Chemistry of Abrasive Action

Knowledge of the scientific principles of grinding is basis of recent progress in abrasives . . .

GRINDING had a very humble beginning: It was used by early man for sharpening tools and shaping and polishing various other objects, both metallic and nonmetallic. From this beginning, the grinding process has developed through a long period of evolution during which it has gradually lost the characteristics of an art and has more and more taken on the aspects of a science. The evolution is by no means complete and much of the process continues to be an art, but it certainly can be said that during recent years a much clearer understanding of the scientific principles involved in grinding has been reached. This understanding has in large measure been responsible for the progress that has been made in grinding wheels during these years.

Our ancestors probably had no clear-cut notion of physical properties for their grinding stones, but they certainly recognized the fact that some stones performed much better than others and contented themselves with the use of these without further worry. The first manufactured wheels and stones had the natural ones as standards and were good enough if they proved equal to or better than the competition—an easy feat usually. As the manufacture of grinding wheels increased in competition with natural products, a struggle for supremacy began between manufacturers; this competition started the improvements that have led to our present-day products.

The first bonds for abrasives were organic—shellac and rubber; the abrasives were quartz, emery, garnet, or corundum. It was recognized that of the abrasives then being used, the hardest—emery and corundum—were the best.

The next improvement in abrasives was the vitrified wheel, whose beginnings coincided with that of the Norton Co., and, shortly thereafter, the first synthetic abrasives were produced—fused aluminum oxide and silicon carbide. These seemed to be the ultimate in abrasives since they were the hardest materials ever produced, and during the next period of development, improvements were primarily made in bonds.

Through all this development period, the grinding process was accepted as a purely mechanical one which could be compared with other purely mechanical methods of cutting metal, such as turning, milling, and planing. The best grinding wheels were made of the hardest abrasive material available, bonded just strongly enough to give the desired freeness of cut. Nothing was known that contradicted these simple principles which also seemed to be sound horse sense.

CHEMISTRY OF GRINDING

The discovery of boron carbide provided a new abrasive that was considerably harder than aluminum oxide and silicon carbide, and hopes were high for a big step forward in grinding wheel efficiency. You know the rest—it proved worthless as a bonded abrasive. The time had come to re-examine fundamental concepts—to ask why this new abrasive had no value—and the period of better grinding wheels through chemistry was begun.

It was found eventually that the poor performance of boron carbide was at least partly due to the oxidation of the abrasive points under the heat of grinding, but even after this discovery there was a tendency to regard this peculiarity as the private property of boron carbide. Later studies showed that wear, of a chemical nature, was a general property of all abrasives under heat of grinding, though these reactions did not always involve oxidation.

This knowledge was obtained through the so-called point-endurance studies on abrasives. For this work single, conical points of various abrasives were run in a lathe on polished rolls of various materials under conditions that avoided fracture of the point. The points described helical scratches on the roll, but after traveling a given distance, the point ceased to scratch and would be found to be polished to a flat which would no longer penetrate the material of the roll under the pressure used. The length of the scratch depended not only on the abrasive and the material of the roll but also on the atmosphere or fluid around the point. It was also found that one abrasive was superior to another under one set of conditions but inferior under another. The controlling factor in every instance seemed to be a chemical reaction. The oxidation observed in boron carbide seemed to be only one of several kinds of reactions which could take place.

Silicon carbide, for example, produced a long scratch on a glass roll but a short one on a steel roll, whereas the reverse was true for aluminum oxide. The silicon carbide chemically resists the attack of the glass but readily dissolves in the steel; aluminum oxide resists chemical attack by steel but is attacked by glass.

Boron carbide in addition to being readily oxidized by the oxygen in the air is attacked by both the glass and the steel.

The presence of water shortened the length of the scratch—that is, increased the rate at which these reactions take place. The water appears to catalyze the reactions sometimes and, at others, to take part in them. For example, with aluminum oxide on steel, the water appears to oxidize the steel to produce an oxide which then readily reacts with the aluminum oxide to produce a soft, low melting material. Oils can lengthen point life by reducing the temperature at the contact and often by merely excluding oxygen from the contact area, as is true of a diamond point on glass.

Much time could be spent in describing these reactions in detail, but it is sufficient for now to realize that they always exist in any grinding process to a greater or lesser extent. It is even more important to realize that, far from being scientific curiosities, they set the practical limit on what can be done with abrasives.

The perfect abrasive in any grinding operation could grind indefinitely without any wheel wear, but wheel wear with ordinary abrasives is necessary to keep the wheel sharp and maintain the cutting rate. In other words, the wheel wear necessary in any grinding-cutting operation is that which just compensates for the chemical reactions involving the abrasive.

In grinding under constant pressure—with Alundum, for example—the maximum metal removal rate that can be obtained at various wheel wear rates follows a curve that is determined by the properties of the abrasive and the conditions of the job. It is impossible to obtain a metal removal rate above the curve with the grinding conditions specified. This curve approaches a limiting value, and its geometry is such that a random line drawn from the origin to the limiting value has an external segment, the horizontal projection of which is inversely proportional to the melting point.

Chemical reactions between solid phases usually begin close to the melting point. The correlation with the melting point, however, breaks down for those abrasives which react readily with steel in its unoxidized condition. The knowledge of these chemical reactions and of the factors influencing them has provided an entirely new basis for the search for better abrasives, and this has already begun to bear fruit.

