HINING WITH ABRASIVES

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MACHINING WITH ABRASIVES

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Preface

This is a book about the machining of precision parts with abrasives, addressed primarily to people in industrial plants and shops, in universities and technical schools—to anyone, in fact, who can benefit by learning more about a group of processing operations which has the capability of increasing productivity, lowering costs, and creating better-quality products.

Grinding (the most common collective name for the majority of the processes) has been traditionally a finishing operation, as it is today for many precision parts. However, in foundries, where the primary purpose of the cleaning of castings is to remove the excess metal as economically and rapidly as possible, the established tool is an abrasive wheel and, to a lesser degree, an abrasive belt. This book is mostly about the in-between area of machining.

The basic idea of the book can be expressed in two ways. First, to assert that if abrasive tools—wheels and belts—are capable of fine precision finishes (as they have been for years), and if they are also capable of probably the heaviest kind of material removal (as they also are), then they should be capable of doing the intermediate machining that lies between these two extremes. Second, to declare that if a part has to be ground at some stage in its machining, then the possibility of doing all the machining with abrasives ought to be checked. The advantages of doing the whole machining sequence on one machine instead of two or more—with one setup rather than multiple setups, with a reduction in transportation, and often with less material to remove—ought to be apparent. Steel cutting tools must be taken off the machine and reground, often at some distance from the production floor. But grinding wheels are to a degree self-sharpening, for when sharpening (or "dressing," as it's called) is necessary, it can be done by the operator without removing the wheel from the machine. In fact, on high-production automatic operations, the wheel dressing is blended into the cycle without involving downtime. Abrasive belts and loose abrasives are simply used until they are worn out, at which time they are discarded. They have been termed the world's first throwaway tools.

Most of what has been written about abrasives has either dealt with the technicalities of the operations or discussed research. Things like the selection of the right grinding wheel or the chemical formulation are common in these books.

One need not be an abrasive engineer to understand that if a part can be completed from a raw blank—or from the solid, or whatever term is used for the part before machining—in one operation on one machine, it is probably possible to save money and time by doing it that way. Nor does it require an engineering background to understand that if the extra amount of stock needed for machining can be reduced, there will very likely be a saving in material.

So there is something to be said for a broad, if not necessarily deep, knowledge of abrasives and how they work, at a number of intermediate levels of industrial management and elsewhere. The foreman or first-level supervisor on the floor, as well as the floor process engineer, must be concerned with keeping his department's production levels up and his costs in line. He may quite possibly be aware of what today's grinding wheels and coated abrasive belts can do but have difficulties in getting his superiors to comprehend what he is talking or writing about. This book is intended primarily for his superiors.

The importance of the abrasives industry to industry in general far exceeds the size of its annual dollar volume, for the manufacture of abrasive tools ranks high in any nation's list of critical industries. But the industry is small in terms of dollars, and fragmented; there is no single trade association, for instance, for all the manufacturers of abrasives. And there are only a few—two or three—companies making a full line of abrasives, and probably fewer than that making both machines and abrasives. It is true that in the mass finishing segment of the industry, most suppliers provide all that is needed—the machines, the abrasives, and the other materials needed—but these are basically machine builders which buy the other products for resale under private labels.

A similar fragmentation exists in what has so far been written on the subject. For example, one book may have an extensive discussion of abrasive wheel surface grinders (for grinding flat surfaces) but never even hint at the fact that there are coated abrasive ("sandpaper") belt grinders which will do the same jobs at least as well, and sometimes even better. Or which may never mention that there are loose-grain machines certainly capable of improving flat surfaces and to some degree of generating them. Further, most discussions are organized on the basis of the way in which the machines are

designed and not according—as they are in this book—to the basis of what they accomplish.

In this discussion there are some deviations from traditional terminology. One French term for a grinding machine is "machine á rectifier," which can be roughly translated as a machine to finish up or correct what some other process began. So the terms "grinding," "abrasive machining," and sometimes "abrasive cutting" have been used interchangeably, reflecting the author's opinion that the three are now synonymous, even though some individuals contend that abrasive machining is a broader term than grinding and that "abrasive cutting" ought to be limited to parting or sawing operations done with thin abrasive wheels.

Grinding, by whatever name it is called, now has the capability to be a broad-range and complete machining process in its own right, and should no longer be considered as limited just to secondary finishing of what has been begun by some other machining process.

But if there are milling cutters, as there are, and cutter-type machining with metal and carbide tools, why not abrasive cutting in a broader-than-traditional sense? When the term abrasive machining was introducted in the mid-1950s, it had tremendous value in its focusing of attention on a different approach to the use of grinding wheels. But now the time has come to recognize that whereas abrasive machining may be slightly more inclusive than traditional grinding, the three are essentially similar processes, and the terms can be considered synonymous.

The growth in the use of abrasives and, even more so, their increased potential have created a need for a book which will enable people without technical background in the subject to discuss it intelligently with those who do have some background. Such a book could also serve as an introduction and a reference to the subject, so it should be accurate without being overly technical. In keeping with that purpose, Chapter 1 is a basic introduction to the uses of abrasives that may be skimmed or omitted entirely by those with previous knowledge in the field.

Acknowledgments. Over the past three decades or so, the number of people with whom I have discussed abrasives and from whom I have learned what these tiny bits of mineral can do must be well up in the hundreds. However, I want to recognize specifically the help and encouragement of Bill Schleicher, who got me into this business to begin with, and of Cliff Duxbury, Chuck Nobis, and Doug Wachs. Without them this book could not have been written. But I should—and do—absolve them of any responsibility for any statements or conclusions contained in the text, which is entirely of my doing.

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inch. This means that the dimension can be over or under the nominal plus or minus two ten-thousandths of an inch, which is fairly close work with respect to commercial production grinding. Some parts, however, require only the removal of some flash (a ragged edge of excess material usually resulting from a forming operation) or burrs (ragged edges resulting from an operation like drilling). If the parts are small, they may be finished by holding them against a simple floor- or bench-mounted abrasive belt grinder; but if there is a large volume of piece-parts, the flash- or burr-removal job can be done more efficiently by loose bits of abrasive, in a barrel or vibratory finishing machine, or possibly by blasting.

CUTTING TOOLS

For years cutting tools have been pieces of hardened steel with either one or a few cutting edges, which could be mounted in a holder and moved across a piece-part under pressure to cut excess metal or other material from the piece-part. If the piece-part is mounted on centers and turned as the cutting tool is pressed against it, the operation is called turning, and the tool will usually have just one cutting edge. If the surface to be generated is flat, it is a milling job and the cutter will have perhaps a dozen or so teeth, and it will be rotated against the surface as the cutter moves across it—or as the piece-part moves under the cutter. A third type of cutter machine tool is the drill press, which makes holes in piece-parts. A fourth is the boring machine, which finishes and sometimes enlarges the holes made by a drill. There are many variations on these basic types, of course, but these are sufficient for the present discussion. Regardless of how hard and tough the steel is or how sharp the original edge, all steel cutting tools eventually have to be resharpened, a requirement that has led to the development of "throwaway" tools, usually made of tungsten carbide, a very hard material, which are held in steel holders, used until they are dull, and then discarded. At least that is the intent, and most shops follow such a practice. There are some shops that resharpen even throwaway tools, however, but this is considered of doubtful value.

Cutting tools are very efficient at removing excess material from piece-parts, but not so good for producing close dimensional surfaces or high-quality surface finishes. In fact, the first abrasive wheels and belts were developed because precision and surface-finish requirements had outstripped the capabilities of the cutting tool. Since that time over a century ago, even though cutting-tool capabilities have increased, so have the requirements for precision and finish. But there has probably been little change in their relative capabilities.

ABRASIVES

Abrasives can probably be best described as microminiature cutting tools, primarily small bits of hard mineral materials called grain, which can be cemented together (bonded is the trade term to be used throughout this book) into wheels of many shapes and sizes, cemented onto a backing of cloth or paper (sandpaper is the colloquial and coated the trade term), or used loose, without being held together in any way. These are the three principal forms. The largest grain is whatever will pass through a quarter-inch screen. The smallest is so fine that it floats in water, and is often sized by flotation, with each size depending on the amount of grain deposited as sediment within a given time.

When these grains of abrasive are bonded together in a wheel or adhered to a backing in a coated abrasive belt, they act like a milling cutter or turning tool, with perhaps millions of cutting teeth instead of the dozen or so characteristic or the milling cutter. (Microscopic studies have established that abrasive grains cut away the material they remove. They do not rub or wear away the material removed from the piece-part. In fact, a rubbing action would produce excessive heat, which is damaging to the abrasive cutting action and often to the work.)

Types of Abrasives

There are four or five types of mineral-like abrasives, depending on whether natural and manufactured diamonds are counted as one or two. Counting them as one is probably more practical, since diamond suppliers handle both.

The most feasible way of examining the types of abrasive is to group them by approximate price. The two cheaper and most-used abrasives are silicon carbide (Fig. 1), the first of the manufactured abrasives, and aluminum oxide (Fig. 2), which was developed only a few years afterward, around the beginning of the twentieth century. Tons of both types are made each year, although aluminum oxide is by far the larger of the two in volume. Both are made in different types of electrical furnaces. The per-pound cost of both is relatively low.

Natural diamond of industrial grade (Fig. 1-3)—any diamond not of gem quality—began to be used extensively as an abrasive shortly before World War II. Manufactured diamond (Fig. 1-4) was developed in the late fifties, and cubic boron nitride (CBN) about a decade later (Fig. 1-5). Both these abrasives are made under conditions of such extreme temperature and pressure that volume production has so far been impractical. The price of both has remained in the range of $3 to $4 per carat, or several thousand

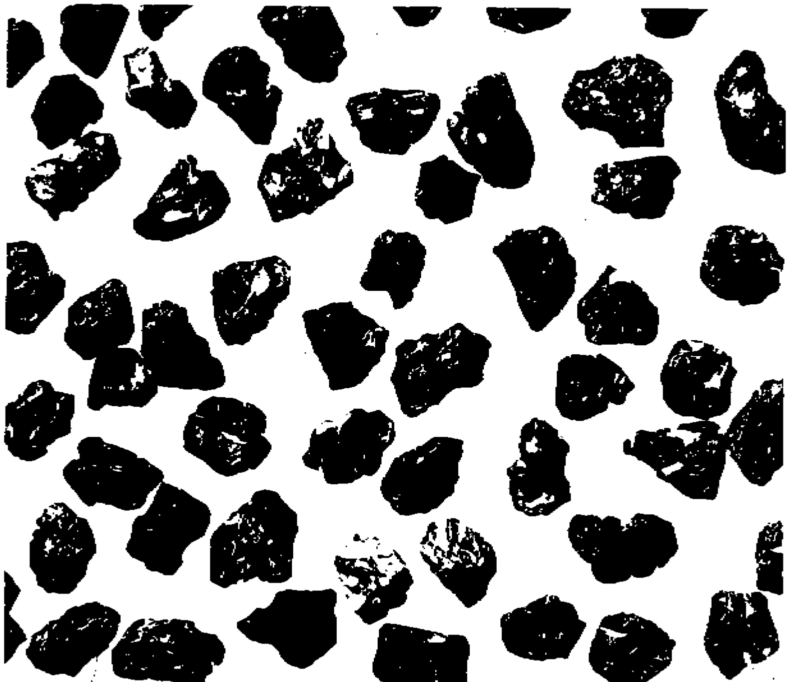


Fig. 1-1. Silicon carbide grain. (Approximately 8 magnification.) (*The Exolon Co.*)

dollars per pound. (It is interesting to note that the first silicon carbide produced sold at about $880 per pound around 1900, which was then probably equivalent to the diamond and CBN price today.)

Of course, price is not the only differential; on some applications, diamond and CBN are so extremely efficient that this factor outweighs the much greater abrasive cost, particularly on hard, difficult-to-grind materials.

Let's start with hardness. Diamond is the hardest substance known; CBN is about two-thirds as hard; and silicon carbide and aluminum oxide, about one-third as hard. On the Knoop scale, these are the relative ratings:

Diamond	7000
Cubic boron nitride	4700
Silicon carbide	2480
Aluminum oxide	2100

Fig. 1-2. Aluminum oxide grain. (Approximate 8 magnification.) (*The Exolon Co.*)

It has been observed that all abrasives are hard, but not all hard substances are abrasive. Indeed, there are several materials which are harder than either silicon carbide or aluminum oxide, but not so abrasive.

Other factors than relative hardness enter into the picture in determining which abrasives to use on what materials. Diamond is harder than CBN, and more effective on carbides, but less effective on steels. One of the disappointments in the use of diamond as an abrasive is that no one has yet come up with a coating or other variation that will enable it to grind steel efficiently. A similar situation exists with the conventional abrasives. Aluminum oxide is more effective on most steels and less so on nonferrous metals and nonmetallic substances than is silicon carbide. The best explanation of the problems of diamond and silicon carbide on steel is that there is a chemical reaction between the abrasive and the steels which in effect "melts" the abrasive and causes excessive wear.

Fig. 1-3. Natural diamond. (Perhaps 2 magnification.) (*General Electric Co.*)

Choice of Abrasives

With respect to the two lower-priced abrasives on the one hand and the two types of high-priced abrasives on the other, the choice is an engineering decision, because there is no significant difference in price. However, when it comes to a choice between, say, an aluminum oxide wheel costing a few dollars and a CBN wheel costing a few hundred dollars, price becomes a definite factor. Bear in mind, of course, that the higher-priced wheel may very well be so much more efficient and long-lasting that the per-unit abrasive price will be less than that for the low-priced wheel. Of course, the operator's experience and skill may also be an effective factor. As one shop owner once remarked, "I don't want anyone right off the street fooling around with a wheel that costs a couple of hundred bucks." He had a point. In fact, many shops feel that the price differential is still too great to allow CBN to be used on most production grinding operations, unless the hardness of the work material is such that aluminum oxide is not effective. Similar reasoning, of course, can be applied to diamond and silicon carbide. Diamond is the accepted abrasive for grinding tungsten carbides—in fact, for grinding most of the carbides. It is also the choice for cutting the "rumble strips" and other grooves in concrete highways.

