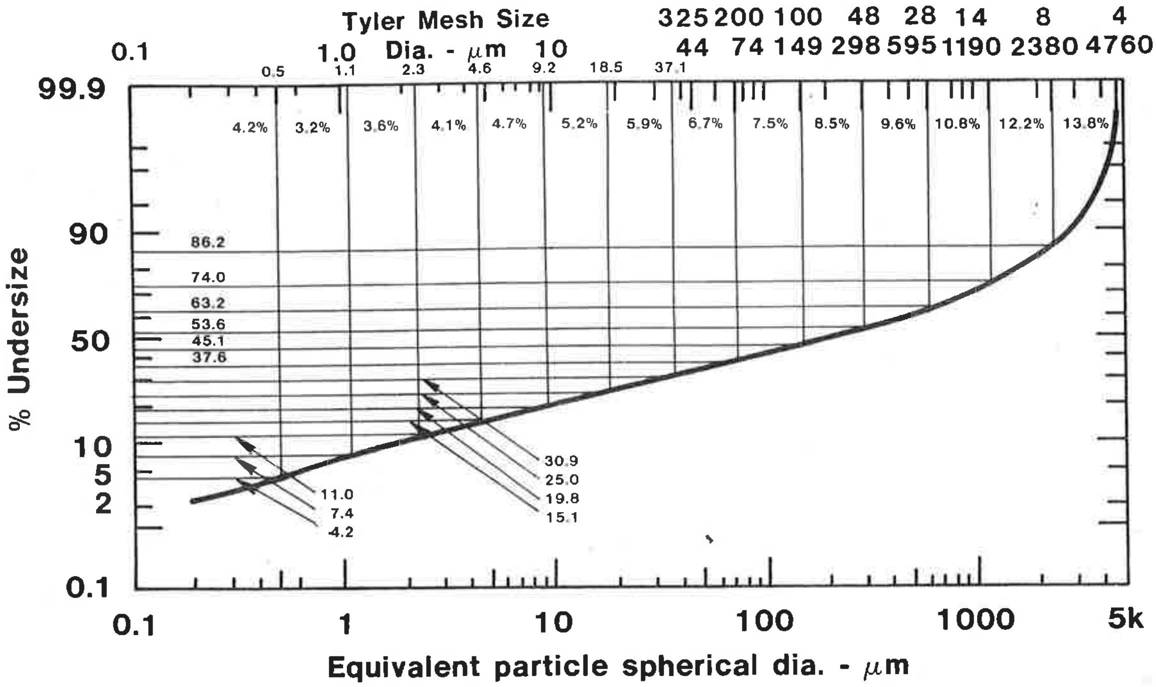
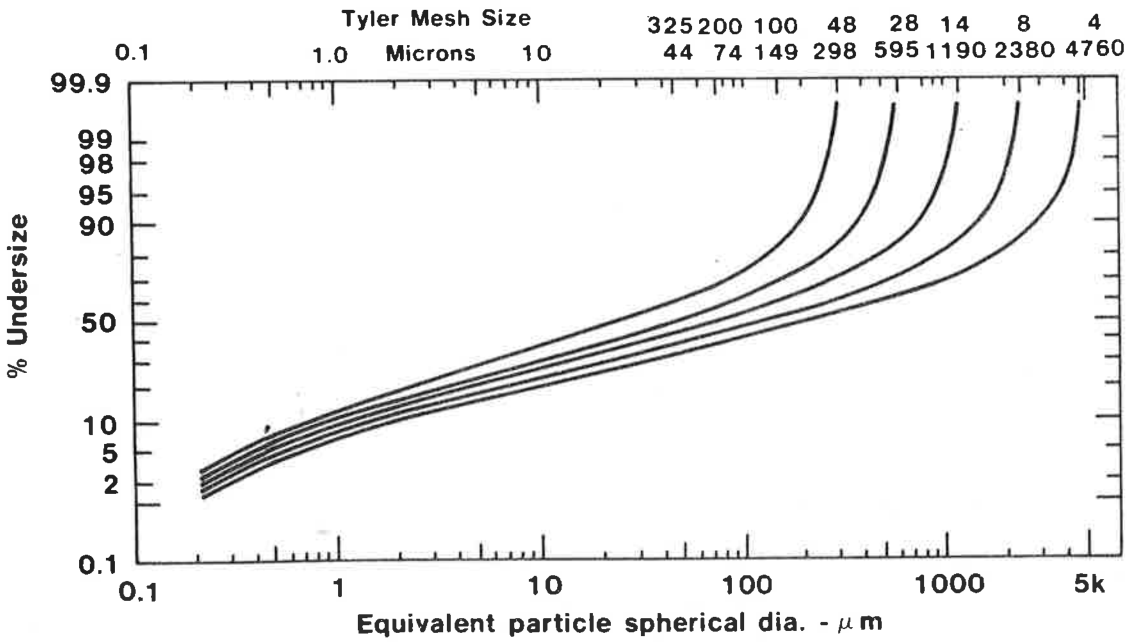


Fig. 2 Continuous Particle Size Distribution Curve for Maximum Density after Furnas

Alcoa Laboratories
R. P. Heilich, G. MacZura and F. J. Rohr



2.1 Practical Considerations in Approximating the Ideal Curves

The importance of the subsieve and, particularly, the submicron portion of particle size distribution in controlling the rheology of monolithic refractory compositions has long been recognized but has received new impetus during the recent 15–20 years with the advent of improved methods for determining the particle size distribution and rheological characteristics of fine powders. Although these methods enhanced the development of new refractory materials for technical refractories, there is need for faster and more accurate particle size measurement and characterization methods.

