AES PROCEEDINGS --- SEE ARTICLE BELOW

TABLE I
Typical Chemical Composition Of Aluminum Oxide Grains

	Percent				
	TiO_2	SiO_2	Fe_2O_3	Na_2O	Cr_2O_3
Dense White	.00	.04	.04	.03	.00
Regular White	.01	.04	.10	.33	.00
Low Titania Pink	.28	.18	.33	.23	.07
Medium Titania	2.30	.60	.30	.03	.00
High Titania	3.05	1.65	.20	.03	.00

gave the maximum toughening, various grains were then roasted at increasing temperatures. Figure 7 shows the results with No. 14 Grits from large crystal crude. Dense white and porous white both toughen to a similar limited degree. Increasing percentages of titania and silica increase the toughening obtainable and lower the temperature for inception of toughening. At high temperatures, the high titania crude loses toughness, even in ten minutes. Also, the grain surfaces are roughened and, therefore, bulk density is reduced by 0.10 to 0.20 grams/cc.

Figure 8 shows the effect of crystal size of the crude on the toughening of the No. 14 Grits as a function of temperature. Some greater toughening of the finer crystalline grain, especially at intermediate temperatures, is noticeable.

Figure 9 illustrates that the differences in net toughening after long firing in wheel kilns found for No. 14 Grits are also true of other grits. For the same composition, large crystalline crude gives about the same toughening for all grits studied. The grit range was limited to No. 14 to No. 60 because only in this range has the Ball Mill Test been adjusted to give comparable results. The fine and intermediate crystal sizes for medium titania crude are seen to give a smaller increase in toughening than the large crystalline crude as the grit size becomes smaller.

The fact that roasting toughens all fused aluminum oxide grains supports the crack propagation theory[3]. Heat treating reseals micro-cracks created in the cooling or crushing of the crude. Some migrating impurities apparently help to seal these micro-cracks. explaining the lower temperature inception of toughening experienced with grain of higher titania and silica. Soda migrates, however, with little apparent effect on toughening. Finely crystalline crudes are tougher in grits highly polycrystalline but, possibly, are slightly weaker in those grits less polycrystalline. In polycrystalline crudes, micro-cracks probably stop at crystal boundaries but cleavage between crystals may be easier. The impurities in fast cooled, finely crystalline aluminum oxide are also more dispersed, which could possibly account for greater net toughening on roasting. Moreover, there may be more micro-cracks created in crushing tougher, fine crystalline grains. More work is needed to clarify these points and to extend this work to finer grits.

In summary, roasting, when controlled as to time and temperature, is shown to be a valuable tool for changing the final toughness of aluminum oxide grains. Because of the varying effect of vitrified wheel kilns on aluminum oxide grains, the toughness of vitrified wheel grains should be determined after firing at wheel kiln conditions. The effect of differing chemical composition and crystal size of common aluminum oxide types on its toughness and roasting is shown.

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THE EFFECT OF CHANGES IN CHEMICAL COMPOSITION ON THE GRINDING ACTION OF ALUMINA-BASE ABRASIVES

R. H. SCHLEIFER, Abrasive Research & Development Engineer
Simonds Abrasive Company

INTRODUCTION:

The work reported herein was undertaken primarily as a survey to determine the type of information of use in designing a research and development program for the evaluation of additives to abrasive crude. This is strictly a literature survey; existing reports of previously run grinding tests were used as data sources, and no tests were run specifically for this work. Since these previously run grinding tests were designed to solve an entirely different problem, the amount of useful information which could be gleaned from the reports was very limited. However, data on the grinding characteristics of two series of abrasive were collected. One series consists of heavy-duty abrasives used for snagging, and the other of "friable" abrasives used for surface grinding. This is particularly fortunate since it illustrates the two basic types of materials which can be used to modify alumina-base abrasives.

TYPES OF MODIFIERS:

Basically, there are two classes of substituents. Class I is composed of those substances which will fit into the

Al_2O_3 or corundum lattice, statistically replacing the aluminum atoms. The oxides of those substances which will not fit into the corundum lattice, and therefore crystallize out as a second phase, are designated Class II. The only Class I modifier currently used in any amount is chromia. Chromic oxide occurs in the same crystal class and system as corundum, and the trivalent chromium ion is of such a size that it fits quite easily into the corundum lattice. Zirconia. which has recently become popular as a modifier for alumina-base abrasives is an excellent example of a Class II additive. It is far too large to fit into the corundum lattice, in addition to having the wrong valence; nor does it form any compounds with alumina. It therefore, crystallizes out of the solidifying alumina as a discrete phase.

FIELDS OF USE OF EACH CLASS:

Class I modifiers would normally be used only in white alumina abrasives, which are essentially single-phase materials. However, the converse is not necessarily true; it may well be worth-while to try Class II additives in white abrasives. In fact, a fused, cast, white alumina which contained zirconia was tested in a snagging wheel several years ago. It gave a better ratio than did a wheel made with standard heavy-duty grain. However, the cost was so high that this material did not appear practical as an abrasive.