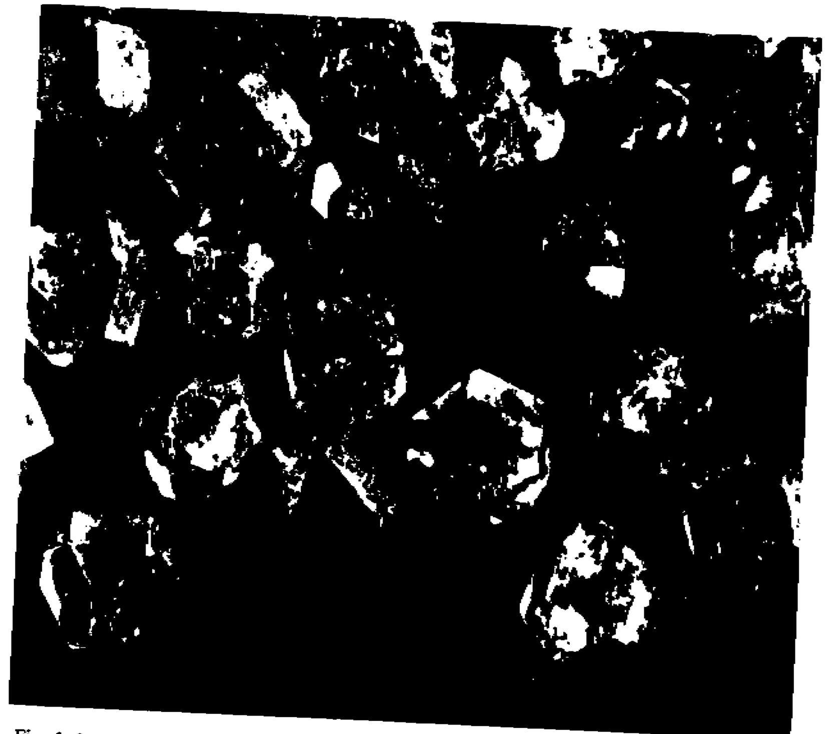


Fig. 1-4. Enlarged metal bond saw diamond. (*General Electric Co.*)

Bonds for Wheels

For wheels the two principal bonds are vitrified (clay-type), which is used primarily with medium and fine abrasive grain for precision work; and resinoid (organic-type), which is used primarily with coarse grain for heavy stock-removal operations such as snagging castings. Rubber is also used as a bond for some specialized applications. There are many different formulations for each of these general types, and grinding-wheel manufacturers regularly come up with new ones, usually targeted at some particular market. And as their research engineers learn more about the effects of changes in formulation of the bond on wheel performance, it is sensible to conclude that bonds are improving.

Because grinding wheels and segments (Fig. 1–6) remove stock from piece-parts so readily, there is a strong tendency among operators to think of the wheel as being very tough and durable. Durable they certainly are,

Fig. 1-5. Uncoated cubic boron nitride. Enlarged. (*General Electric Co.*)

but tough, especially in vitrified bonds, they are not. The reason is not difficult to determine. The clays used as bonds in vitrified wheels are similar to those used for dishes; and the vitrifying process is similar to that used for dishes; so it is not surprising that the product is also similar to dishes. Resinoid wheels with a thermo-setting bond that is somewhat gummy before the wheel is baked are not as fragile, it is true; but neither are they so tough as to justify using a wheel that has been dropped or has received a similar physical shock. The risk of cracking is too great for a tool that when in use may be rotating at speeds of up to 3 miles per minute. (Vitrified wheels travel slower, at a little more than a mile per minute.)

Wheel Making

Most wheels are formed by pouring a mix of abrasive and bond into a round mold in which the mix is distributed as evenly as possible, inserting a

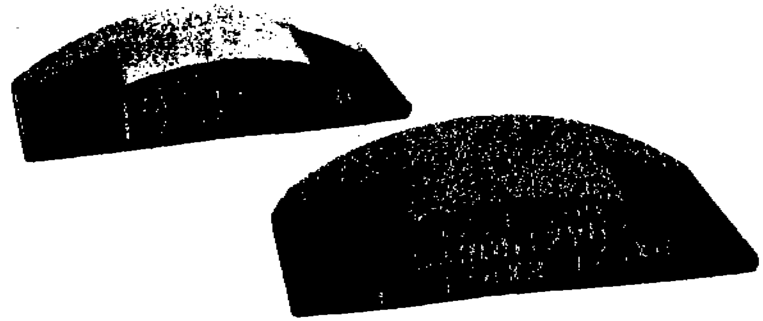


Fig. 1-6. Bonded abrasive segments. These are fitted into a holder, probably, in this style, to make a continuous flat grinding surface with the sides opposite to the marked sides. (*Bay State Abrasives, Dresser Industries.*)

top plunger into the mold, and compacting the mix under very high pressure. After vitrifying (at over 2000°F) or baking (resinoid, at 300 to 500°F) the wheel is finished to prescribed tolerances for dimensions and balance and is ready for shipment. Rubber-bonded wheels are handled differently, by a sort of cookie-baking procedure. The abrasive and rubber are kneaded together and rolled out in sheets of the required thickness when properly mixed. They are then cut or died out, just as with cookies, and baked. The scraps are kneaded, rolled, and cut out again, just as with cookies. Wheels can thus be made very thin—much thinner than is possible with the molding method, so many of the thinnest cutoff-type wheels are rubber-bonded.

Coated Abrasive Adhesives

Adhesives for coated abrasives function somewhat in the same way as bonds, in that they hold the abrasive grain in place. In the making process, a long web of paper or cloth about 52 inches wide is coated with a film of adhesive called the *make coat;* the adhesive is then applied (from the bottom up, drawn upward by electrostatic force); and after a drying period, a second film of adhesive called the *size coat* is applied. Then the long strip is dried again; and after a preliminary flexing operation to control the spacing and direction of breaks in the adhesive, it is ready to be cut, one way or another, into a finished product—belts, discs, strips, square sheets for incidental industrial and home shop use, sleeves, and other products.

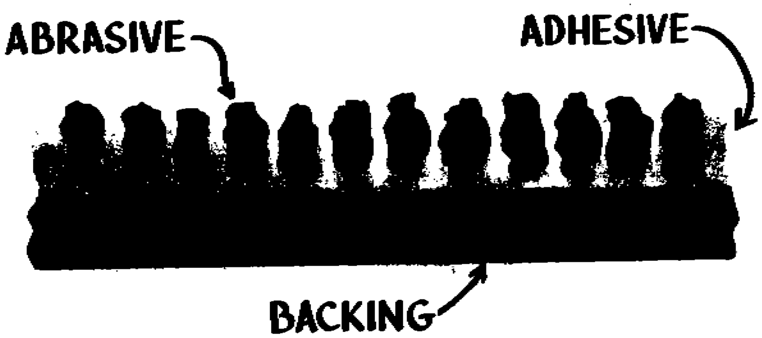


Fig. 1-7. Enlarged side view of coated abrasive, with abrasive grain imbedded in adhesive on a backing. (*Hitchcock Publishing Co.*)

There are two principal adhesives—glue and resin—and the two coats of adhesive may be the same; or there may be resin over glue or glue over resin, depending on the final application intended. The advent of resin as a waterproof adhesive probably signaled the start of the use of abrasive belts for serious stock removal. Before that, when glue was the only adhesive used, belts could not be used with water or any other coolant, because the glue would dissolve and release the abrasive. But because of the development of waterproof coated abrasives, they are now used routinely with water or whatever other coolant is appropriate.

Coated Abrasive Backings

A word about backings. While they are generally considered to be paper and cloth, paper is actually limited to noncritical applications, such as the home-workshop market and very light duty applications. And the cloth backing used for belts must meet two somewhat conflicting objectives: it must be flexible enough to bend around the pulleys (contact wheels or rolls) on which belts (Fig. 1-8) are used and yet strong enough not to tear when pressure is applied—and pressure is obviously one of the key factors in any grinding. The really heavy, stiff cloths can be used as backing for abrasive discs, but the backing for belts must be more flexible. In fact, this one problem may well have been holding back the progress of belts into heavy stock removal applications.

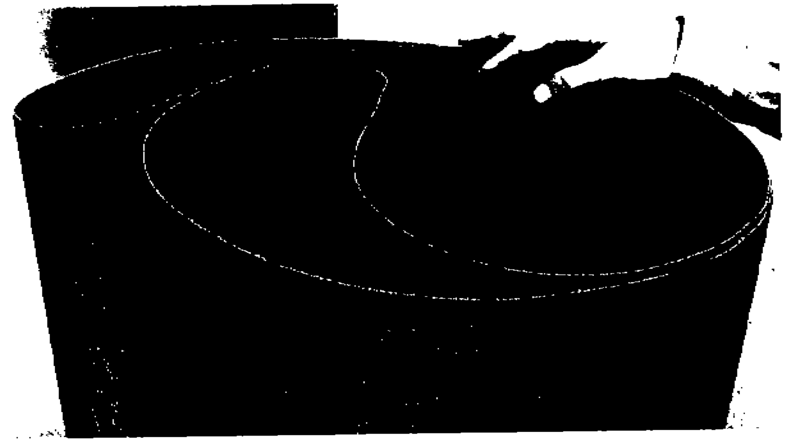


Fig. 1-8. Coated abrasive belt. (*3M Company.*)

CLASSIFICATIONS OF GRINDERS

Not surprisingly, most of the grinding machines in function resemble milling machines and lathes or other machine tools. In fact, the first center-type cylindrical grinders of a century ago were lathes that had been modified to use a grinding wheel instead of the single-point cutting tool. And it would hardly be amiss to describe the most common types of surface grinder as milling machines with several thousands of teeth rather than a dozen or so.

It has been said that a grinding wheel or belt can do anything a cutting tool can do except drill a hole, and that is probably true. But once the hole is made, there are jig and internal grinders (Figs. 1-9, 1-10) that will finish the hole excellently.

Cylindrical Grinders

In a center-type cylindrical grinder (Fig. 1-11) the piece-part is supported on either end by centers and rotated for the stock-removal and finishing operation, duplicating the lathe. Either the piece-part or the wheel may traverse; the piece-part travels unless it is too large or too heavy to be moved readily, in which case it remains stationary and the grinder wheel travels. From a quality standpoint it is preferable to mount the wheel securely and to move the work. There is also less overall vibration.

However, as the rate goes still higher, stock removal resumes its upward trend.

Pressure. Pressure on the wheel or belt is another aid to higher stock removal, even though the bulk of machining with abrasives is considered as a light-pressure method. In billet grinding or foundry snagging, it has long been known that a strong and heavy man who can exert greater manual pressure on the wheel he is using can grind more billets or clean up more castings than can a lighter man who is not as strong. So by increasing pressure mechanically to several hundred pounds per square inch, steel mills and foundries have increased their grinding output tremendously.

The successful replacement of cutting tools by abrasive tools for heavy stock removal thus depends a great deal on the development of higher-speed—and consequently, higher-powered—machines that can exert greater pressure on the wheels or belts.

One of the factors holding back the increased use of belts in such situations is the development of belt backings that will be both flexible enough to move at high speeds around the contact rolls and wheels and at the same time strong enough to withstand considerable pressure without tearing—a point that will be discussed in more detail later. There are, of course, quite strong cloth backings used for abrasive discs, but such backings do not bend to any considerable degree. On the other hand, the area of contact between abrasive and piece-part surface in belt applications is almost without exception greater than that for wheels. Belts are characteristically wider; a 12-inch width is very common, the possibilities go up to 48 inches without splicing and even wider with splicing, though that increases belt cost significantly.

SUMMARY

No one has ever maintained that grinding—or abrasive machining, or cutting or finishing—is a simple process. Currently it is probably becoming a science, but with a generous infusion of art. The fact is there were—and maybe still are—many who call it akin to witchcraft. Some long-ago abrasive salesmen were suspected, with some basis in fact, of fostering such an attitude. Competition is keen, and comparative testing of abrasives to determine which of two or three different brands is superior is difficult and time-consuming, a procedure which can be justified only for high-production applications. However, if you have understood what has been written in this chapter, you should comprehend the following chapters and be able to understand what others are talking about when they discuss abrasives, and thus be able to make judgments with a better comprehension of the value of the proposed alternatives.

2
Abrasive Grain

Little bits of irregularly shaped, very hard minerals, less—usually much less—than a quarter of an inch thick, are the heart of any abrasive cutting system. All the parts of the grinding machine, which may total up to several tons, are designed and assembled for just one purpose: to make sure that the little bits of mineral cut the work material as precisely and as rapidly as is required.

It should not be surprising, therefore, that the major advances in machining with abrasives have come about through the development of new abrasives or of significant modifications of existing abrasives. We have thought in terms of five groups of abrasives—silicon carbide, aluminum oxide, natural diamond, manufactured diamond, and cubic boron nitride, but each has subtypes that have been developed to fill a range of needs. Aluminum oxide that is essentially pure, for an example, is a fast-cutting but relatively fragile (friable is the term used in industry) abrasive. Some of the naturally occurring impurities actually make it a tougher, longer-lasting abrasive. And the addition of zirconia makes aluminum oxide still tougher and longer-lasting. Depending on the application, each has a place. Though wear life is a factor in choosing an abrasive, it is not necessarily the controlling factor; there are many applications in which a friable abrasive does a much better job.

DEVELOPMENT OF ABRASIVES

The development of silicon carbide and aluminum oxide around 1900 freed industry from its total dependence on natural abrasives of uncertain quality and composition, and gave abrasive cutting its first shove forward. The discovery of the abrasive qualities of diamond, about the time of World War II, facilitated the cutting of materials that the other abrasives just nibbled at; and thus, incidentally, provided a use for diamond boart, the scrap diamond left over from cutting gems, which had become a drug on the market. Diamond abrasive was an instant success, so much so that the excess was soon used up and the search for an artificial diamond, something that could be manufactured, was stimulated again. Natural diamond had to be rationed to applications for which it was most efficient rather than used for all the applications for which it was preferable to the established silicon carbide, primarily, and aluminum oxide.

Research efforts were rewarded during the late 1950s, when the General Electric Company announced that it had succeeded in producing authentic manufactured diamond. For 2 to 3 years, maybe more, teams of engineers from General Electric and a principal grinding-wheel manufacturer talked about the new development wherever they could find an engineering society meeting. It wasn't very long before DeBeers, the principal supplier of natural diamond, was able to produce a similar abrasive, and these two have been the principal suppliers since that time.

Cubic boron nitride (CBN) was developed a few years later, also by General Electric. CBN is manufactured by a technique similar to that which creates diamond, but is a substance not found naturally. It is useful in grinding hard steels which can be machined, though not always so effectively, by aluminum oxide.

DEVELOPMENT OF MACHINES

The development of machines has been a much more gradual process, with many small improvements. Even the practical application of centerless grinding, which came about 1920, was something that had been known for a number of years in principle: the first production of centerless grinders was preceded by a number of earlier, experimental machines which had demonstrated that centerless grinding was a workable process for producing cylindrical shapes.

TYPES OF ABRASIVE GRAIN

A point that was made earlier deserves reemphasis here. Even though we speak of four or five different types of abrasives—silicon carbide, aluminum oxide, natural diamond, manufactured diamond, and cubic boron nitride—and even though all of the abrasive grains of each type are basically similar, especially in terms of the kinds of material on which they are effective, considerable other differences exist. These have to be taken into account when different grains are compared. Color, for example, is a useful, but not infallible, means of distinguishing between grains of different subtypes. For example, the purest and most friable of the aluminum oxides is naturally white, so all the grain and wheel suppliers take great pains to maintain this color, even sometimes discarding wheels that are slightly off-color. Some suppliers even color their wheels as a means of product identification.

"Conventional" Abrasives

A number of factors make it practical to consider silicon carbide and aluminum oxide together. They are by a substantial margin the most-used abrasives; one furnace load of either, at any one of the manufacturers, probably weighs more than the entire annual production of either diamond or CBN, and quite possibly more than both put together. Between them, they do a generally good job of covering the range of industrial materials to be ground. And they are what most people think of when they consider abrasives or grinding wheels.

Silicon Carbide

It has never been made entirely clear what Dr. Edward G. Acheson was looking for in 1891 when he discovered silicon carbide, a substance that hadn't been known up to that time. What is known is that in one of his experiments he had mixed sand and coke, heated the mixture electrically to a point where in poking through the cooled mixture he found a few bits of a shiny black substance that was hard enough to scratch glass. What he thought he had found was something involving carbon and corundum, a natural abrasive much used at that time. So it was logical to call the new material Carborundum. He later organized a full-range abrasive manufacturing company with the same name. The company has been consistently a major manufacturer of the material from which it derives its name.