X-ray dispersive particle size techniques (Sedigraph) give excellent reproducible results when an immersion ultrasonic probe is used for dispersing powders that contain substantial amounts of submicron particles. However, these techniques are inadequate for differentiating small changes in the submicron fraction which so critically influences the rheology of aggregate systems for casting materials. For example, no significant change in particle size distribution can be determined by the X-ray dispersive particle size method after adding 5% of a superground 0.3–0.5 μm median alumina* to a 4–5 μm median alumina** that contains 3–5% <1 μm during a light-intensity wet dispersion grind. Yet, the thick, highly viscous suspension became fluid and free flowing after adding the submicron alumina.

For this reason, it is important to verify the refractory wet processing performance of different fine powders containing submicron particles. The small differences in submicron fractions can go undetected except through such processing or by experimentation and evaluation of the rheological properties of the ultrafine powders. The former is preferred because the interactions occurring between the coarser aggregate particles and the fine powders can be better appraised and related to commercial practice.

Complete dispersion of the submicron agglomerated fines is required for the installed monolithic linings to approximate their designed theoretical ideal distributions. Since high shear mixers are not readily available in the field, mixing times should be extended to practical limits. This will maintain good placement characteristic and ensure the wetting and dispersion of the agglomerated fines. For example, the workability of a castable using casting grade cement*** increases to a maximum at 15 minutes after the initial water addition, as indicated by the increasing flow table index (Table I). Displacement of the pore water as the submicron agglomerates are dispersed is believed to account for the more efficient use of the tempering water. In general, mixing dense castables for 5 minutes is preferred as long as good placement characteristics can be maintained and will provide more optimum microstructures than when using shorter mixing times. Also, more water is generally required if added incrementally than when added all at once, a key point in optimizing castable properties.

The excellent hot MOR values for high CA cement castable shown in Fig. 3[14)] were obtained by using closed aggregate sizes to approximate the ideal distributions shown in Fig. 2. It is impractical and costly to use 8–10 different closed size fractions. Segregation problems become more pronounced as aggregate size increases and screening costs increase with fineness. Therefore, a reasonable compromise for economy while maintaining good bag-to-bag uniformity seems to be the use of 2 or 3 coarse closed screen fractions and 2 or 3 open-ended fine screen fractions.

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*Alcoa reactive alumina A-16SG.
**Alcoa low soda alumina A-14 minus 325 mesh.
***Alcoa CA-25C cement.

TABLE I. INCREASED DISPERSION OF CASTING GRADE CAC CASTABLE WITH EXTENDED MIXING[1)]

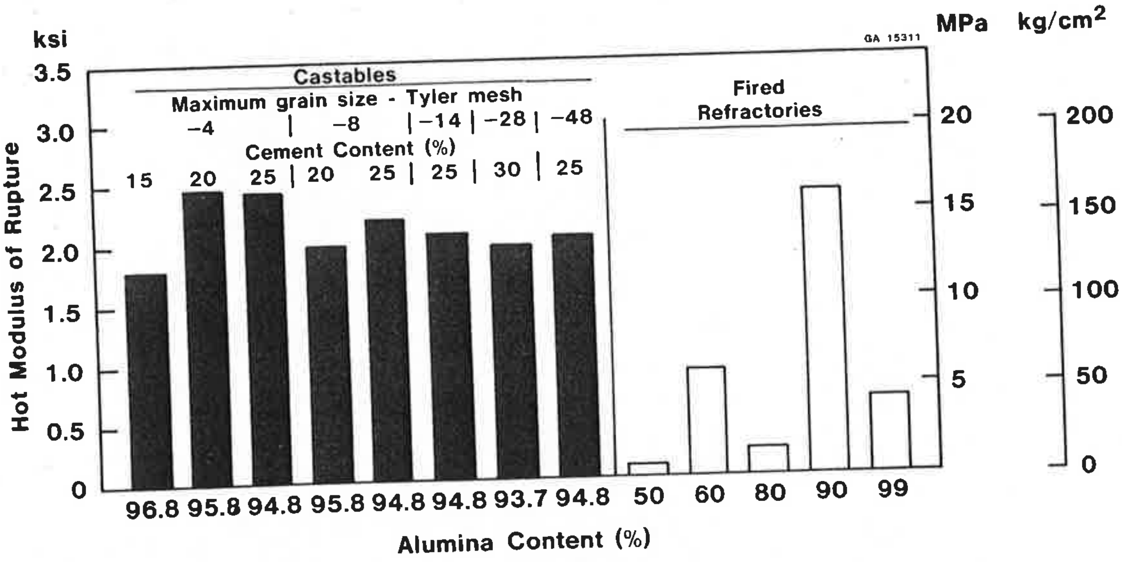
Lapsed Time After Initial H_2O Addition minutes	15% CAC/Tabular Castable[2)] (8.5% H_2O) Flow Table[3)] Index, %	BIH[3)] Consistency
5	95	Soft
15	112	Very Soft
30	91	Soft
50	84	Soft
60	73	Good
70	62	Good

Notes: 1) Original batch mixed 3 minutes after H_2O addition and tested for flow. All castable returned to the Hobart mixer after test and allowed to set without mixing until 1.5 minutes before test time when the batch was remixed for 30 seconds and tested.