But in actual use one would expect Class II modifiers to be added to the regular alumina-base abrasives, the brown or grayish-brown materials. These abrasives already have an exsolved, intercrystalline phase. In effect the zirconia modifies, not the corundum crystallites, but this intercrystalline "slag". The effect of a Class I additive on the grinding characteristics of a regular abrasive would generally be negligible compared to the effect of this intercrystalline material on these same grinding characteristics.

TYPES OF DATA TO BE CONSIDERED:

Customarily, new abrasives are screened by some form of resistance-to-breakdown, or toughness test, and then evaluated by grinding tests. However, grinding tests are expensive, and it is highly desirable to have a screening test which will enable one to make optimum use of them, and the effectiveness of toughness testing for such screening is questionable. A possible reason for this will be seen in the discussion on the series of crudes modified by zirconia. Since this was to be a basic study, it was necessary to decide what were the appropriate data to work with. Obviously, it was necessary to treat the two series of abrasives separately, since different parameters are important in snagging and in surface grinding.

ZIRCONIA MODIFIED ABRASIVES:

The basic parameters measured in our snagging tests are as follows:

- Cut Rate—reported as pounds of metal remover per hour.
- Grinding Ratio—reported as pounds of metal removed per pound of wheel lost.
- Wheel Wear—reported in pounds per hour.

Within reasonable limits, the wheel wear is not as important as the cut rate; a wheel with a high cut rate is better than another wheel with the same ratio but a long life and a low cut rate. Therefore, grinding ratio and cut rate are considered in the zirconia modified series of crudes. Figure #1 shows grinding ratio plotted against weight per cent zirconia. The correlation is linear to a surprising degree; the point marked "TZ" is added for information only, since this material contains no alumina. It is felt that the 20% zirconia material was somehow defectively manufactured. It was out of line in every test run on it; in fact, in Figure #2, in which cut rate is plotted against weight per cent zirconia, the point for the 20% zirconia crude has dropped completely off the graph. Even its specific gravity failed to fall into line. In this second figure, the scatter is more pronounced, but the correlation is still reasonably good. Again, the point "TZ" is added only for information.

In Figure #3 a resistance-to-breakdown index is plotted against the zirconia content. Here it appears that a maximum toughness is reached, and that resistance to breakdown decreases with continued addition of zirconia. This may explain why the zirconia-base abrasives, which showed up well in laboratory grinding tests, failed to perform well under more severe field conditions. However, the actual shape of this curve is largely conjectural, since these crudes were not produced under controlled conditions. Rather, they were obtained as they became available from various manufacturers, and in many cases were obtained as finished grain. Non-standard grain shape will in itself affect both grinding tests and toughness tests. It is hoped to engineer a repeat of this work from scratch, sometime in the future. Crudes containing systematically varied amounts of zirconia will be crushed and graded in a standard way. By doing this, scatter due to manufacturing variations will be eliminated, and more data will be available.

In both the 1.5% zirconia and the 10% zirconia there seemed to be a reaction between the zirconia and the titania. Where the TiO_2: ZrO_2 ratio was high there was a strong tendency for the cutting rate to be higher and the grinding ratio lower than in material with the same amount

Figure 1

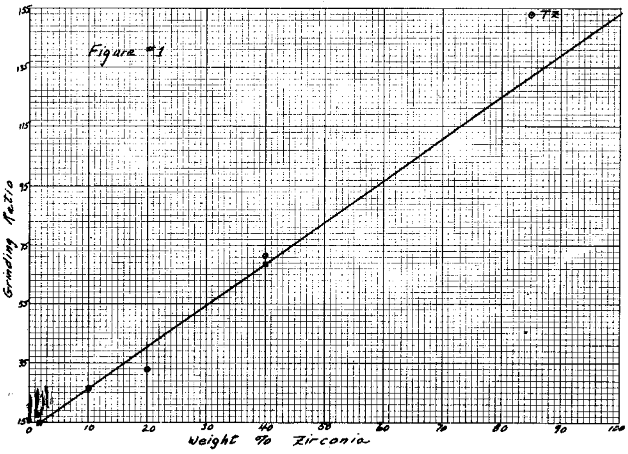
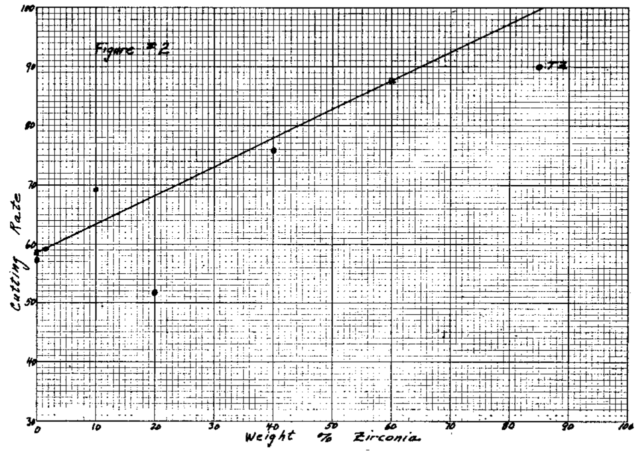