This abrasive is manufactured by the ton in troughlike furnaces (Fig. 2-1) for which typical dimensions could be 40 feet long, 10 feet wide, and 10 feet high when loaded. The sides are removable, and the ends are wired to conduct very heavy loads of electricity.

In the furnacing process pure coke is mixed with white silica sand, small amounts of salt and sawdust, and a generous amount of partly converted old mix. The furnace is partially loaded; a trough is scraped out in the top of the mix, between the two electrodes in the ends of the furnace, to hold pure graphite, which acts as an electrical conductor. After the furnace loading is finished, the current is turned on, and the mass eventually

Fig. 2-1. A bank of electric furnaces for producing silicon carbide which heat a loose mass of mostly coke and silica sand to over 4000°F and hold it for a run of a few days. The two in front are ready for unloading, with the imperfectly converted material scraped off. The fifth furnace back is still in process. (*The Exolon Co.*)

reaches a temperature of over 4000°F, at which point a large part of the load crystallizes in a sort of flattened tube. The duration of the cycle is a matter of days. When the conversion is complete, the furnace is cooled down and the sides are removed. Then the imperfectly converted mix, which is still grainy, is scraped off to expose the hollow core of crystalized silicon carbide. As mentioned above, the partly processed mix is reused in a later furnace load.

When the silicon carbide has been cleaned, the tube is broken into chunks (Fig. 2-2) for further reduction by crushing and rolling. For such a hard material, it is relatively easy to break up. At this stage the chunks of abrasive are quite pretty: regular grain is black or a somewhat iridescent dark blue; the purer type is dark green. Silicon carbide in chunks is also very abrasive; so that while souvenir pieces of the abrasive are attractive they can scratch any surface on which they are placed.

Subsequent treatment of silicon carbide involves a series of crushing and screening operations designed to reduce the size of the individual bits of grain and to separate them by size (Fig. 2-3). The sequence of operations

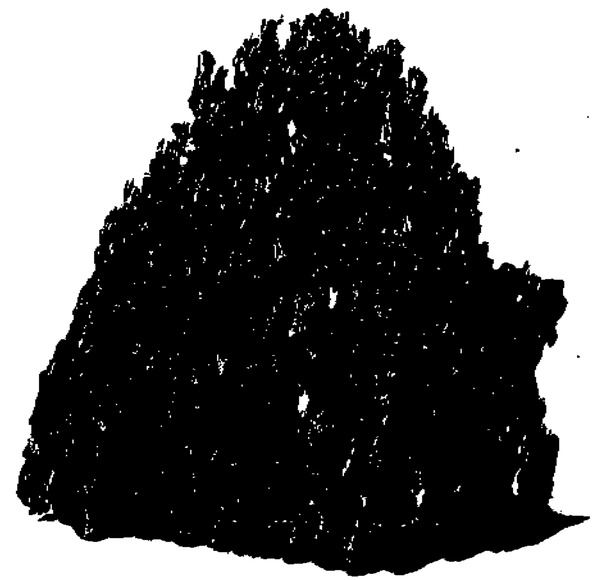


Fig. 2-2. A chunk of silicon carbide from early in the crushing cycle. Note its rather fragile appearance, in contrast to the aluminum oxide chunk in Fig. 2-5. (*The Exolon Co.*)

also modifies the shape of the grain—sharp and elongated, for coated abrasives; or blocky, for foundry and snagging applications; or somewhere in between, for general work.

Silicon carbide is the first of the successful manufactured abrasives to be developed, and in tonnage produced per year is second only to aluminum oxide. Apart from its historical significance, it has a definite place in the grinding and shaping of nonferrous metals, ceramics and other nonmetallic materials, and cast iron.

Silicon carbide is generally black, but some in a purer form is green. Wheels made with this grain are most often black because of the color of the grain.

Aluminum Oxide

Aluminum oxide is the most widely used abrasive in the world, primarily because it is used in grinding practically all kinds of ferrous metals. Its development occurred at about the same time as that of silicon carbide,

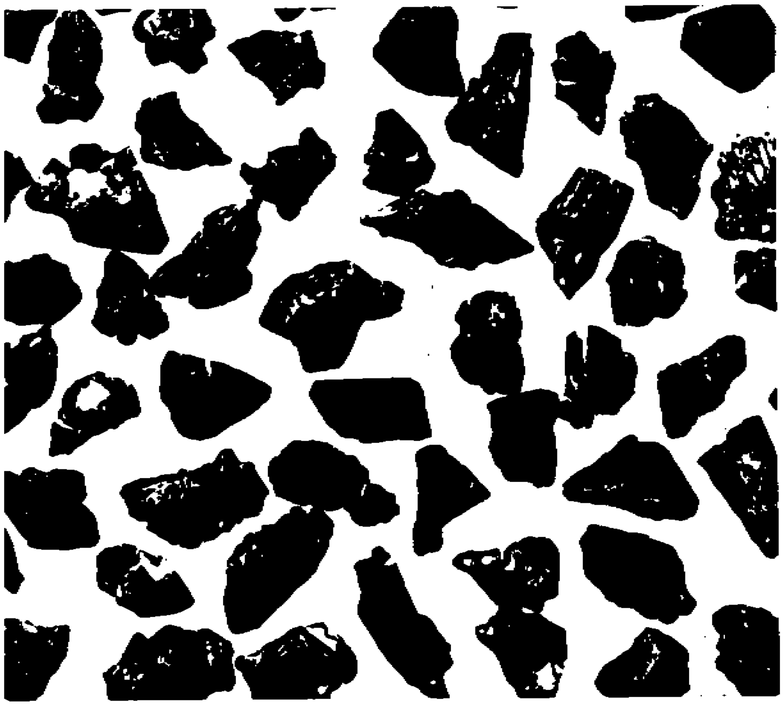


Fig. 2-3 Magnified about eight times, the end result is sized silicon carbide grain ready to be bonded into wheels or adhered to a backing. (*The Exolon Co.*)

though not quite in the same manner. Some time before 1900, aluminum oxide was identified as the abrasive element in emery, a widely used natural abrasive at that time. Its principal developer was Charles B. Jacobs, an engineer with the Ampere Electro-Chemical Company, who fused bauxite (an impure form of aluminum oxide named after the town of Les Baux, France, where the material was first quarried). After the fusing, he crushed the resulting dense mass into abrasive particles. This basic process is still being followed, though of course there have been many improvements in the details of the procedure.

The fusing process is simple to describe, but it was originally difficult to carry out, principally because of degree of heat involved. Pot-type furnaces (Fig. 2-4) of several tons capacity each are used. The heat is supplied by two electrodes. In the beginning, a small amount of bauxite (with some

Fig. 2-4. A battery of aluminum oxide furnaces, which are noticeably smaller than the silicon carbide "troughs." To heat these furnaces, electricity arcs between the tips of the two electrodes in each furnace. (The second barely shows through the smoke in the front pot.) Aluminum oxide fuses at over 4000°F. (*The Exolon Co.*)

minor additives) is loaded into the furnace and the electrodes are lowered into it. Sufficient current is sent through the electrodes to create an arc through the bauxite, which when heated to a temperature of something more than 4000°F becomes molten. As more bauxite is added, the electrodes are gradually raised, and the process continues until the pot is filled with molten bauxite. Originally the charge was left to cool in the original pots, but modern practice is to pour the molten material into cooling pots of construction similar to the furnace, where it can cool at leisure; the original pot is then refilled with another charge of alumina while the pot is still warm. This method reduces both the time and the electrical energy needed.

Fig. 2-5. A chunk of aluminum oxide. Looks much solider than the silicon carbide piece in Fig. 2-2, and it probably is. (*The Exolon Co.*)

After the "pig" has cooled, it is dumped out onto a floor for primary crushing with a "skull cracker" to break it into lumps (Fig. 2-5) for further jaw and roll crushing. After a series of crushing and sizing operations, plus possibly some roasting or heat-treating operations to increase the toughness of the grain, it is ready for fabrication into wheels or coated abrasive products (Fig. 2-6).

The abrasive characteristics of both types of abrasive are established during the furnacing and crushing operations, so very little that is done later affects those characteristics significantly. Note that most vitrified wheels carry the color of the grain—bluish-black or green for silicon carbide and white, gray, or tan for aluminum oxide. However, adding chromium oxide in small amounts will produce a pink wheel, and similar amounts of vanadium oxide create a green aluminum oxide, but these are for identification and marketing only. The additions have at most only a minor effect on the cutting ability of a wheel. Vitrified bonds are essentially colorless, so the color of the grain is generally the color of the wheel. Resinoid

Fig. 2-6. Bits of aluminum oxide grain, at about 8X magnification; probably a random sample, but some look slivery enough to be used for coated abrasives. (*The Exolon Co.*)

bonds, particularly, are mostly black, so most resinoid wheels are black or very dark gray.

Types of Aluminum Oxide Grain

Aluminum oxide is essentially a tougher grain than is silicon carbide. Four types of gradations of toughness—or the lack of that quality, which is termed friability—are generally recognized. It might seem as though the toughest, longest-wearing grain would always be the best, but in practice this is not so. A grain that is too tough for an application will simply become dull and rub the piece-part surface, creating heat, which is the enemy of precision work. It is true, on the other hand, that too friable a grain will wear away very rapidly, thereby shortening wheel life, and this is not desirable either. But one need not stay in the middle all the time. Sometimes it is more desirable to have the wheel wear without overheating the piece-part; at other times for some applications where because of the wheel speed and principally the pressure involved, even the toughest grain wears down and is torn out of the wheel with ease. So there is a range of grain toughness suitable to a very wide spectrum of applications. And as it happens, the purer the raw materials, the more friable the grain.

Friable aluminum oxide, then, is made of relatively pure materials. It is white, practically always vitrified-bonded, and mostly used for tool grinding or similar precision work. In this range, the fact that the wheel may wear faster than normal is not a major consideration; toolroom grinding is by most standards not a production job. What is critical is that most tool steels are heat-sensitive, a criterion that far outweighs the consideration of the number of tools ground per wheel.

The next step is semifriable grain, an aluminum oxide whose titania content has been reduced to a little more than half that of the bauxite. It should be noted in passing that the sharpness of the fractured grain also affects its friability. The sharper the grain, the more friable it tends to be. Heating or roasting is another means of increasing toughness, if such should be desirable. In fact, through adjustment of the chemical content of the raw material, to some extent through modification of the fusing process, and through selection of the crushing and grain-treatment processes, the grain manufacturer has considerable flexibility in determining the final character of the grain, and can modify the product to take care of virtually any application within the broad range of the capability of the abrasive. Of course, this requires strict control over the grain-making processes by the manufacturer to ensure that for a given designation the same grain is delivered each time. It should also be mentioned that some crushing processes tend to produce a blocky shaped grain essentially for wheels, while others tend to produce grain for coated abrasives that is longer in relation to its thickness. The manufacturing process for wheels does not allow grain orientation, while that for coated abrasives does. Hence, grain for wheels must have several cutting points, moreso than that for belts.

Grain produced from bauxite with approximately its normal content of titania is considered "tough"; and if the molten abrasive is cooled quickly, the crystals formed in the fusing are small—hence the term "microcrystalline"—and the grain is considered extra tough. Another variation in the tough range is a grain consisting of about 25% zirconia and 75% alumina, cooled rapidly.

These tougher grains are used primarily in heavy stock-removal operations such as foundry snagging and steel-mill billet grinding. However, as one-step machining with abrasives—essentially producing finished parts from the "solid" or from rough parts entirely by abrasives—become more prevalent, it is entirely likely that these tougher grains will be more widely used for the stock removal needed in rough machining.

Physical Properties of Conventional Grain

In the discussions of silicon carbide and aluminum oxide, the principal physical property mentioned has been toughness or friability. Others which are important are grain size, hardness, shape (which is measured by bulk density), specific gravity, and crystal structure.

Grain size, oftentimes called grit size, is a tangible quality of all abrasives, both manufactured and natural. For the two conventional types,

the accepted regulations concerning size are contained in two Department of Commerce publications, *Grading of Abrasive Grain for Grinding Wheels,* and *Grading of Abrasive Grain for Coated Abrasive Products*

Size. Originally, grain size was determined by the number of abrasive grains required to fill a linear inch. The method has never been described. However, with the adoption of United States standard sieves (with standard numbers of openings per square inch) in the early 1940s, the sizing process became much more accurate. And even though the standard sieves changed the sizes slightly, the original numbers have been retained. Their interpretation is easy: the larger the number, the smaller the grain.

Coarse sizes range from 4 and 8 to about 24; medium, from 30 and 46 to about 80; fine range, from 100 to 220; and powder sizes, from 240 to about 1000. These are not hard-and-fast groupings; the numbers are different for diamond and CBN, and the terms "fine" and "coarse" vary in meaning in different shops. For example, in a foundry, 36 grit would be regarded as a fine size, whereas in a precision machine shop, 60 grit or 80 grit would be coarse.

Abrasive grain of 240 grit and coarser is generally sized by passing it over a series of vibrating screens—usually several screens within each unit—which grow progressively finer. Grain smaller than 240 is sized by sedimentation or by centrifugal separation.

The minute size of abrasive grains, even the coarsest, is sometimes difficult to appreciate. For example, the sieve for a comparatively coarse 12 grit would theoretically have 144 openings per square inch, although the actual total would of course be somewhat less. For 240 grit, the number of holes per square inch would be something in excess of 55,000.

Another way of quantifying the size has been to estimate the number of grains per gram of powder. For silicon carbide, 240 grit, the estimate is 3,500,000. But for 600 grit, well into the powders range, the figure reaches 440,000,000.

Fortunately, the specifications do not call for grain to be 100 percent of the nominal size. Even though we talk of 60 or 100 grit, this represents a size with a small percentage of coarser grain and a somewhat larger percentage of smaller grain; because grain that is significantly coarser would scratch the surface too harshly for the rest of the grain to smooth out, leaving a low-quality surface. Finer grain presents no such problem, of course, but it simply does not have the stock-removal capability of coarser grain, which means that the finer grain does not pose much of a problem, but neither does it do much good. So the number given to any grain size means that the grain is primarily of that size, along with some coarser and some finer grain. Abrasive grain that totally includes the nominal size can be obtained, but the extra work required to refine it to that degree raises its price.

Hardness. All abrasives are significantly harder than the materials they cut, although that is not the only reason for the cutting. Hardness is usually defined as resistance to penetration by another material. In fact, the traditional method of comparing hardness of two materials has been to see what scratches what, as Acheson did with his first crystals of silicon carbide. In fact, one of the earliest comparisons, the Mohs scale, was established with 10 materials ranging from the softest, talc, as number 1, to diamond, number 10. Corundum, an impure natural aluminum oxide much used in the 1800s, is number 9; but there is a considerable gap between the last two numbers—9 and 10—of the sequence, enough to make the system of little other than historical value.

There are a number of hardness scales, mostly based on the principle of the depth made in the material being tested by a standard indenter under a standard pressure. However, because of the great range of hardness in materials, there is no standard that covers the entire range; and indeed, within a given test, it does not follow that a number twice as big means that one material is twice as hard as another. The two scales of most importance to users of abrasives are probably the Rockwell C scale for hardened steels (there are at least a half-dozen other Rockwell scales for a wide range of materials) and the Knoop hardness numbers, which are used for hard minerals like abrasives. The major abrasives on the Knoop scale line up like this:

Diamond	7000
Cubic boron nitride	4700
Silicon carbide	2480
Aluminum oxide	2100

On the Rockwell C scale (abbreviated R_c) a significant number of hard steels have numbers in the 45–50–60 range. For a very general comparison, since the relation is not a constant one, an R_c number could be multiplied by 100 for an equivalent Knoop number. This should be done with caution, however. For example CBN, at 4700 Knoop, is not absolutely 100 times as hard as a steel at 45–50 R_c. And there are factors other than relative hardness that determine the difficulty of grinding. Some relatively hard material can be ground quite readily; some comparatively soft materials cause all kinds of problems in grinding.