2) Tabular Test Mix: 180–4760 µm = 22%; 1190–2380 µm = 9.8%; 595–1190 µm = 18.7%; 0–298 µm = 34.5% (wt); Alcoa CA-25C cement = 15% wt.

3) Refer to ASTM C860 for basic flow table and ball-in-hand (BIH) consistency tests.

Key: CAC = Calcium aluminate cement



2500°F (1372°C) Hot MOR of Tabular Alumina Castables and Fired Brick
Fig. 3

3. New Fine Alumina Products

Considerable R&D effort is being extended to develop innovative, economical alumina products for use by the refractories industry. The following describes some of these new alumina product developments.

3.1 Sintered Corundum Powders

A new corundum material* has been developed which provides particle size distributions having a top size of 125, 63 and 20 µm without the need for costly screen separation, nor the use of an intensive grinding operation to obtain single crystals. These pure white, high-alpha alumina crystalline products are characterized by consistent grain size and comparatively low iron content even in the finest grade.

In fact, the shape and properties of sintered corundum make it suitable for many applications outside the refractories industry, such as grinding, lapping and polishing, with numerous advantages over more familiar abrasive materials. In high alumina refractory brick, on the other hand, it can improve hot flexural strength, cold crushing strength, and wear resistance. One particular example worth noting is an application where the coarse grade replaces fine fused alumina (0 to 0.2 mm) in ceramic tubes for fast firing roller hearth kilns with a service temperature of 1200°C. In this application, good results were obtained including improvement in the bending strength by about 715 kg/cm^2 (70 N/mm^2), a low apparent porosity (less than 7%) and the possibility of obtaining a harder and smoother surface.

3.1.1 Manufacture

Manufacture of these corundum crystals is quite different from that of fused and tabular aluminas, and considerably more economical because of a cheaper feedstock and use of a much lower process temperature. Energy requirements are over 50% less than that required for producing fused alumina. The process, for which a patent has been applied, involves the calcination of aluminum hydroxide in the presence of various fluoride-containing mineralizers at about 1450°C. In comparison, fused alumina requires calcined alumina for electro-fusing into large blocks, which then must be crushed and graded. The fusion process uses much more energy than direct production of the sintered corundum, especially since the new process avoids the crushing step. As a result, the new approach yields a very cost effective grain.

The loosely bonded clusters of hexagonal, platelike macrocrystals of α-Al_2O_3 are easily separated into dense, single crystals (Fig. 4a,b) that range in size to 250 µm (hexagon dia.). The ratio of the diameter to thickness is usually between 3:1 and 7:1. Four sizes are produced: a coarse unground product as calcined that contains both single crystals and sintered agglomerates of single crystals, and the three 125, 63, and 20 µm grades consisting of single crystals and fragments produced by subsequent light milling and classification. The SEM crystalline structure of these different grades can be seen in Fig. 4c,d,e. By careful control of the ball-to-charge ratio, separation of the single crystals can be made with minimum fragmentation. The platelike dense, single crystals and fragments are characteristically low in porosity.