GRINDING AIDS

Chemical reactions involving the abrasive are, however, by no means the only ones involved in grinding, nor can they be said to be the most important. An equally important field of chemistry is that of grinding aids. A grinding aid might be regarded as something which assists the grinding process, but it is actually more than that. In fact, it is impossible to grind in the absence of a grinding aid. Experiments have shown that in the complete absence of oxygen, no grinding takes place at all and that, under these conditions, the metal is merely pushed around with no direct chip formation. The reason for this is that a freshly formed and uncontaminated metal surface welds instantly to a similar surface. In the absence of any oxygen, the chips reweld to the base metal as fast as they are formed.

If a small amount of oxygen is present, then the freshly formed surface is immediately covered with an oxide film which prevents rewelding, and normal grinding takes place. The oxygen in this case can be regarded as a grinding aid, and many substances are known which will perform the same function; some perform this function better than oxygen does.

Some metals oxidize slowly, and the oxide film produced in the time available is not sufficient to prevent rewelding of the chips. In these cases, improvements can be made by incorporating in the grinding wheels substances that will form antiwelding films on the chips. These substances are usually sulfides or chlorides and rapidly form sulfide or chloride films on the fresh surfaces.

The substances are, in general, the same as those used as additives in extreme pressure—that is, lubricants used for the lubrication of metals under very high pressure. Grinding oils and fluids are often compounded to perform the same function and frequently contain chlorine or sulfur or phosphorus as the active element. This, of course, is not true of all grinding fluids since the purpose of most fluids is merely to keep the workpiece cool and to prevent rust.

Fillers used in grinding wheels do not always function by chemical reaction with the chips. Some accomplish the same thing, though usually much less effectively, by a simple lubrication process; this is a property in general of substances melting between 500° and 1000° C.

Not all fillers have a beneficial effect on the grinding process. Some—for example, cryolite, which has been used as a standard filler in grinding wheels for many years—actually react with the abrasive under the heat of grinding in much the same way as the metal does and detract from the performance of the abrasive. The cryolite, however, functions as a lubrication type of grinding aid, and the net result of its use may be an improvement in performance.

The possibility of a chemical reaction that might take place before chip formation has been the subject of much speculation. In snagging operations, it is customary to rate performance of wheels on the basis of their quality number which is defined as the square of the metal removal rate divided by the wheel wear. This quality number is supposed to represent the value of the wheel to the customer. Annealed cast iron can show about 20 times the quality number of a stainless steel. A chemical reaction altering the properties of a stainless steel in the direction of those of a soft cast iron, produced either by a grinding fluid or by an ingredient of the wheel, but to precede the actual chip formation, could greatly improve the grinding economy of stainless steel.

Positive evidence of such a reaction has been obtained in the use of metallic telluvium in a grinding wheel. If telluvium is used as a filler, the wheel will actually show a performance on stainless steel which is better than that which might be expected from an Alundum abrasive. That this actually is due to an intergranular corrosion preceding the actual chip formation seems reasonable on the basis of corrosion studies on active fillers.

In these studies blocks of grinding wheel compositions sandwiched with weighed pieces of stainless steel sheet were put in furnaces at 700° C. After 5 minutes of heat, the sheets were weighed again to determine the amount of reaction of the filler in the wheel with the steel under these conditions. By this method it is easy to separate the grinding aids, such as cryolite, which function by lubrication only, from the chemically active fillers, such as the chlorine and sulfur compounds, which are aids functioning by chemical attack of freshly formed surfaces.

In this test, telluvium is in a definite class by itself, showing corrosion rates several times that of the next most active filler. The question of reaction rate is important; there is so little time available for reaction before or even during chip formation that all substances are definitely in one class or the other.

This is well illustrated by sulfur as an extreme pressure lubricant. Sulfur between steel surfaces reduces the coefficient of friction to about one third its ordinary value. The coefficient stays constant as the sliding velocity is increased to about 1000 surface feet per minute and then suddenly jumps to its normal unlubricated value and stays substantially constant as the speed is further increased. At this velocity, the sulfur reaches a point beyond which it no longer has an opportunity to react.

Such effects also apply to grinding wheels. Most reactions are too slow to affect the steel before chip formation is nearly complete but act, for the most part, on the chips themselves and prevent rewelding and the accumulation of load on the wheel. On some metals, lower wheel speed is desirable in order to give sufficient time for the reaction of the metal with the grinding aid to take place. It has been found in grinding titanium metal under fixed feed conditions that very much better results are obtained by using wheel speeds of about one third the usual speed with chemically active, highly chlorinated grinding fluids.

In this case, the oxygen and nitrogen from the air do not function as efficiently as grinding aids as the oxygen does with steel, even though they react rapidly with the titanium. In order to get an effective grinding aid, chlorine must be supplied by means of the grinding fluid, and the wheel speed must be low enough to provide time for reaction.

Much of this brief survey of the chemical reactions involved in the grinding process can be attacked on the grounds of insufficient evidence. However, the important points which we want to bring out are these:

1. There is a great deal of chemistry involved in the grinding process.
2. Most of this chemistry is not completely understood and needs further study.
3. Most of the progress in the recent past has been due to a better understanding of chemical reactions involved in grinding.
4. Probably most of the progress in the immediate future will be based on an even better understanding of these reactions.

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