Grain shape is another important factor which is determined during the processing for the use for which a particular lot is intended. For grinding wheels there is no way of orienting grain in the wheel-making process, so the grain for wheels is blocky. For applications where high pressure is needed as in snagging, blocky grain withstands pressure better than does elongated grain. For all coated abrasives products, however, the making (manufacturing) process includes a step in which the grain can be oriented, so an elongated grain is preferable.

Tests for determining shape in abrasive grain follow the familiar pattern that a given volume of steel balls weighs more than the same volume of nails. Such tests are comparatively simple and readily adaptable to production quality-control requirements. Of course, microscopic comparison with standard samples is probably the best means, but is hardly applicable to production.

Other Physical Factors. Two other factors of interest are the specific gravity and the crystalline structure, which are established in the furnacing process and hence are not tested as routine procedures in the production sequence. The specific gravity of silicon carbide is about 3.2, and that of aluminum oxide, nearly 4.0. In comparison, water is, of course, 1.0, cast iron is 7.2, and gold, roughly 19.3. Generally, the larger the crystals, the more friable the grain. And the slower the cooling process for aluminum oxide, the larger the crystals. For very fine crystals the charge is cooled as quickly as possible, and the abrasive grain is fused in relatively small 1- or 2- ton pigs. Coarse crystalline material results from large 5- or 6- ton furnace loads, which are allowed to cool in the furnace shell.

Superabrasives

The term "superabrasive" has come into use as a group name for the two high-priced, high-performance abrasives; natural and manufactured diamond (Fig. 2-7) and cubic boron nitride (Fig. 2-8). There is no question about the superiority in performance, on hard-to-grind materials, of the two, nor about their cost. As it happens, both are manufactured by processes involving both extremely high temperatures and pressure. There are basically two major suppliers in the world.

Very little has actually been published about the details of the manufacturing process, and considering the whole situation, it is not likely that there will be any such publication for quite a while. There is really no need to know. Moreover, there are probably very few companies in the world with the know-how and the resources—plus the desire—to bring out a competitive product.

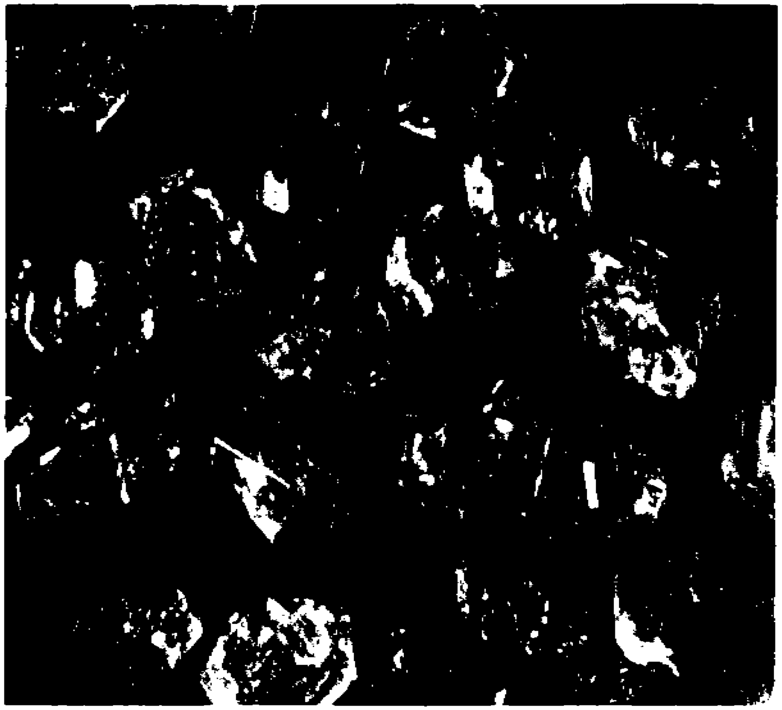


Fig. 2-7. Manufactured diamond, probably 40-50 mesh size at 60X magnification. (*General Electric Co.*)

Obviously, in a superabrasive wheel the most-expensive element is the abrasive, and in the specification for the wheels there is a spot for the thickness of the abrasive layer on the wheel core. Grain size numbers for the superabrasives are roughly the same as for the other abrasives, although the numbers are larger, indicating that the grains are not as large.

SUMMARY

Perhaps the most significant information that anyone who is not directly concerned with machining can glean from a discussion like this is that (1) abrasives, even the very expensive ones, are not really very costly in terms of unit cost, and (2) the tool (i.e., abrasive) cost is rarely the major expense

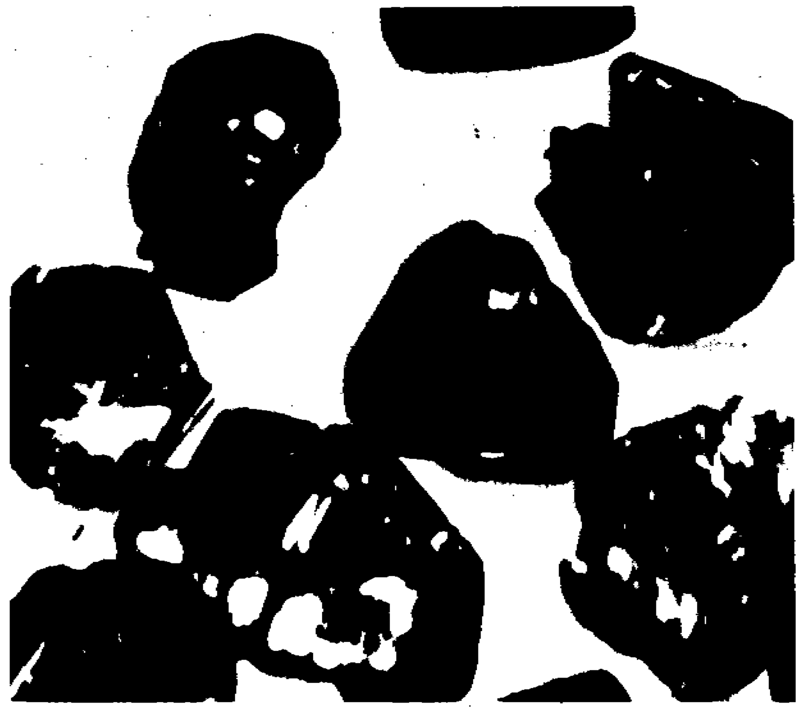


Fig. 2-8. Manufactured cubic boron nitride (CBN), probably 60 grit—slightly finer than the diamond—at 100X magnification. (*General Electric Co.*)

item in the total machining cost. Direct labor time, setup time, transportation, tool-resharpening time, and the quality and consistency of the finished parts are all likely to weigh more heavily in any decision about machining than are the comparative costs of the tools involved.

3
Bonded Abrasive Products

Bonded abrasive products (Fig. 3-1) are often considered to be abrasive wheels or other shapes made of either silicon carbide or aluminum oxide grain cemented together with one of several bonds, particularly a glass-type inorganic bond known in the industry as vitrified, or an organic bond such as resin or rubber. Vitrified wheels are used for practically all precision work, resin (or resinoid) wheels are used for heavy stock removal in foundries and steel mills, or wherever the purpose is to grind off a lot of metal. The group also includes sticks, stones, segments, and other shapes made of the same grains and held together the same way. Bonded products may contain inserts of various kinds, either inserted during the molding operation or cemented in after the wheel is finished. The temperature at which the wheel is fired determines when the insert is placed.

Wheels and other products made of either diamond or CBN grain are also considered bonded abrasives, although the expense of these grains dictates making wheels with a thin layer of abrasive bonded around the rim of a plastic or metal core. These superabrasives are also made in other shapes, though rarely of solid abrasive.

Most abrasive grain that goes into a wheel made from conventional abrasives never cuts anything; it simply supports the cutting layers. It is the same grain, of course, but when the rpm of the machine will not revolve the wheel fast enough for cutting, the stub must be either discarded or moved to a faster machine, one fast enough to make the grain cut.

The three elements of a bonded abrasive wheel are the abrasive, the bond, and air. Wheels are not solid. Vitrified wheels are porous enough to allow coolant (sometimes called grinding fluid) to flow through a hollow spindle, through the bushing—if any—between the wheel and the spindle,

Fig. 3-1. An assortment of grains and bonded abrasive products. In front are mounted wheels and points. Behind them, three piles each of silicon carbide (left) and aluminum oxide (right); and next, a chunk of each kind of grain. Upper left are a straight cup and a flaring cup wheel, with two straight wheels behind them. In the center is a small straight wheel, with a couple of "plugs" for mounting on a heavy portable grinder. At top right are a couple of thin cutoff wheels. (*Hitchcock Publishing Co.*)

and out to the wheel-piece-part interface. This idea has never really caught on, even though it is an efficient way to deliver fluid to the interface, but it does demonstrate the porosity of vitrified grinding wheels. Resinoid and other organic-bonded wheels are not so porous because of the flow of the bond under heat.

Grinding wheels come in sizes ranging from little mounted points 1/8 inch in diameter and 1/4 inch thick or small slitting wheels perhaps a couple of inches in diameter and thin enough to slit the point in a pre-ball-point fountain pen to thick centerless wheels (Fig. 3-2) to huge wheels 5 feet in diameter and 12 inches thick (in one piece). Side-grinding "wheels" for grinding flat surfaces can be made of abrasive segments held in place on a wheel mount (Fig. 3-3). But the biggest grinding wheels of all are probably the pulp wheels (which convert logs into wood pulp) made of segments bolted into place around a central core.

Wheel sizes are usually stated in a standard pattern: diameter, thickness,

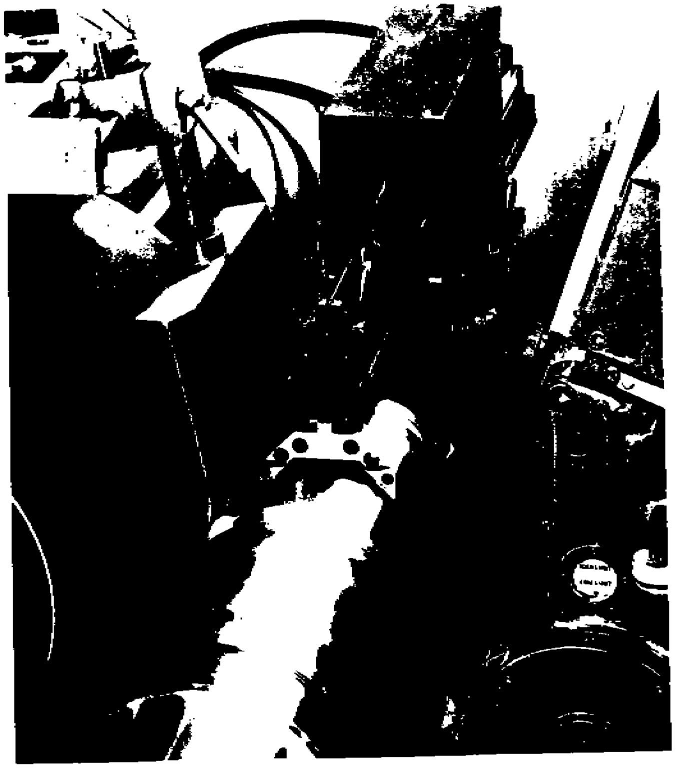


Fig. 3-2. The grinding wheel (left) in this centerless setup is one of the thickest molded. The regulating wheel is at the right, with the wide coolant nozzle near the grinding wheel and automatic gaging equipment between. (*Hitchcock Publishing Co.*)

hole size, in inches. For example a 12 × 1 × 1 wheel is 12 inches in diameter, 1 inch thick, and has a 1 inch hole. Inch marks may or may not be used. There are a few variations.

STANDARD WHEEL MARKINGS

Most grinding wheels made from conventional abrasives, excluding the very small ones, carry markings which indicate to those who know the code the type and size of the abrasive, the grade or hardness of the wheel (which is a different characteristic from the hardness of the abrasive itself), the structure (or degree of porosity), and the bond type. However, two points about standard wheel markings must first be understood.

Fig. 3-3. Bonded abrasive segments mounted in a vertical-spindle holder. The wide spacing between the segments makes for easy removal of swarf from grinding. (*Hitchcock Publishing Co.*)

Wheel Choice Limited

While there are theoretically several thousand different combinations of five factors—abrasive type and size, grade, structure and bond—for a given application only a few that warrant consideration. For example, suppose that a wheel is to be selected for precision cylindrical grinding of high-speed steel. Since the piece-parts are steel, and quantities are high, the abrasive will most likely be aluminum oxide, thus eliminating all the possible silicon carbide wheels. Every wheel manufacturer uses different aluminum oxides, but the field is narrowed considerably. There is thus a choice between two or three different grit sizes and about the same number of wheel grades and structures, though there might even be a "standard" structure, which would eliminate choice in structure. And finally, it would be a vitrified bond of some kind, so there might be a choice among three or four different vitrified bonds. But all the organic bonds have been eliminated. More important, the original thousands of choices have been pared down to a relative handful. An experienced abrasive engineer starting from this level may actually have to choose between only two wheels which are identical except for a difference in grade or grit size. If he is that close, he will likely ask for trial orders of the two wheels and make his choice on the outcome of the trial.

Symbols Standard, Not Wheels

The second caution about the meaning of the standard markings is that whereas the numbers and letters are standard, differences in manufacturing procedures with identical markings from two different suppliers may not be —and actually will probably not be—equally effective. Grit size, of course, is standard; it conforms to U.S. standards; but there are even different mixes of grit sizes in addition to the standard, as will be explained later. It takes some doing to determine which of the various kinds of types of abrasives, wheel grades, and bonds match up with similar designations from other suppliers. The suppliers, of course, have data showing how their products compare with other suppliers' wheels, but these data are generally not available. However, in any plant using large quantities of wheels, it should not be too difficult, over a period of time, to accumulate such information from trials or actual use. The specifications for the wheels that are being used on any particular application are a good starting place for any salesman wishing to displace the wheel being used with one of his own.

Anyone directly involved with selection of abrasives should of course be familiar with the details of the standard marking system (Fig. 3-4). And anybody who is at all involved with machining should understand these details enough to follow what they say about a wheel. The marking system is not all that complicated; much of it follows a logical pattern that can be readily picked up. In this section only silicon carbide and aluminum oxide wheels will be covered; markings for diamond and CBN wheels are similar, but different enough to warrant separate treatment.