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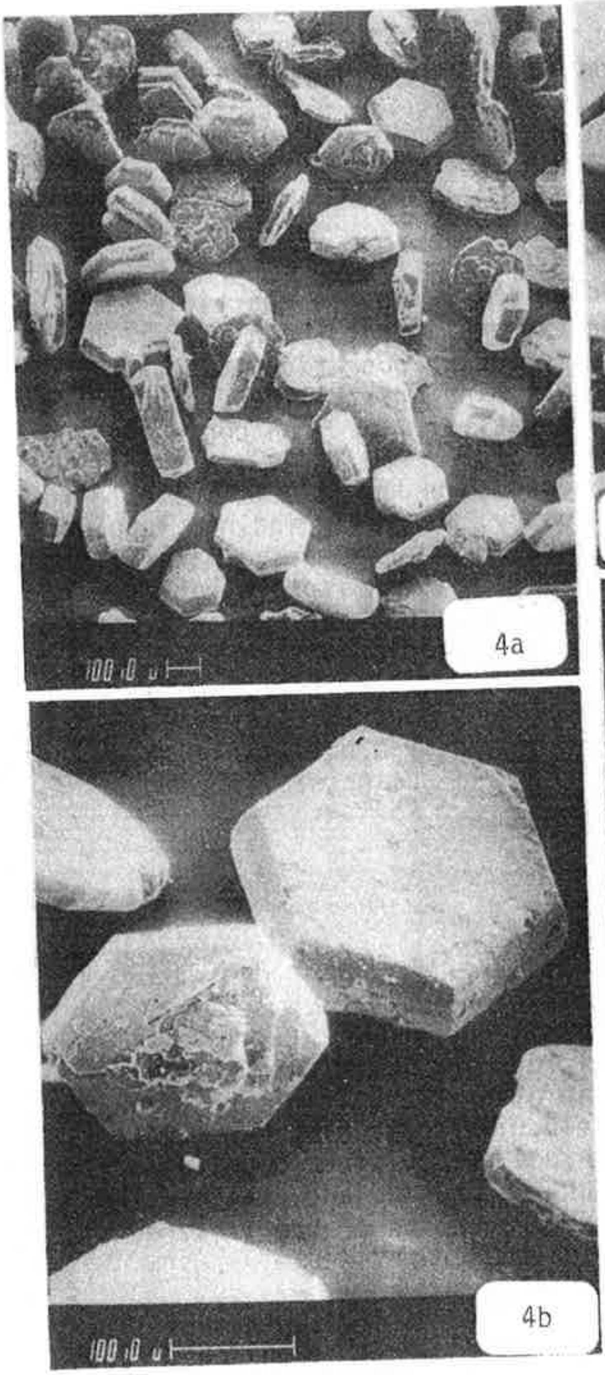
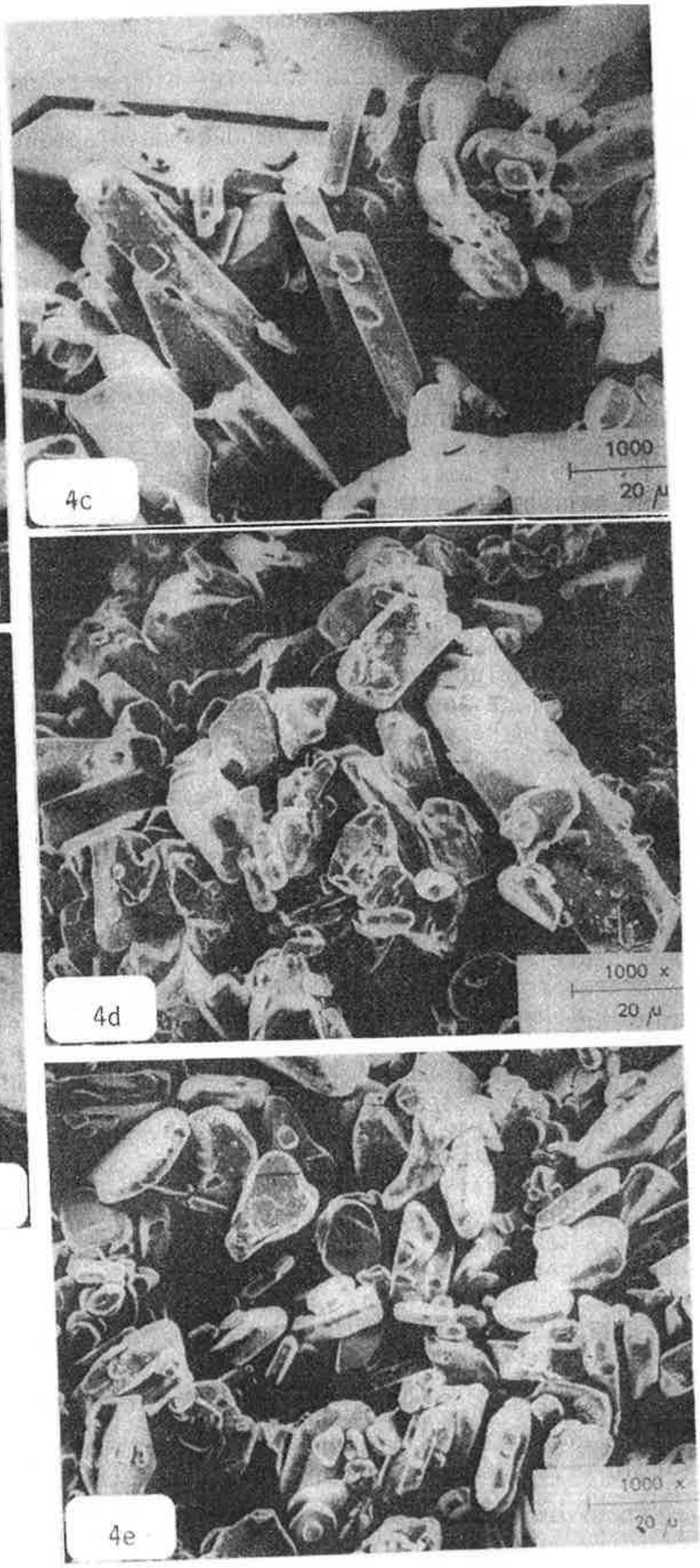
* GILOX(R) - Alcoa Chemie GmbH, Ludwigshafen, F.R. Germany





4a - Single crystals

4b - Large single crystals

4c - 125 μm grade

4d - 63 μm grade

4e - 20 μm grade

FIGURE 4. SEM — SINTERED CORUNDUM

3.1.2 Properties

Table II lists the chemical and physical properties of these pure (99.4% Al_2O_3) nominal 99% α-Al_2O_3 products. Iron oxide is particularly low, being 0.03% total and only 0.01% acid soluble. The nominal 0.4% Na_2O is comparable with the high purity fused aluminas. Hot water soluble Na_2O ranges from 0.05 to 0.1%, generally increasing from the coarsest to the finer grades. As with tabular alumina, most of the soda is tied up in the alumina structure as a relatively insoluble form.