Figure 2



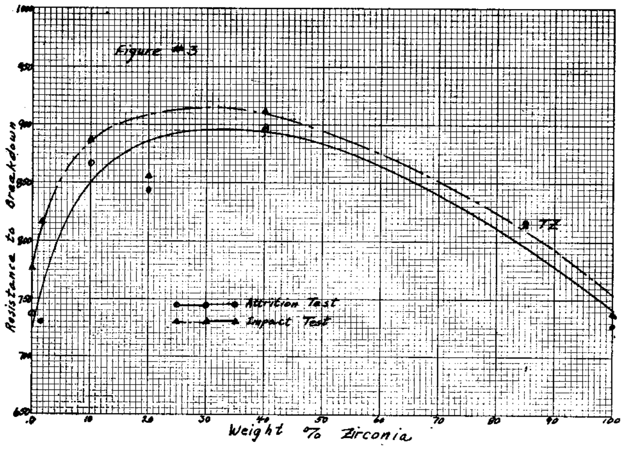


Figure 3

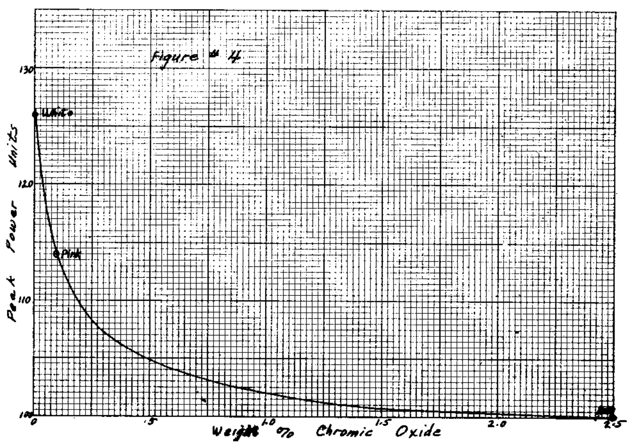


Figure 4

of zirconia but less titania. The crude containing 1.5% ZrO_2 was manufactured in two modifications, having the same chemical composition, but differing crystal sizes. Here the modification with the large crystal size showed a very high cutting rate and a comparatively poor grinding ratio, while with the smaller crystal size the converse was true. This material is probably anomalous in that the amount of zirconia present is actually lower than that of the titania. Several crudes containing 10% ZrO_2 were tested, and in addition to having a high cutting rate and a relatively poor ratio, the material with a high TiO_2: ZrO_2 ratio was quite sensitive to heat treatment. The grinding ratio of this abrasive was directly related, and the cutting rate inversely related, to the calcining temperature. The resistance to breakdown was also raised by increasing the calcining temperature.

While the corundum crystallites are quite pure chemically, the intercrystalline phase is very complex, with many possible compounds whose melting points are in the range of temperatures used for calcining. When the crude is poured it is cooled very rapidly and non-equilibrium conditions probably exist. During the calcining operation, as carried out, the grain is at a higher temperature for an extended period of time, and some re-melting of the intercrystalline material, along with deuteric reactions, would bring about a closer approach to chemical equilibrium.

In summary, both the cutting rate and the grinding ratio are increased by the Class II modifier zirconia in direct proportion to the amount added, up to about 40 or 50% ZrO_2. Above this point, the effect begins to fall off, the ratio more so than the cutting rate. The toughness also begins to drop after going through a maximum. The titania to zirconia ratio has a strong effect on the zirconia modified abrasives; this effect is also influenced by the thermal history.

CHROMIA MODIFIED ABRASIVES:

There are three abrasives available in this series; white alumina with zero chromia, a ruby grain with 2.2% to 2.4% chromia, and a pink grain intermediate between the two in composition. Unfortunately, there were only two analyses available for the pink grain, and the reliability of both is open to question. However, it will be shown that the chromia content could be uncertain over a very large range without basically affecting the results.

In evaluating these grains it was felt that grinding ratio was probably not as important as surface finish and heat damage. Therefore, the grinding ratios were varied by changing the wheel specifications and depth of cut and the power drawn during grinding was recorded. It was found that for a given grinding ratio, the power consumed was inversely proportional to the chromia content. Plotting peak power against per cent Cr_2O_3 in Figure #4, one would expect the slope to be much steeper at the 2.5% chromia level than at the zero level.

This is because the behavior of chromia dissolved in alumina changes at about 5 to 7% Cr_2O_3. Here the density and hardness of the ruby crystal begins to decrease, and the material becomes a less efficient abrasive; the power consumption curve should go through a minimum and then increase. Since the curve is non-linear but continuous, the actual analysis of the pink grain would determine the slope of the curve at that point, but not its shape.

This lowered peak power consumption with increased chromia content basically means that the grain becomes more friable. This in turn, means that a harder wheel may be used to increase efficiency and/or deeper cuts may be made without causing heat damage. As an alternative, a better finish may be obtained with standard depths of cut.

Summarizing, friability of pure alumina abrasives increases with increasing chromia, giving cooler grinding action. This action is limited by the fact that above a certain chromia content phase changes cause the abrasive to become less efficient.