Abrasive Type

A full-line wheel supplier might easily offer as many as a dozen different kinds of aluminum oxides and half-a-dozen silicon carbides. These range all the way from a friable white to an extremely tough alumina-zirconia alloy. In a symbol or marking such as the following,

29*A* 60 K 5 V9

The A in the first position indicates that this is an aluminum oxide. (This is, by the way, an actual recommendation by one of the wheel-making companies for cylindrical grinding of high-speed steel. Like all such recommen-

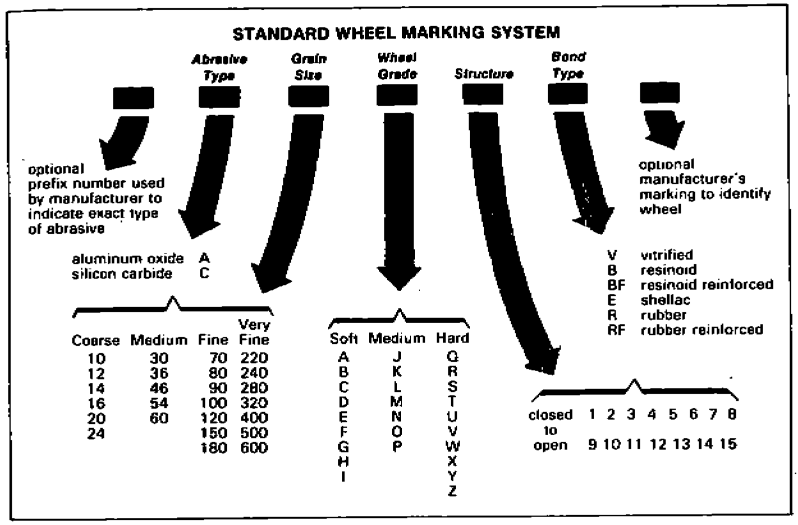


Fig. 3-4. A chart that shows the standard marking system with a complete listing of the symbols for the "conventional" abrasives, silicon carbide and aluminum oxide. (*ICS-Intext, Inc.*)

dations, it is intended as a starting point for determining the final recommendation for an actual application on a particular machine in a given location grinding a given material.)

In this company's listing, 29A is listed as one of two next-to-toughest aluminum oxides. The 29, of course, is the company's identification of a particular kind of aluminum oxide; it is an optional marking.

Grit or Grain Size

29A *60* K 5 V9

The 60 in the second position of the marking symbol tells the size of the grain in the wheel. As has already been mentioned, the larger the number, the smaller the grit size. This (see Figure 3-4) is considered about the smallest of the medium-size group. Of course the grouping as indicated in this table is rather arbitrary; in a precision grinding-shop working to tolerances in millionths, 60 grit would be considered quite coarse.

The conventional axiom about grit size is: coarse grain for stock removal; fine grain for finish. It does have exceptions. For one, if the piece-part material is exceptionally hard, coarse grain will not remove significantly more stock than fine. So it is better practice to use a finer grain than normal, because there will be more small chips removed thereby. The smaller the grain size, the more cutting grains there are in a given area of wheel surface. The second exception is that it is occasionally desirable to mix two or sometimes more sizes of grain in a wheel. Such a mixture is called a combination grain; it is indicated by a digit added to the basic size number. This could cause a problem, because there are fine-grit sizes with three digits, like 600, in the basic number. The solution is simple. If the size number in the marking symbol ends in a zero, then a grit size in the powder range is indicated. If, however, the number ends in some other digit, say 3, as in 603, then the grain is a basic medium 60 grit in a 3 combination, a much larger grain. Finally, it should be reiterated that any size designation is a nominal one, though the final screening would produce a breakdown something like this: no grain more than two sizes larger; a maximum of 25 percent one size larger; 52.5 percent or more of the total either of nominal size or one size smaller; and a maximum of 3 percent finer than two sizes smaller. Most of the grain of any nominal size is thus either that size or one size smaller.

It is obviously impossible to monitor the size of all the grain processed on a production basis, but all the abrasive grain producers maintain continuous random sampling of their product, and any lot not meeting size standards is rerouted for additional screening.

Wheel Grade

Grade could easily be considered the most baffling of the wheel characteristics to understand, probably because it is. By definition, it is a measure of the strength with which the bonding material holds the abrasive grain in the wheel. One might think that it would be best to use a bond that would hold grain indefinitely, but if this were the case the grain would become dull, burnishing the piece-part rather than cutting it, and heating it up in the process. Ideally, if the wheel is right on grade, grains will be shucked out as soon as they reach a certain degree of dullness; but in practice this rarely happens, so the wheel must periodically be dressed (i.e., have dull grain removed by passing a diamond or other type dressing tool across its face as it rotates) to remove spent grain. On the other hand, if the bond is not strong (i.e., hard) enough, grain will be released prematurely, while it is still capable of cutting, and the wheel will wear out more rapidly than it should, (Fig. 3-5).

Thus wheel grade depends on the strength of the bond holding the grain, which in turn depends on the percentage of bond in the mix. The more bond, the stronger the holding power, and the harder the grade. (Fig. 3-5.)

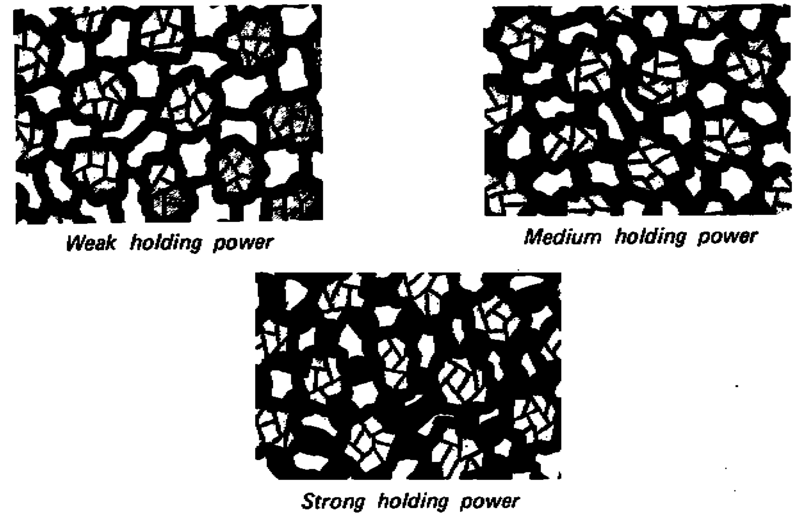


Fig. 3-5. Three levels of grade are illustrated above, ranging from soft (top) through medium to hard (bottom). The bond shows as increasingly thicker "posts" connecting the abrasive grains. (*Bay State Abrasives, Dresser Industries.*)

"Hard" and "soft" in reference to the grade of abrasive wheels probably arose from the early days of wheel manufacture, when someone with a screwdriver or an ice pick graded the wheels as hard or soft according to the indentation that could be made in the wheel with the tool.

Grade is indicated by a letter of the alphabet in the third position of the marking symbol:

29A 60 <u>K</u> 5 V9

with the range nominally from A (extremely soft) to Z (very hard). In practice, E grade is about as soft a wheel as any company makes; and grades harder than Z are manufactured for applications involving heavy stock removal and very high pressures, like foundry snagging and billet grinding for scale removal. K grade would be considered toward the soft end of the medium grades. As with size and stock removal, there is also a trade axiom: "Hard wheel grades for grinding soft materials; soft grades for grinding hard materials."

Grade may well be the most important single factor in a grinding wheel's performance; it is certainly the most intangible. (A number of wheel manufacturers have introduced intermediate grades such as J+, which is purported to be midway between J and K.) Grade is based on the percent of bond and abrasive grain in the wheel mix. It is checked during and after the manufacturing process by either electronic or mechanical means, and the final marking which goes on the product is based in varying degrees on all these determinations.

But there is another complicating factor beyond the control of the wheel manufacturers. Grinding conditions such as wheel speed or work speed, or the hardness, softness, or "stringiness" of the piece-part material may make the wheel "act soft" or "act hard" depending on whether, under those conditions, the grain is held less tightly or more tightly than is normal for the nominal grade.

Research and experience in the area of operating variability of grade has been summarized in what is known as the "grain depth of cut" theory; anything that increases grain depth of cut also increases the force tending to tear the grain from the wheel, and thus makes the wheel appear softer. Any condition which decreases the grain depth of cut has the opposite effect.

Here are some of the conditions which make a wheel appear softer than its nominal grade. (These are based on the assumption that other conditions remain constant.)

1. Increase of work speed
2. Decrease of wheel speed
3. Reduced wheel diameter
4. Reduced work diameter

The extent to which these conditions can be manipulated in practice varies a great deal; there may frequently be questions about whether they can be altered on any one production batch to make a difference. On most grinding machines the work speed is easier to change than is the wheel speed; wheel speed is often constant. Furthermore, most machines are built for a certain diameter, or perhaps a range of diameters, of grinding wheels, although it is true that as the wheel wears, its diameter decreases. For any one production lot, the work diameter is fixed, but if another lot has a substantial difference in diameter (this variation applies only to cylindrical grinding, of course), there could be reason to consider a different grinding wheel. Piece-parts for surface grinding either reciprocate on a square or rectangular magnetic chuck, or rotate on a round chuck under the grinding wheel. The reciprocating speed can be controlled, as can the rotation, and in the latter case, there is some variation depending on whether the particular piece-part is toward the rim or the center of the chuck. In fact, in loading the chuck, a blank space is left in the center, because any piece-

parts placed there would not move fast enough for the grinding action to be effective.

Choosing the optimum grade in a grinding wheel specification requires consideration of the material being ground, the condition and location of the grinder, and most important of all, the area of contact between the wheel and the work.

The hard material–soft wheel, soft material–hard wheel relationship was mentioned earlier; its justification is as follows. On very hard materials, neither aluminum oxide nor silicon carbide is going to make very deep scratches or cuts on the material, so it is preferable to use a wheel that wears away and frequently exposes fresh, sharp grain. Of course, if one can justify the cost of either a diamond wheel or a cubic boron nitride wheel, then that is the way to go. On soft materials, a harder wheel of conventional abrasive can dig in to remove stock without a significant problem of wheel wear; the abrasive grains stay sharp in spite of their digging in.

Soft-grade wheels can be very effective when used on machines that are comparatively free of vibration, whether the vibration comes from within the grinder (from worn spindles, for example) or from without, from failure to insulate the grinder from railroad or other traffic-caused vibration or from location on an upper floor of a building. Where there is vibration, grinding wheels must be definitely harder in grade—other things being equal, of course.

For many, the most important factor in grade selection is the area of contact between the grinding wheel and the piece-part. At first thought it might be concluded that all such areas are very small, and indeed they are, except for side grinding wheels generating flat surfaces on piece-parts on a surface grinder, and for internal grinding wheels grinding the inside surfaces of holes. The first exception involves a flat-to-flat relationship, with resulting low unit pressure; and such applications require the softest wheels, like grades E and F, and occasionally harder ones, like J, K, or L. The most-common application of this kind is on a vertical-spindle surface grinder, where the grinding is done either with the flat side(s) of a cylinder wheel (a side-grinding wheel with a hole almost as big as the wheel diameter) or with the flat side of a cup wheel, or with abrasive segments in a holder to form a wheel-like tool. All these are possibilities for flat surface grinding.

Next smaller—much, much smaller—in area of wheel-work contact is internal grinding, where the contact is between the external arc of the periphery of the grinding wheel and the somewhat larger internal arc of the work. Wheels for internal grinding are rarely softer than grade J, and range up to about grade M. These would be considered medium-hard wheels.

Peripheral surface grinding, where the contact is between the outside arc of the wheel and a flat surface, probably has a little less contact area.

Peripheral cylindrical grinding, with contact between the large arc of the wheel and the smaller external arc of the workpiece surface, takes somewhat harder wheels, although still mostly in the medium range.

Structure

Structure in the standard wheel marking is indicated by a number (usually 1 to 12) immediately following the grade letter of the marking. Structure is considered to be in the fourth position in the symbol. It indicates the grain spacing, or grain density of the wheel, with the large numbers representing the more open spacings. The voids, incidentally, allow the coolant to be fed, as it occasionally is, through the wheel. The voids also provide chip clearance, so that the bits of metal removed from the piece-part surface may be thrown off by the wheel. If a wheel is too dense, that is, if the voids are too small, the bits of metal can be retained in the wheel face (a condition called loading) and eventually these bits will reduce the cutting efficiency of the wheel. And in view of the fact that a vitrified grinding wheel revolves at something more than a mile a minute, the spaces in the wheel create a breeze with significant cooling action, which causes such a wheel's action to be known as "cool cutting." A normal structure is illustrated in Fig. 3-6.

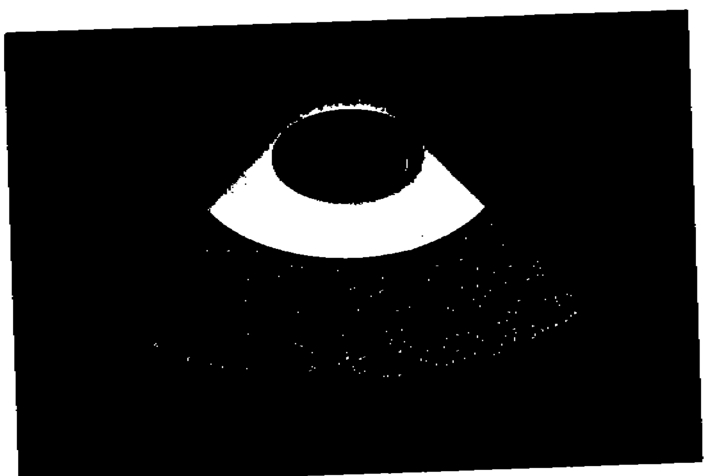


Fig. 3-6. Normal structure in a wheel. Probably in the range of 6 to 8 in the standard marking. (*Hitchcock Publishing Co.*)

Where exceptionally wide spacing (Fig. 3-7), described by a number 13, 14, or 15, is desired in a vitrified wheel, to the mix is added something like ground walnut shells, which burn out in the vitrifying or firing cycle, leaving behind small extra voids, because the pressed and dried wheel is close to its finished size by the time it is ready for firing.

In the sample specification we have been using (29A-60-K-5-V9), the 5 structure is relatively dense. It is one that is frequently used in centerless and cylindrical grinding and in snagging.

Since both structure and grade are determined largely by the relative amounts of abrasive and bond in the mix, there has been a trend toward elimination of the structure symbol entirely. Structure itself is not being disregarded; rather, there has been a trend toward considering that in relation to the other elements of the marking, particularly bond and grain size, there is a "standard" structure which is best for that combination. The standard structure would of course vary with different combinations of the other parts of the marking, so there would not be one across-the-board standard.

Changing structure is not the only way of dealing with wheel loading, nor, for that matter, is grain spacing (structure) the only way of providing for chip disposal. In wet grinding, the coolant tends to help prevent lodging of chips; indeed, some grinders are equipped so that a jet of coolant is directed toward some point in the wheel for the sole purpose of dislodging chips. In dry grinding it is sometimes possible to impregnate the wheel with

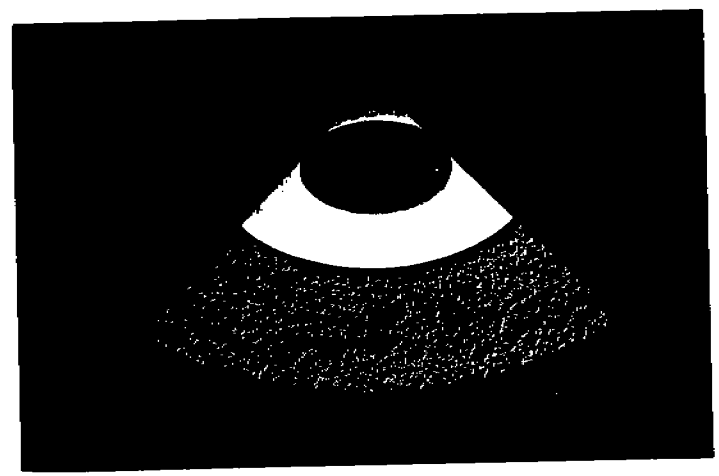


Fig. 3-7. Open structure. Note that there are more pores and that the grain is more widely spaced than in Fig. 3-6. (*Hitchcock Publishing Co.*)

a substance to fill the voids and reduce loading, or to coat the grinding face of the wheel with stick tallow or something similar.