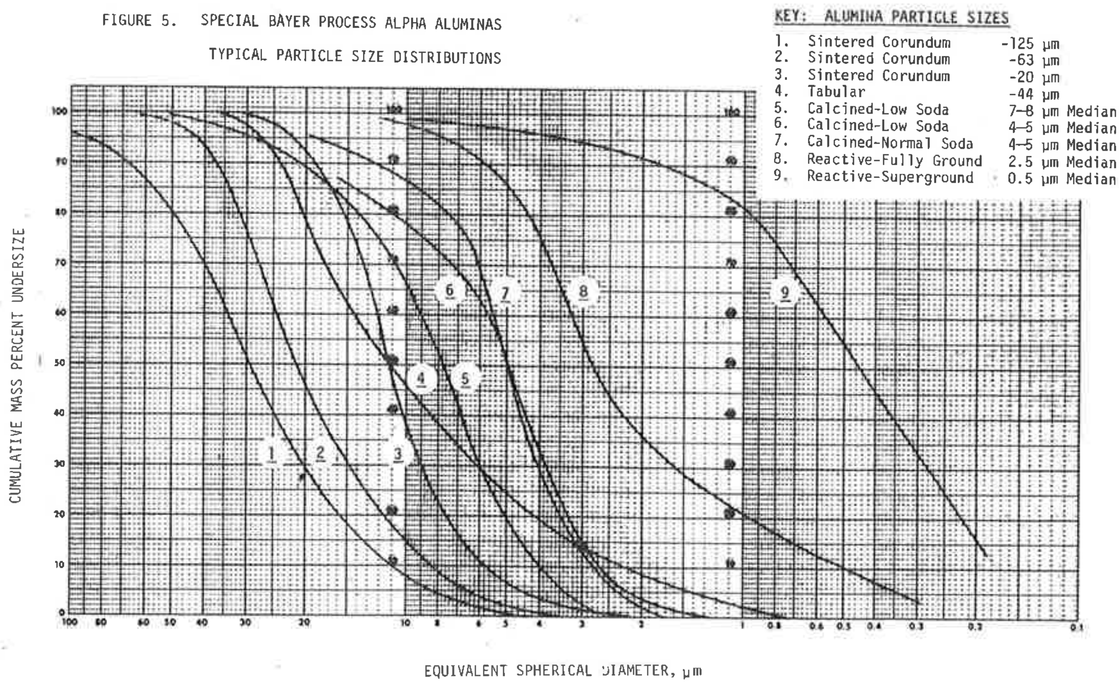
TABLE II. TYPICAL PROPERTIES OF SINTERED CORUNDUM*

Al_2O_3, %	99.4
Total Na_2O, %	0.4
H_2O Soluble Na_2O, %	0.05–0.1
SiO_2, %	0.06
Total Fe_2O_3, %	0.03
Acid Soluble Fe_2O_3, %	0.01
Loss on Ignition, %	0.1
pH (10% suspension)	8–9
Melting Point, °C	>1950
Alpha Al_2O_3, %	>99
True Density, g/cm^3	3.92
Specific Heat, cal/kg·°C	0.2
Coefficient of Thermal Expansion X 10^{-6}/°C	8.7
Hardness (Knoop), kg/mm^2	1800–2200
Specific Surface (BET), m^2/g	0.2

*GILOX(R) - product of Alcoa Chemie GmbH, Ludwigshafen, F.R. Germany

FIGURE 5. SPECIAL BAYER PROCESS ALPHA ALUMINAS

TYPICAL PARTICLE SIZE DISTRIBUTIONS



The particle size of the comminuted grades are shown in Fig. 5 in comparison with ground tabular, calcined and reactive aluminas available for use by the refractories industry. Gnauck[15] has shown that a 2:1 blend of the 63:20 µm sintered corundum products closely approximates the size distribution of tabular alumina ground to pass 325 mesh. These coarse crystalline products complement the size distributions of the finer crystalline calcined aluminas and offer the refractory companies some versatility in design of their refractory compositions by filling the gap between the crushed and finely ground products.

3.1.3 Dry Vibration Compaction in Coarse Tabular Alumina Mix

These intermediate particle size sintered corundum products can generally be substituted for the ground tabular and fused alumina components used in various wet process refractory monoliths and shapes, particularly when combined as demonstrated by Gnauck.[15] Because refractory installation characteristics and performance are primarily controlled by the coarse and fine ends of the particle size distribution, the use and selection of these intermediate sized products will primarily be cost driven, except in applications where refractory performance can be optimized by one of their unique properties.

One such property of the sintered corundum appears to be its relatively smooth surface in comparison to the roughened fractured surfaces of tabular and fused alumina. This can be beneficial where monolithic mixes are placed and consolidated by vibration with no liquid addition. Table III shows that the 63 µm sintered corundum compacts to the highest density (2850–60 g/ℓ) when used by itself or in mixtures with the 125 µm grade as the fine fraction in a generic tabular alumina composition. The coarsest crystalline calcined alumina (7–8 µm median)* ground to pass 325 mesh produced similar results. This low soda product has been available and used for many years by the spark plug and high alumina technical ceramic manufacturers.