Bond Types

If one single factor in the standard marking system could be singled out as most important, it would be the bond, which is indicated by a letter in the fifth position. And since most manufacturers use more than one of each type of bond, there is usually a second symbol, in what is sometimes called the sixth position, to indicate which particular formulation has been included. In the wheel marking which has been used as an example (29A-60-K-5-V9), V9 designates the bond—a vitrified bond for which the manufacturer's formulation is 9.

The symbols used are as follows:

Vitrified	V	Shellac	E
Resinoid	B	Rubber	R
Resinoid reinforced	BF	Rubber reinforced	RF

The derivation of the symbols for vitrified and rubber bonds are obvious. The other two are a little more obscure. Shellac was formerly known as an "elastic" bond, hence the E. And whereas today resinoid is used to a much greater extent than was rubber, rubber was used first. The earliest resinoid-type bond was Bakelite, which accounts for the B.

In general terms, the bond determines the maximum safe speed for a grinding wheel. Vitrified bonds are the slowest. (The maximum is usually considered to be 6,500 sfpm—a little more than a mile a minute.) Resinoid wheels for years had a maximum of 9,500 sfpm; but in some wheel shapes, and particularly when the bond is reinforced, they may go as high in industrial usage as 16,000 sfpm, which is about 3 miles per minute. Of course all grinding machines are designed with wheel guards to protect the operator at the safe speeds (and for that matter even at much higher speeds).

Wheel bond also determines the method of manufacture and thus has an influence on wheel design. For example, resinoid-bonded wheels, which are cured at about 4000°F, can be reinforced with plastic webbing or with molded-in iron rings. But this design is not possible with vitrified wheels, for which the firing temperature is above 2000°F. Both vitrified and resinoid wheels are pressed in molds, a process that limits the minimum thickness; rubber wheels are rolled out like cookie dough and then cut to

size, again like cookies, and so they are limited in thinness only by grain size. The thinnest abrasive wheels are rubber-bonded.

Bond type has also had an influence on the different applications of wheels. Early in this century vitrified was the dominant bond. It was used for practically everything. With the development of resinoid bonds, however, the possibility of higher speeds and consequent higher stock-removal rates led to the displacement of vitrified for work like foundry snagging and billet grinding. At the present, this is the situation: Because vitrified-bonded wheels are inert to all grinding fluids and can be readily shaped for form grinding, they are the choice, for a couple of reasons, for precision grinding of all kinds. Resinoid wheels are the choice for high-speed, high-pressure applications involving maximum stock removal. Most regulating wheels in centerless machining are rubber-bonded. Cutoff wheels, sometimes called abrasive saws, are almost all rubber- or resinoid-bonded.

Advantages of Standard Markings

The adoption of the standard wheel-marking system was a considerable step forward in the use of bonded abrasives, even though it contains factors—grade is probably the prime example—that are difficult to measure. And it has not become sufficiently standardized to eliminate the differences caused by variations in processing by different wheel suppliers or by their differing interpretations of the requirements. Each wheel supplier knows, of course, how to convert competitive wheel specifications. He knows, for an example, that grade K is equivalent to another's grade L, or perhaps J. Volume users of bonded abrasive wheels can also approximate this information if they want to do so, but for users it is more often an impression they get rather than a demonstrable similarity.

The standard wheel marking, however, is the shorthand of the industry for bonded abrasives made with conventional abrasives, and some knowledge of it is necessary for anyone who wants or needs to understand these tools. It also helps to explain why the choice of the best wheel for a particular operation is still somewhat a matter of trial, and error, a procedure that wheel suppliers generally welcome. It may also help one understand less-than-satisfactory performance.

But even at less than peak performance, an abrasive wheel that is only approximately the correct specification can save time and money on many applications; and when everything goes together, the bottom line on a change to grinding from some other machining process can look very good.

Manufacturing Process—Vitrified

Most vitrified wheels are pressed, a process that is generally divided into the operations of mixing, molding, drying, firing or vitrifying, finishing, and inspection.

Mixing. In mixing (Fig. 3-8), measured amounts of carefully prepared feldspars or clays (the bond) and abrasive grain are carefully weighed and thoroughly mixed in power mixers. Small amounts of other materials, like the powdered walnut shells mentioned earlier, may be added to provide the finished product with the desired characteristics. The mix is moistened with water or another temporary binder to make the wheel stick together after it is pressed.

Molding. During molding (Fig. 3-9), the mixture of bond and abrasive is uniformly distributed in a steel mold and then compressed (Fig. 3-10) in a powerful hydraulic press to form a wheel, or sometimes a block, somewhat

Fig. 3-8. One of the early steps in wheel making is to mix grain and other ingredients—some from overhead bins, some from smaller container—in the huge mixing bowl at the left. (*Bay State Abrasives, Dresser Industries.*)

Fig. 3-9. Distributing the mix in the mold. The wheel molder tries to get the mix as level as possible to produce a wheel in better balance. He has, of course, weighed out the mix to the exact weight specified by the process engineer. (*Bay State Abrasives, Dresser Industries.*)

larger than its finished size. The amount of pressure varies according to the structure desired. The molded product is placed on ceramic batts to dry.

In this green stage, the ware (product) must be handled very carefully because it is fragile. Sticks and stones, which are essentially rectangular shapes, are often cut in the green stage rather than being molded individually. And small wheels can be cut out of green slabs by fly cutters on a drill press. Vitrified product is molded straight, without recesses or relieved sides; but if such sides are required, they are generally "shaved" after the piece is dried, on a device resembling a potter's wheel. Some vitrified bonds cannot be treated this way however, so if relief or a recessed side is required, it must be hogged out after the wheel is vitrified, a much more difficult procedure.

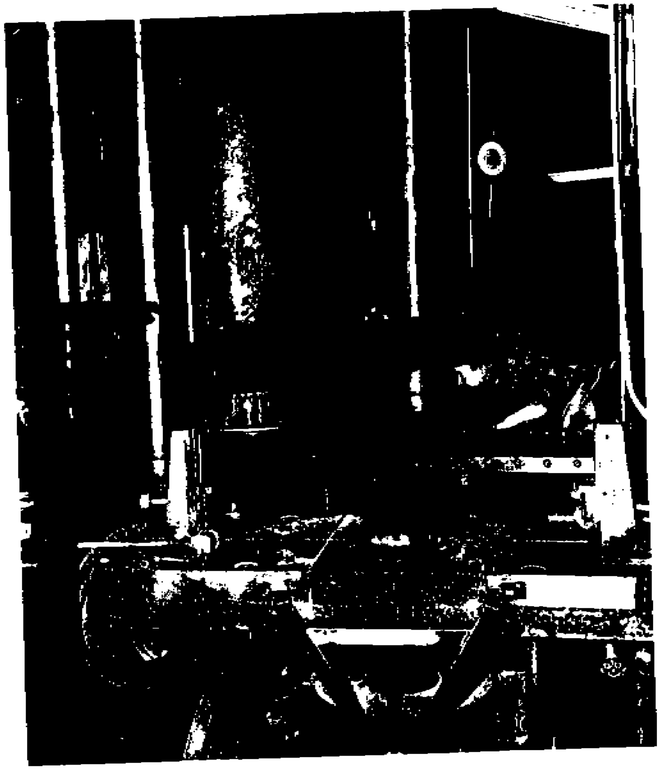


Fig. 3-10. Once the mold has been closed, the next step is to press the wheel to shape. The 2000-ton press closes top and bottom plates simultaneously to achieve uniform density through the wheel. (*Bay State Abrasives, Dresser Industries.*)

Vitrifying. Firing or vitrifying was once done in brick periodic kilns into which ware had to be carried, piece by piece, until the load was complete. Then the door was cemented shut and the heat was turned on. Now considerable firing is done in tunnel kilns, where the ware on batts is placed on a moving belt for a ride through the kiln. When the ware comes out the other end, it is vitrified. This is mostly for small wheels, sticks and stones. Larger wheels are fired in a bell kiln, a kiln in which the ware is stacked out in the open on a base (Fig. 3-11) to a prescribed height, after which the bell or cover is lowered over the stack and secured. Then the heat is turned on. At the end of the run the bell is removed, and the ware can be easily unloaded. Vitrifying is done at temperatures in a range of about 2000 to

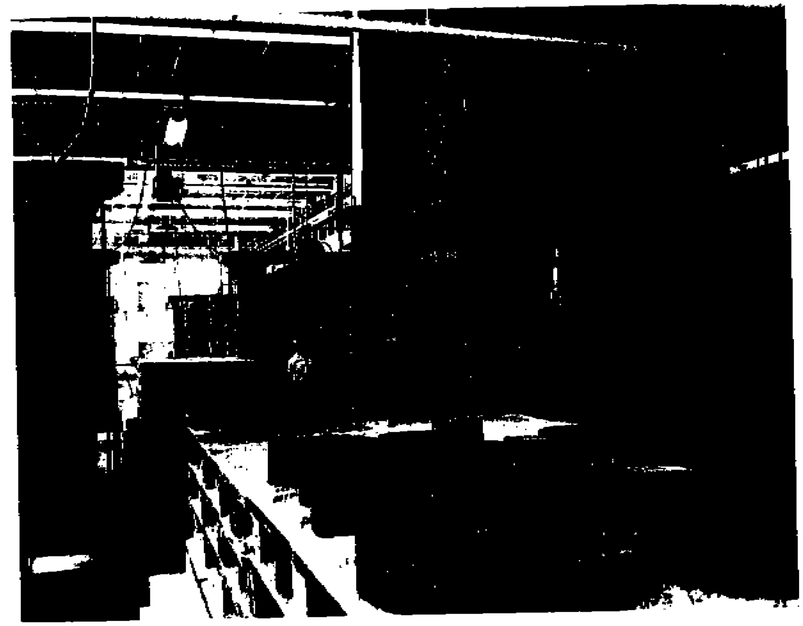


Fig. 3-11. These vitrified wheels—"ware" is the floor term—have been bedded for firing under the huge cover at upper right. This type of kiln eases the job of building the load within the kiln. (*Bay State Abrasives, Dresser Industries.*)

2300°F. It is a process similar to that for making china dishes—and the end product has resemblances to dishes, including easy cracking.

Once the firing is complete, only the size and the shape of the wheel can be changed. Its quality and cutting effectiveness have been established.

Finishing. In the finishing operations the wheels are trimmed to finished size and shape with hardened steel cutters, other abrasive wheels, or diamond cutters. With proper application, the steel cutters do a surprisingly good job of removing abrasive from the wheel. The arbor holes may simply be reamed to size, or they may be bushed with lead, babbitt, or another material. Any metal insert, such as a mandrel for mounted wheels, threaded inserts for discs, or cylinder wheels bolted onto backing plates rather than on a spindle as most wheels are, is cemented into place.

Other finishing and testing operations include balancing (Fig. 3-12), which is similar to that for automobile tires and wheels; speed testing for wheels over 6 inches in diameter; grading and marking; plus a final inspec-

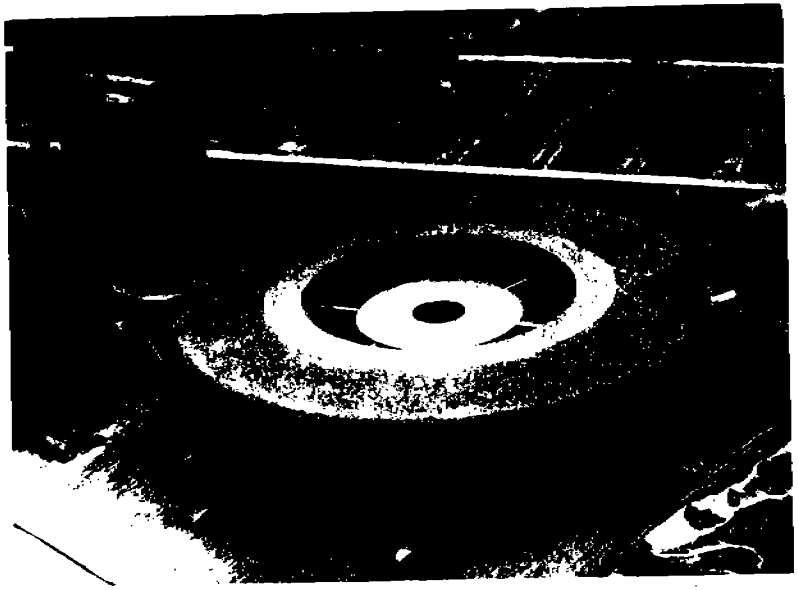


Fig. 3-12. Like automobile tires, wheels must be balanced by adding weight at the right places to ensure smooth rotation at high speeds. (*Bay State Abrasives, Dresser Industries.*)

tion (Fig. 3-13) to ensure that the wheel is of the required shape, size, and specifications, and that it is not chipped nor cracked.

Speed Testing. In the speed test, wheels are run without load at 150 percent of the established safe operating speed for their bond and size. Research by the wheel-making companies and through the Grinding Wheel Institute has established that this level is safe for a sound wheel under load at the maximum safe speed.

The market share for vitrified-bonded wheels with conventional abrasives is probably around 50 percent. There has been a trend toward its replacement with resinoid bond, but some resinoid bonds react unfavorably with some coolants, while vitrified bonds are inert to all coolants.

Manufacturing Process—Resinoid

The manufacture of resinoid-bonded wheels differs from that for vitrified in the mixing and in the firing or curing operations. Otherwise there is little difference.

Fig. 3-13. There are many quality control checks during wheel manufacture. After the wheel has been trimmed to specified thickness, this inspector "mikes" the wheel to make sure specifications have been met. (*Bay State Abrasives, Dresser Industries.*)

Mixing and molding resinoid wheels requires air conditioning. In mixing, thermo-setting synthetic resins are mixed, in powder or liquid form, with abrasive grain and a plasticizer to make the mix moldable. Resinoid mix tends to be a little bit gummy, in contrast to vitrified mix, which is at most slightly moist and could generally be considered as a dry mix. Molds are similar to those for vitrified wheels, with the exception that the wheels can be molded to shape. And molding to shape is done for two reasons: it can be done without danger of cracking during curing, and resinoid wheels cannot be easily shaped in the green state. Molding to shape also conserves on mix, which is not, however, a major factor.

After the wheel is hydraulically pressed to process size—and frequently to shape—in a mold similar to that for vitrified wheels, it is cured at a temperature of 300 to 400°F for a period of 12 hours to about 4 days, depending on its size. During this operation the mix softens first and then hardens as the oven reaches curing temperature. The bond retains its final hardness after cooling. The remainder of the making process is similar to that for vitrified wheels.

Resinoid wheels account for approximately 35 to 40 percent of all grinding wheels used today. There has been a continuing trend over several years away from vitrified and shellac bonds toward resinoid for high-speed rough operations like foundry snagging, portable grinding operations, cutting off, and, rather surprisingly, roll grinding steel mill rolls, which is presently one of the most precise of all grinding operations. The major reason for this swing to resinoid is probably because it is almost certainly the strongest of the bonds; wheels made with it can operate at higher speeds than those made with other bonds; and they can probably take rougher treatment than any others. This does not mean, of course, any relaxation in the safety requirement that a wheel be checked out if it has been dropped or bumped.

Historically, the problem of resinoid bond for wet grinding has been its tendency to soften and wear excessively when used with coolants. This has been common knowledge over a long time, and the problem has been attacked on three fronts—coolant research that develops new formulations that are kinder to resinoid bonds, grain coatings which resist coolants, and, of course, the development of resins that are more coolant-resistant.

Manufacturing Process—Rubber

Rubber bond is pure rubber, either natural or synthetic. (The mixing, or kneading, process by which it is combined with the grain was described earlier.) Sulfur is added as a vulcanizing agent. After the mixing operation, small batches are passed and repassed through calender rolls until the sheet reaches the specified thickness; then wheels like cookies are cut out of the sheets, to a specified diameter and hole size. Next the wheels are vulcanized in molds under pressure in ovens at about 300 to 350°F. Finishing and inspection are similar to the operations for other wheels.

The wheels are specially made for specific uses, such as wet cutting-off, for which they produce nearly burr-free cuts. (As has been noted, the manufacturing process permits the making of extremely thin wheels.) Rubber wheels are also used as regulating wheels in centerless grinding: as the second abrasive wheel in a two-wheel operation to keep the work from spinning at the same rate as the grinding wheel; and as finishing wheels on ball-bearing races where a high finish is required. Rubber wheels constitute somewhat less than 10 percent of the total market.

Manufacturing Process—Shellac

Shellac is a natural organic bond the use of which goes back a long way; today, however, shellac-bonded products make up only a very minor share of the total market. Inasmuch as the bond appears to provide a burnishing ac-

tion on the work, shellac-bonded wheels are used to produce high finishes on camshafts, rolls, and cutlery.

To make these wheels involves mixing abrasive grain with shellac in a steam-heated mixer which thoroughly coats the grain with the bond. Wheels in the cut-off range of 1/8 inch thick or thinner are molded to exact size in heated steel molds. Thicker wheels are hot-pressed in steel molds. After the pressing, the wheels are set in quartz sand and baked for a few hours at about 300°F. Finishing is standard.

DIAMOND AND CBN WHEEL MARKINGS

Both diamond and cubic boron nitride wheels, because of the expense of the abrasive, are molded in a thin (1/32 to 1/4 inch) layer around a core, in contrast to conventional grinding wheels which are all abrasive. The marking system (Fig. 3-14) is similar to that for conventional wheels but with significant differences, that will be indicated in the text which follows.

The degree of standardization among diamond wheel makers is not the same as that of manufacturers of conventional abrasive wheels, even though a few of the bigger companies manufacture both types. Hence, in-

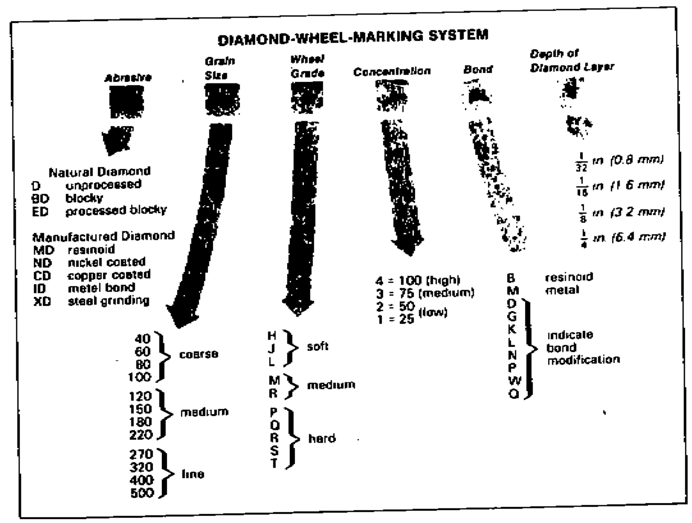


Fig. 3-14. A chart for a diamond wheel-marking system. Concentration, in the fourth position, replaces structure of the other system, whereas "depth of diamond layer" is new. (*Intext, Inc. Used by permission.*)

asmuch as the discussion that follows is a general explanation of the diamond (and CBN) markings, there are differences among the products of individual companies that make it difficult to make comparisons without some interpretation of each specification involved.

Abrasive Type

Starting from the left of the marking, the first position indicates the general type of abrasive: D for natural unprocessed diamond, and B for cubic boron nitride. Each may be modified by a preceding letter to indicate some processing or perhaps the metallic coating. Synthetic or manufactured diamond is always indicated by a two-letter symbol for example, MD.

Grain or Grit Size

The numbers and the sizes they indicate are substantially the same as those for aluminum oxide or silicon carbide. The major difference is that for diamond and CBN the coarse sizes are much finer than those for the others. For example, one diamond wheel maker lists coarse sizes as anything between 40 and 100; medium, 120 and 220; and fine, 270 and 500. Some size symbols indicate a range, as 100 to 120.

Wheel Grade

Grade, a letter in the third position, has essentially the same significance as in the conventional wheel marking system, although the range of grades is not as wide. The manufacturer just mentioned lists a range of grades from H on the soft end to T on the hard side. Some indication of the trend comes from the listing of "hard" grades P, Q, R, S and T. Diamond wheel grades tend to be on the hard side, but this has no relation at all to the actual hardness of the diamond abrasive.

Diamond (or CBN) Concentration

Diamond concentration is a term peculiar to the superabrasives, and it is indicated by a numeral—4, 3, 2, or 1—in the fourth position of the marking. Since it is determined by the volume of abrasive in the wheel, it does bear a resemblance to the wheel-structure symbol in the conventional wheel specification, but it is much more important because of its bearing on the price of the wheel. The number signifies the weight of diamond per cubic inch of the layer of diamond and bond (matrix) which makes up the grinding surface of the wheel. A 4 is the symbol used for what is termed 100 concentration, which is 72 carats of diamond per cubic inch of matrix. A 3 or a 2 indicates, in that order, 75 or 50 concentration, or 54 or 36 carats of diamond per cubic inch of matrix, respectively. It may be assumed that the fewer diamonds there are per cubic inch, the farther they are apart, hence the analogy to wheel structure.

Once this is understood, it is relatively easy to calculate the comparative weights of diamond in two different wheels by simply reading the specifications. All the necessary figures are stated in inches—wheel diameter and width, and thickness or depth of the diamond layer (the final element in the specification). The calculation is as follows: circumference × width × depth of diamond × 72 (for 100 concentration—or 54 for 75 concentration or 36 for 50 concentration). The result is the number of carats of diamond in each wheel. This is not a determination of which is best of the three; the most economical percentage of diamond may very well be different for any two applications.

Bond Type

Bond type is indicated by a letter of the alphabet in the fifth position, and any bond modification in the sixth; they are usually linked, as, for example, BL, a resinoid bond of the subtype indicated by the manufacturer by an L. The bond symbols are the same as are those for conventional wheels—B for resinoid, V for vitrified, and, a new one, M for metal-bonded. The modifiers vary with the manufacturer; they are not standard.

Depth of Diamond Layer

The depth or thickness of the diamond layer, as noted above, is the last element in the symbol, in the seventh position. The range is from 1/32 at the thinnest, to 1/16, 1/8, and at the thick end, 1/4. These are actual dimensions, not symbols or a code. The usefulness of this element of the symbol was explained above.

Core Material

Some manufacturers of diamond wheels add an eighth element to the wheel marking to indicate the kind of core used, but this is not a universal practice. If it is used, however, it will be accompanied by an explanation of its formulation. However, core material is generally determined by the manufacturer.

GRINDING-WHEEL SHAPES AND SIZES

If the description of a grinding wheel were confined only to its formulation, which has just been discussed, it would be incomplete. It is also essential to know the wheel dimensions diameter, thickness, and hole or arbor size—plus the dimensions and location of any recesses or relieved areas in the wheel.

The need for a code differentiating the various shapes of wheels was recognized early in the twentieth century, probably before the recognition that some kind of standardization in the expression of formulation was needed. The code was started appropriately enough with what is called a type 1, or straight, wheel, which is defined as one having a diameter, a thickness, and a hole. Each shape is designated as a "type" followed by a numeral from 1 to 30, although some numbers have been needed for a while, but later eliminated. Wheels are basically divided into those for peripheral grinding and others for wall or side grinding, although there is *one* which is considered safe for grinding on either the side or the periphery. The grinding face of each type is indicated, and it is not considered safe practice to grind on any other face.

Peripheral Grinding Wheels

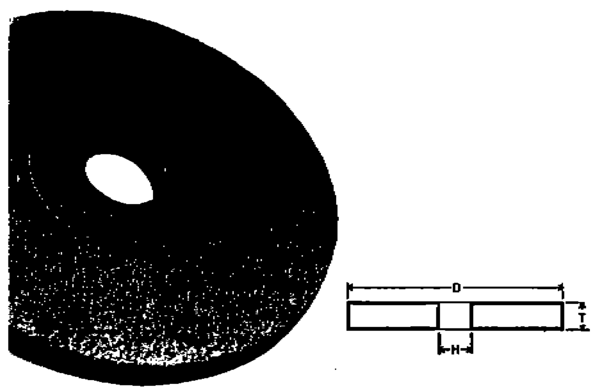
The basic peripheral grinding wheel is the type 1 straight wheel, with three dimensions—diameter, thickness, and hole, the order in which the dimensions are listed. This is also by far the most numerous group. The smallest standard wheel, one for internal grinding, is 1/4 × 1/4 × 3/32, though a 6 × 1/8 × 5/8 cutoff wheel is not very big. The largest one made in one piece is a 60 × 12 × 12 wheel for cutlery grinding. (Numerals are used for both shape designation—type 1, type 5, etc., and for dimensions. Dimensions are always expressed in inches, and in a set order: diameter, thickness, hole, as 60 × 12 × 12 above.) There are also some wheels for centerless grinding which are 22 or 24 inches thick to increase the cutting range of the wheels as the piece-parts rotate between; because in centerless grinding, the width of the wheels of the grinder determines the length of time that the piece-part will be ground (assuming a steady feed rate, of course). These wheels are made from two slightly angled halves cemented together. With a thickness of more than 12 inches it is difficult to maintain uniform pressure, and uniformity, within the mold. The hole of a type 1 wheel is usually much less than half the wheel diameter, although in some cylindrical grinding wheels the dimensions may be 20 inches × 2 × 12, or 30 inches or 36 inches × 3 inches or 4 inches × 20 inches. Wheel mounts are either 12 inches or 20 inches in diameter on this type machine, as indicated by the last numeral of each dimension, the hole size.

Other common types of peripheral wheels (Fig. 3-15) are type 5, which is recessed on one side, and type 7, which is recessed on two sides. (These are abbreviated rec. 1/s or rec. 2/s, respectively.) And there are other combinations which are either recessed or relieved (tapered inward) on either one side or both sides. The reason for a recess or relief is that it enables the user to make a desirable combination of productive capacity (the wide grinding face of the wheel) with a shorter and consequently more rigid spindle (since the thickness at the hole is less than the thickness at the periphery.)

Side- or Rim-Grinding Wheels

This group of wheels is designed for grinding on the flat side (Fig. 3-15), so the side or rim is usually narrow (except for type 27, which has a flat grinding face); but since the wheel—used mostly for portable grinding—is held at approximately a 15° angle to the work (Fig. 3-16), the effect is still that of a narrower grinding face. The exception to this is the bonded abrasive disc, which is a flat-sided circular piece with several countersunk holes scattered in a pattern across its face so that the disc may be bolted to a

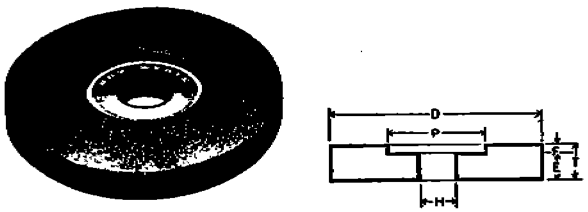
TYPE 1 — STRAIGHT



Straight wheel for grinding on periphery. Has a straight face, side and hole.

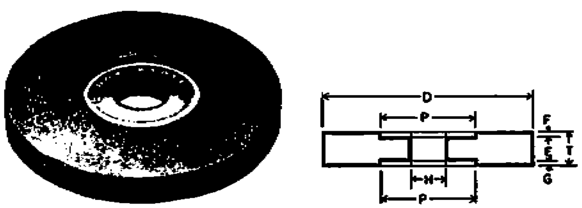
Fig. 3-15. Commonly used grinding wheel shape types. Types 1, 5 and 7 are for peripheral grinding; types 2, 6, 11 and 27 are for side or rim grinding (See also pp. 78, 79, 80.) (*Bay State Abrasives, Dresser Industries.*)

TYPE 5 – RECESSED ONE SIDE



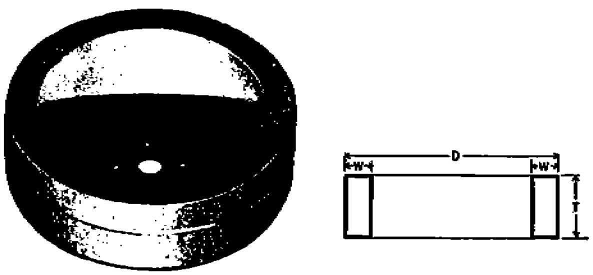
Recessed wheel (one side) specified DxTxH– Rec. 1/s DxF (diameter of recess x depth or recess). This is similar to a Type 1 wheel for peripheral grinding and allows for a thicker wheel to be used providing clearance for the flange and nut.

TYPE 7 – RECESSED TWO SIDES



Recessed wheel (two sides) similar to Type 5 shape, but with two recesses of equal diameter and depth of recess is either equal or not as required for mounting extra thick wheel.

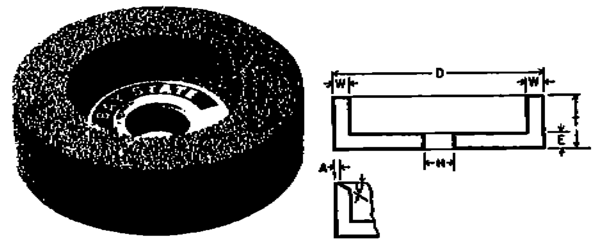
TYPE 2 – CYLINDER



Cylinder wheel where I.D. (hole) is nearly as large as the O.D. Grinding is performed on the rim or wall end of the wheel.

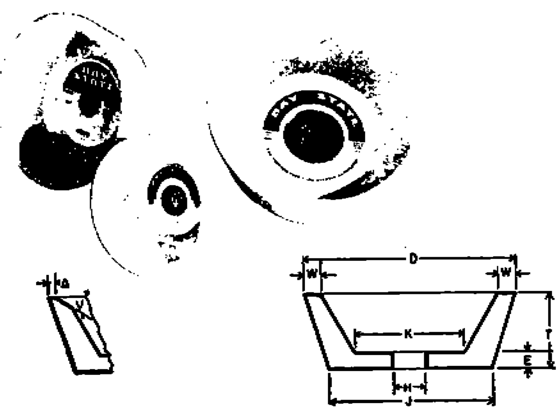
Fig. 3-15 *(continued)*

TYPE 6



Straight cup wheel; similar to Type 5 except recess is much deeper. Grinding is performed on the rim or wall end of the wheel rather than on the periphery.