TABLE III. EFFECT OF FINE ALUMINA COMPONENTS ON DRY VIBRATION COMPACTION OF TABULAR ALUMINA TEST MIX

Fine Al_2O_3 Description				Tabular Test Composition[1)]											
	Particle Size, µm		Na_2O	Fine Alumina Component, %											
Type	Coarsest	Median	%	1	2	3	4	5	6	7	8	9	10	11	12
Sintered Corundum	125	30	0.4	15	--	--	5	5	--	--	--	--	--	--	--
Sintered Corundum	63	22	0.4	--	15	--	5	10	10	--	--	--	--	--	--
Sintered Corundum	20	11	0.4	--	--	15	5	--	5	--	--	--	--	--	--
Tabular (Ground -44 µm)	3% +44	10	0.1	--	--	--	--	--	--	15	--	--	--	--	--
Calcined-Low Na_2O (-44 µm)	2% +44	7–8	0.1	--	--	--	--	--	--	--	15	--	--	--	--
Calcined-Genl Purpose (-44 µm)	2% +44	4–5	0.4	--	--	--	--	--	--	--	--	15	--	--	--
Calcined-Low Na_2O (-44 µm)	2% +44	4–5	0.03	--	--	--	--	--	--	--	--	--	15	--	--
Reactive (Fully Ground)	3% +10	2.5	0.08	--	--	--	--	--	--	--	--	--	--	15	--
Reactive (Superground)	1% +10	0.5	0.08	--	--	--	--	--	--	--	--	--	--	--	15
Powder Density Properties															
Loose, g/ℓ				2220	2320	2220	2440	2330	2270	2220	2280	2040	2070	2020	1920
, pcf				139	145	139	152	145	142	139	148	127	129	126	120
Vibrated Compaction[2)], g/ℓ				2770	2850	2770	2850	2860	2780	2790	2850	2500	2740	2730	2380
, pcf				173	178	173	178	178	173	174	178	156	171	170	149

Notes: 1) Tabular Test Composition = Coarse Fraction: 1680–4760 µm = 22%; 1190–2380 µm = 9.8%; 595–1190 µm = 18.7%; 0–298 µm = 34.5%.
2) 1-kg batch hand mixed dry in plastic jar and table vibrated in 1-ℓ graduate at 60 cycles for 2 minutes.

* Alcoa low soda alumina A-10.

The 4–5 µm median normal soda alumina* commonly used by the refractories industry for alumina enrichment in products using wet binders demonstrated the lowest compacted density, whereas the fully ground 2.5 µm median reactive alumina exhibits a much higher density but lower than the sintered corundum or minus 325 mesh tabular products.** Pelletization of the submicron fines and insufficient energy of dispersion during hand mixing of the batch in a plastic bottle resulted in low vibration densities of the 0.5 µm median superground alumina.

It is apparent from the results on this generic dry alumina mix that the sintered corundum grades and the ground 7–8 µm calcined aluminas offer the refractory companies some pertinent alternatives in attempting to maximize the density of their dry, vibratable mixes. It is recognized that intensified mixing could alter these results significantly with regard to the utilization of the finer ground aluminas.

3.2 Dispersible Fine Aluminas

The 2.5 µm median alumina*** shown in Fig. 5 was developed in the 1960s for ease of dispersion in preparing large high-purity alumina slip cast technical and electronic ceramic parts.[16] Because of its ease of dispersion this fully ground, low soda reactive alumina found application in effectively extending the particle size distribution in the new technical refractory compositions being optimized during the 1970s, even though the cost was about twice that of the high volume 4–5 µm normal soda alumina being used by the refractories industry. Water requirements are reduced and the density of specialty refractories are maximized with its use, even when mixing in the low shear field mixers commonly used by the industry.

Demand by both the ceramic and refractory industries exceeded the supply of this product in recent years. Although the grinding capacity for producing this unique 2.5 µm alumina has been increased, the source feedstock has a finite limit. To meet the growing demand for this type alumina in technical refractories, three similar products have been developed using readily available Bayer hydrate feedstock. This ensures an unlimited supply and reduced cost for the refractories industry. Table IV shows that the new products are ground to approximate the particle size distribution of the standard. The new, less costly intermediate soda products will find applications where slightly higher total and soluble sodas can be tolerated.

The new, intermediately priced low soda product should be evaluated as a substitute for the standard in technical refractory applications requiring a lower soda product. Direct substitution experimentation of these aluminas in each product line is necessary to establish the most cost effective alumina for each application.

3.3 Low Cement Castable Binder

Low cement castable technology has been applied with much success. However, the sensitivity of these specialty products to water requirement and the unpredictably short working times have caused mixed reactions regarding their total acceptance and full utilization. One problem seems to be that the various calcium aluminate cement grades do not respond similarly in low cement

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*Alcoa calcined alumina A-2.
**Alcoa tabular aluminas T-60, T-61.
***Alcoa reactive alumina A-17.

TABLE IV. NEW DISPERSIBLE FINE CRYSTALLINE BAYER CALCINED ALUMINAS FOR REFRACTORIES

Typical Properties	Standard[1] Low Na_2O Reactive Grade	Refractory Grades Low[2] Na_2O	Refractory Grades Intermediate[3] Na_2O
Na_2O, %	0.053	0.05	0.19
Soluble Na_2O, %	0.030	0.029	0.068
SiO_2, %	0.017	0.041	0.031
Fe_2O_3, %	0.008	0.047	0.037
Surface Area, m^2/g	2.6	2.1	2.9
Minus 325 Mesh, %	99.83	99.99	99.99
Sedigraph, % Undersize			
10 µm	98	97	98
8 µm	96	95	96
5 µm	87	89	87
3 µm	56	62	56
2 µm	36	40	35
1 µm	21	20	20
Median Particle Size, µm	2.5–3.0	2.5	2.7

Notes: 1) A-17 alumina (USA).
2) A-17-RLS alumina (USA).
3) A-17-R alumina (USA); a similar grade produced in Europe (Alcoa Chemie GmbH) is designated A-17-E.

castable compositions that contain submicron fumed silica,* a fully ground reactive alumina and a dispersant, such as sodium polyphosphate.

Table V shows a varied working time response with 70** and 80%*** Al_2O_3 cements in low cement castables formulated from 5% each of 2.5 µm alumina, fumed silica and cement with and without sodium polyphosphate electrolyte. Replacement of a normal 15% cement mix by the finer components causes a marked reduction in working time to an unacceptable level of about 10 minutes for both the 70 and 80% Al_2O_3 cement grades. Fine material substitution alone, without electrolyte addition, causes a varied water response by the two cement grades, with the high alumina cement water requirement being reduced much more than with the 70% Al_2O_3 cement. However, the lower alumina cement responds positively to addition of the sodium polyphosphate electrolyte by reducing the water requirement still lower and extending working time to acceptable levels; whereas the 80% Al_2O_3 cement fails to show a significant decrease in water requirement and working times remain unacceptably short. Surprisingly, both cements respond the same in the higher (normal) cement mixes by becoming faster setting with sodium polyphosphate addition (Table V).

* Product from the ferrosilicon and/or silicon processes.
** Alcoa CA-14 cement.
*** Alcoa CA-25 cement.

TABLE V. EFFECT OF CEMENT GRADE AND SODIUM POLYPHOSPHATE ADDITIONS ON WORKING TIME OF LOW AND NORMAL CEMENT CASTABLES

TABULAR ALUMINA CASTABLE

	Composition[1)], % (TWB)				CAC Grade			
					70% Al_2O_3		80% Al_2O_3	
Castable Type	CA Cement	Reactive Al_2O_3 (2.5 μm)	SiO_2 Fume	Sodium[2)] Polyphosphate	GBIH[3)] H_2O %	Working[4)] Time minutes	GBIH H_2O %	Working[4)] Time minutes
Low Cement	5	5	5	0	8.5	9	5.5	13
	5	5	5	1.0	5.0	44	6.0	14
	5	5	5	2.0	5.0	136	5.3	12
Normal Cement	15	0	0	0	10.5	294	9.0	44
	15	0	0	0.2	10.0	15	8.5	18
	15	0	0	1.0	10.0	19	8.5	16
	15	0	0	2.0	10.0	11	8.5	14

Notes: 1) T-61 tabular aggregate: 1680–4760 μm = 22%; 1190–2380 μm = 9.8%; 595–1190 μm = 18.7%; 0–298 μm = 34.5%.

2) A dry powder form distributed by Alcoa under the name Agilu.

3) GBIH = Good ball-in-hand consistency by ASTM C860.

4) Vicat setting time on castable,[17)] conducted at 24°C (75°F).

Key: TWB = Total weight basis. CAC = Calcium aluminate cement.

TABLE VI. NEW 80% Al_2O_3 CAC FOR LOW-CEMENT CASTABLES

Tabular Castable

	Composition, % (TWB)					
Castable Type	CAC	Reactive Al_2O_3 (2.5 μm)	SiO_2 Fume	Sodium Polyphosphate	GBIH H_2O %	Working Time min.
Low Cement ↓	5	5	5	0	4.75	52
	5	5	5	0.005	4.75	65
	5	5	5	0.01	4.75	74
Normal Cement ↓	15	0	0	0	8.8	48
	15	5	5	0	7.0	17
	15	5	5	0.2	6.5	29
	15	5	5	1.0	6.5	103

An experimental 80% Al_2O_3 cement being developed specifically for low cement castables provides an acceptable working times of 52 minutes, with only 4.8% water and no additional electrolyte as shown for the low cement castable in Table VI. Working times are extended still further with small additions of sodium polyphosphate.

This new 80% Al_2O_3 low cement binder also appears to have possibilities in normal cement castables containing 5% each of the reactive alumina and fumed silica as shown in the lower portion of Table VI. Although fumed silica additions normally make CA cement castables set faster, acceptable working times are exhibited with this new cement when adding small amounts of sodium polyphosphate. Its response to the electrolyte addition is directly opposite that of the standard 80% Al_2O_3 CAC product.

At the present stage of development this new product appears to offer the refractory companies greater versatility in the design of their low and normal cement castable compositions.

4. New Brown Tabular Aggregate

There are several other exciting cost effective new refractory raw materials under development. One of the most interesting is a product being dubbed "brown tabular." It has been produced as a nominal 95% Al_2O_3 sintered refractory aggregate containing less than 1.5% Fe_2O_3 that effectively demonstrates one of the main advantages of a sintered product compared to a fused one. Brown tabular also exhibits over twice the individual grain strength of brown fused, which should lead to improved hot strength and erosion resistance in end-use applications. This new product can also offer numerous advantages compared to refractory grade bauxite, including more uniform grain and firing control, better grain strengths and higher purity.

By taking advantage of lower cost raw materials and special processing techniques, it has been possible to develop a high quality product with substantial economic advantages. This new material will fit into the "no-man's-land" between comparatively low cost refractory grade bauxite and higher cost white sintered or white fused aluminas. At the same time, it should offer several performance characteristics previously found only in the more expensive products. Although this is still a very new product, its ultimate utility merits mention even at this early stage of development. Production from the initial successful plant test run is being processed for evaluation by the refractories industry.

5. Conclusions

The successful development of new technical refractories has enabled significant advances to be made in processing technology by the iron and steel, petrochemical, nonferrous metal, energy and environmental industries. The increasingly severe processing environments involved in these new and improved operations provide the need and motivation for further development of more cost effective, high performance refractories. Therefore, several new products have been developed to provide economy and improved flexibility in compounding refractories. These include three grades of less costly intermediate sized sintered corundum; three grades of readily dispersible, fully ground, fine calcined aluminas having cost/supply advantages; a special calcium aluminate cement for low cement castables having extended working time; and "brown tabular," an economical sintered grain to satisfy the need for an aggregate intermediate between calcined refractory grade bauxite and the more expensive white fused and white sintered products. Continued close cooperation between raw material producers, refractory manufacturers and users is required to properly appraise the true cost effectiveness of these new products and to provide a basis for further modification, improvement, and development of new products in the future.

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8. Appendix

COMPARISON TABLE OF U.S., TYLER, CANADIAN, BRITISH, FRENCH, AND GERMAN STANDARD SIEVE SERIES

U. S. (1)		TYLER (2)	CANADIAN (3)		BRITISH (4)		FRENCH (5)		GERMAN (6)
Standard	Alternate	Mesh Designation	Standard	Alternate	Nominal Aperture	Nominal Mesh No.	Opg. M.M.	No.	Opg.
107.6 mm	4.24"			1.06"					
101.6 mm	4"								
90.5 mm	3½"								
76.1 mm	3"								
64.0 mm	2½"								
53.8 mm	2.12"								
50.8 mm	2"								
45.3 mm	1¾"								
38.1 mm	1½"								
32.0 mm	1¼"								
26.9 mm	1.06"	1.05"	26.9 mm	1.06"					
25.4 mm	1"								25.0 mm
*22.6 mm	⅞"	.883"	22.6 mm	⅞"					
19.0 mm	¾"	.742"	19.0 mm	¾"					20.0 mm
*16.0 mm	⅝"	.624"	16.0 mm	⅝"					18.0 mm
13.5 mm	.530"	.525"	13.5 mm	.530"					16.0 mm
12.7 mm	½"								12.5 mm
*11.2 mm	7/16"	.441"	11.2 mm	7/16"					
9.51 mm	⅜"	.371"	9.51 mm	⅜"					10.0 mm
*8.00 mm	5/16"	2½	8.00 mm	5/16"					8.0 mm
6.73 mm	.265"	3	6.73 mm	.265"					
6.35 mm	¼"								6.3 mm
*5.66 mm	No. 3½"	3½	5.66 mm	No. 3½					
							5.000	38	5.0 mm
4.76 mm	4	4	4.76 mm	4					
*4.00 mm	5	5	4.00 mm	5			4.000	37	4.0 mm
3.36 mm	6	6	3.36 mm	6	3.35 mm	5			
							3.150	36	3.15 mm
*2.83 mm	7	7	2.83 mm	7	2.80 mm	6			
2.38 mm	8	8	2.38 mm	8	2.40 mm	7	2.500	35	2.5 mm
*2.00 mm	10	9	2.00 mm	10	2.00 mm	8	2.000	34	2.0 mm
1.68 mm	12	10	1.68 mm	12	1.68 mm	10	1.600	33	1.6 mm
*1.41 mm	14	12	1.41 mm	14	1.40 mm	12			
							1.250	32	1.25 mm
1.19 mm	16	14	1.19 mm	16	1.20 mm	14			
*1.00 mm	18	16	1.00 mm	18	1.00 mm	16	1.000	31	1.0 mm
8841 micron	20	20	841 micron	20	850 micron	18			
							.800	30	800 micron
*707 micron	25	24	707 micron	25	710 micron	22			
							.630	29	630 micron
595 micron	30	28	595 micron	30	600 micron	25			
*500 micron	35	32	500 micron	35	500 micron	30	.500	28	500 micron
420 micron	40	35	420 micron	40	420 micron	36			
							.400	27	400 micron
*354 micron	45	42	354 micron	45	355 micron	44			
							.315	26	315 micron
297 micron	50	48	297 micron	50	300 micron	52			
*250 micron	60	60	250 micron	60	250 micron	60	.250	25	250 micron
210 micron	70	65	210 micron	70	210 micron	72			
							.200	24	200 micron
*177 micron	80	80	177 micron	80	180 micron	85			
							.160	23	160 micron
149 micron	100	100	149 micron	100	150 micron	100			
*125 micron	120	115	125 micron	120	125 micron	120	.125	22	125 micron
105 micron	140	150	105 micron	140	105 micron	150			
							.100	21	100 micron
*88 micron	170	170	88 micron	170	90 micron	170			90 micron
							.080	20	80 micron
74 micron	200	200	74 micron	200	75 micron	200			
									71 micron
*63 micron	230	250	63 micron	230	63 micron	240	.063	19	63 micron
									56 micron
53 micron	270	270	53 micron	270	53 micron	300			
							.050	18	50 micron
*44 micron	325	325	44 micron	325	45 micron	350			45 micron
37 micron	400	400	37 micron	400			.040	17	40 micron

(1) U. S. Sieve Series – ASTM Specification E-11-61.
(2) Tyler Standard Screen Scale Sieve Series.
(3) Canadian Standard Sieve Series 8-GP-1B.
(4) British Standards Institution, London BS-410-62.
(5) French Standard Specifications, AFNOR X-11-501.
(6) German Standard Specification DIN 4188.

*These sieves correspond to those proposed as an International (ISO) Standard. It is recommended that wherever possible these sieves be included in all sieve analysis data or reports intended for international publication.

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