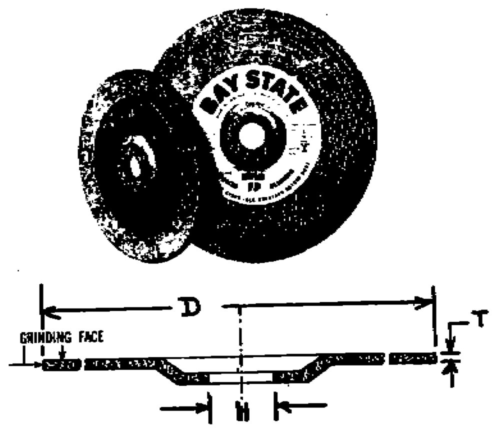
TYPE 11



Flaring cup wheel is similar to Type 6 but with a tapered outside diameter to provide clearance of the work piece on certain types of grinding applications. Grinding is performed on the rim of the wheel.

Fig. 3-15 *(continued)*

TYPE 27 – RAISED HUB DISC WHEEL



Raised hub disc wheel (sometimes called "depressed-center" or "hat" wheel) is a reinforced organic bonded product used on off-hand, portable grinding applications.

Fig. 3-15 *(continued)*

backing plate without the danger of bolt heads interfering with the grinding action.

The basic shape of rim-grinding wheels is the type 2, or cylinder, wheel, also with three dimensions, except that because the hole is so big in relation to the diameter, the third dimension is the wall thickness rather than the hole. Wheel diameters range, in standard sizes, from 8 to 20 inches; in thickness, from 4 to 5 inches; and in wall dimensions, generally from 1 to 1 3/4 inch. Cylinder wheels are used almost exclusively for surface grinding.

The other major group of side-grinding wheels are the cup wheels—type 6, a straight cup; and type 11, a flaring cup. Portable grinding, for very rough jobs, is limited to organic bonds only. Cup wheels are also used in vitrified bonds for tool grinding. Portable grinding cups wheels are all 6 inches or less in diameter. However, wall thickness for portable grinding wheels is much greater (3/4 to 1-1/2 inch) that it is for tool grinding wheels (type 6, 3/8 inch; type 11, 1/4 inch).

Another side-grinding wheel warrants brief mention. Type 28 are rather thin depressed-center (or raised-hub) wheels, 7 or 9 inches in diameter, and

Fig. 3-16. Grinding with a type 27 depressed center wheel. Holding the grinder at an angle limits the grinding face to about 2 inches. (*Bay State Abrasives, Dresser Industries.*)

made only in reinforced resinoid (BF). They are used on portable grinders for weld grinding and other rough jobs. The offsetting of the hole permits these wheels to be conveniently bolted to backing plates. There is a similar wheel, type 27A, that is used for cutting-off.

The effect of the type of grinding wheel used on the ground surface should be mentioned. The scratches made in the piece-part surface by a peripheral grinding wheel are essentially straight and parallel. But the surface produced by any side-grinding wheel is essentially a pattern of overlapping arcs, which is sometimes known as a "dutch" surface. This is frequently considered a desirable appearance for the finished product.

Standard Shapes of Grinding Wheel Faces

Although we customarily think of a peripheral grinding wheel as having its grinding face at right angles to the side, grinding-wheel suppliers are prepared to furnish other "standard" face shapes, as designated by the American National Standards Institute (ANSI B74.2-1974) or the International Standards Organization (ISO), as shown in Figure 3-17. If a plant uses any quantity of formed wheels with any of these standard faces, it may be more economical to order the shaped wheels rather than to order wheels and shape them in the plant. Wheel faces are likely to be a little more consistent if ordered from the wheel manufacturer.

Mounted Wheels, Points, Cones, or Plugs

Another group of wheel shapes is one that includes abrasive wheels or points which have mandrels cemented or molded in so that the wheels can be held in a chuck as if they were some kind of drill; or cones and plugs, which have a blind-hole threaded bushing for mounting. Cones and plugs

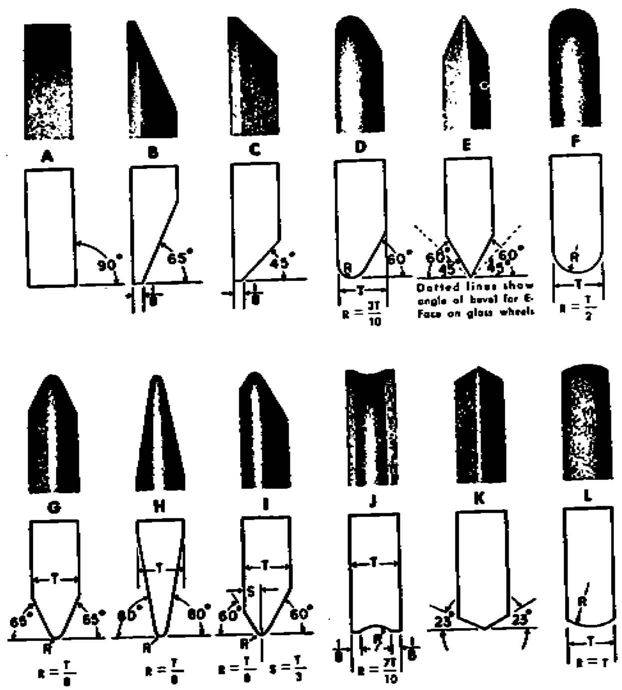


Fig. 3-17. Wheel face shapes for straight wheels, available from manufacturers. (*Bay State Abrasives, Dresser Industries.*)

are used in portable grinders for rough foundry snagging of castings; mounted wheels and points are used mostly for touch-up work, or for internal grinding. Since their diameter is at most 3 inches, and often only a fraction of an inch, the wheels must be rotated at high revolutions per minute (rpm) to achieve an efficient surface speed in surface feet per minute (sfpm). The rate of these grinders (Fig. 3-18) sometimes exceeds 100,000 rpm.

Cutoff wheels, sometimes called abrasive saws, should probably be considered separately as a group, even though they are technically very thin resinoid or, in small, very thin sizes, rubber-bonded type 1 straight wheels. They function as abrasive saws, rather than as grinding wheels, for parting materials that are too hard to cut with bandsaws or similar sawing methods. (Fig. 3-19) In nonreinforced bonds, they range in thickness from 1/16 inch and 6 inches diameter to 1/4 inch and 34 inches in diameter. The range for reinforced bonds is from 6 inches × 1/8 inch to 48 inches × 3/8 inch.

Abrasive cutoff or sawing is the only material-parting process that produces two finished ends with virtually no burring to be removed later. It is thus particularly desirable for high-production cutting, mainly on harder materials, since automatic raising and lowering of the wheel, infeed of the

Fig. 3-18. Grinding with a mounted wheel, also with a portable grinder. (*Hitchcock Publishing Company.*)

Fig. 3-19. An assortment of parts cut off with a thin abrasive wheel. Abrasive cutting like this leaves no burrs. (*ACCO Industries, Inc.*)

rod or wire from which the parts are cut, and ejection of the finished parts are simple machine-design problems.

Sticks, Stones, and Segments

Mention was made earlier, in connection with vitrified bonds, that abrasive sticks and stones, like the pocket sharpening stones that are common souvenirs at trade shows, can be "shaved" from pressed blocks of green or unfired vitrified mix. This is the standard method for making such abrasive tools, because it is much faster and produces a better-quality product than

would probably result from individual molding. But, segments (Fig. 3-20) used in specially designed holders (called chucks) for vertical-spindle surface grinding are a somewhat different story. Because of their odd shapes, standard pressing methods can not be used. For one thing, the inventory of molds required would be excessive. For another, and more important, factor, the shapes would make it difficult to produce a segment with equal grade throughout; the segment would tend to be hard on the outside and softer on the inside. However, because of the large area of abrasive-work contact, only soft grades are needed—mostly D through G or H at the outside, with *very* open structure—11 through 15—so that high pressure is not needed. Grinding with segments will be considered in more detail in the chapter on surface grinding. Segments are very efficient and effective abrasive tools.

Diamond and CBN Wheel Shapes

Diamond and CBN shape symbols bear some resemblance to those for conventional grinding wheels, but they look more complicated because they tell more about the wheel. Most of the similarities stem from the fact that the diamond wheels were developed after the other symbols were well established, so it was logical that both should have type 1 straight wheels, type 6 straight cups, and type 11 flaring cups. For diamonds and CBN, there are 9 basic core shapes that can be made in 35 different variations, many of them of the type 1 shape.

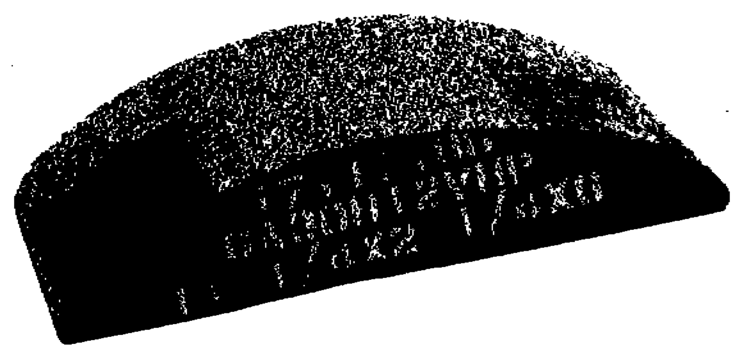


Fig. 3-20. A common type of segment. The pads on top help to cushion the segment in its holder. (*Bay State Abrasives, Dresser Industries.*)

GRINDING ACTION

Grinding action is a term used in the abrasive industry to express the overall efficiency of a grinding wheel. Many factors can affect a wheel's performance, not all of which are related to the wheel itself. Some, in fact, may be quite remote, particularly those that cause vibration, which is the arch foe of good grinding. One problem is that frequently there is no clear knowledge of how a change in one factor affects the others. What is known, of course, is that some seemingly small changes in wheel specifications or in other grinding conditions can have a disproportionate effect on a wheel's total performance—its grinding action.

Wheels

A continuing complaint of suppliers' representatives and engineers is that when there is trouble, the wheel gets an unfair amount of the blame. Let a grinding operation go a little bit sour, and everyone, say the representatives and engineers, begins to fiddle with the wheel specification, when more attention should be paid to the grinding machine and its condition, to the coolant, and perhaps even to the machine's location.

Of course, the wheel is a definite object. It is made with a known kind of abrasive grain within a given size range. Its bond is known, though its particular variety of, say, vitrified bond may not be common knowledge. Its grade and porosity are also known quantities. The specification is a starting point. (Fig. 3-21)

But if a wheel of a given specification has been performing adequately for a time before the trouble arises, it is worth while to look elsewhere when trouble comes.

(For example, there is a consensus among grinding-wheel experts that many grinding machines in this country are underpowered and not sufficiently vibration-free to provide topnotch grinding performance, and that machine parts, particularly wheel spindles, are used past the point of top performance. It is a truism of the field that vibration of any kind demands a harder wheel, which is usually less desirable overall. But this is not a discussion of trouble-shooting.)

Still another factor in grinding action is the speed of the wheel, together with the speed at which the piece-part travels. It is logical that the higher the speed of the wheel (within safe limits, of course), the greater the number of abrasive "teeth" that pass across the surface to be ground, and the greater the amount of stock removed. Some research into speeds above those currently considered safe has shown that there are plateau ranges, where increases in speed do not increase stock-removal rate, but eventually

Fig. 3-21. The color of a wheel often gives an indication of its formulation, as in these white wheels. But the standard marking on the wheel blotter is a better one. (*Bay State Abrasives, Dresser Industries.*)

further increases in wheel speed result in greater stock removal. Currently these are matters of interest in research rather than in production.

Coolant

Another gray area in the matter of grinding action is the influence of the grinding fluid or coolant. There are many instances, reasonably authenticated, in which a change of coolant produced a significant improvement in the grinding action of wheels on a particular application. Naturally, no one ever publicizes the changes that go in the opposite direction. And the decision about whether or not it is better for a plant to use a central system with the same coolant for all grinding operations (which may mean that the coolant is something of a compromise but that removal of heat generated in grinding is easier, for one factor) is not one to be made lightly. Using only one coolant also simplifies storage, probably reduces the per-gallon price, and so on; but obviously the coolant selected can not be the best one possible for all the operations. This topic will be discussed at greater length in the chapter on grinding fluids; all that is intended here is to point out that the coolant used, along with the machine and its condition, the general conditions surrounding the machine, or indeed, the work material itself, all have an effect on the efficiency of the operation, and in the event that efficiency declines, one must look at any recent change in any of the factors just listed to try to determine what effect it may have had. For one example, if piece-parts come to a grinding operation with more stock to be removed than had been the case before, then the grinding operation is going to look bad unless this change is compensated for.

Wheel Selection

Selection of a grinding wheel of a particular specification for a particular application can be tricky, because one can not as yet read the correct specification from a list. Of course, as was pointed out in the discussion about the possible number of combinations of the various factors, the first gross elimination of possible specifications is relatively simple. The broad abrasive type is usually pretty well indicated; grain size can be narrowed down to perhaps three or four adjacent sizes. Grade will probably be similarly limited. Structure is standard in many specifications, based on grain size and grade. And gross selection of a bond is easy, but when the choices narrow down to two or three similar vitrified bonds, for one example, then the selection task gets rougher.

The actual selection may be made by a supervisor or engineer who is close to the job, but it is often left to the expertise of a distributor or company salesman. Grinding-wheel company salesmen, particularly the experienced ones, see a great many jobs and a great many machines, and most of them try to give their customers the best wheel that they have for a particular application.

However, if there is a prospect of a larger order, or of continuing business, most wheel companies will supply, say, half a dozen "trial" wheels which can be used on the job to compare with other wheels. This used to be fairly common practice; but with increased costs and greater performance predictability, the requirements for trials may have been tightened up, though it costs nothing to ask for free trial wheels.

If your company does get wheels for a trial from two or three suppliers, it is in your best interest to make the test as even-handed as possible. (Obviously, if any one is predisposed to the wheel supplied by one company, it's less than fair to the others to have them submit wheels for a contest that has already been decided.) Here are some suggestions for proper testing procedures:

1. The scope of the test must be in keeping with wheel usage. People tend to think of testing as involving a lot of paperwork, records, and the like, but this need not be the case. It may be as simple a thing as keeping track of the number of parts ground per wheel, or ground between wheel dressings (resharpenings). It could also involve some detailed accounting, not only of wheel wear, parts per dress, and so on but also records of the surface(s) produced, the burn, or some other undesirable condition. If the wheel is in intermittent use only, all that may be needed is a record of when a wheel was mounted and when it was discarded. Perhaps the key is to do the simplest test that will give a satisfactory ranking of the test wheels.
2. Grinding conditions must be kept identical, so far as it is possible to do so. This usually means that the tests will be carried out on one machine, using the same coolant for all wheels, and preferably, if conditions warrant, using the same operator. In other words, for accurate wheel testing, only the wheels should be changed. And incidentally, to avoid unconscious—or sometimes conscious—operator preferences, it may be desirable to identify the wheels only by an alphabetical code or some other similar device. A skilled operator can skew test results if he is so inclined.
3. Test conditions must be as near actual operating conditions as is possible to ensure that the test results will carry over into actual production.
4. The basis of the test must be clearly delineated, for this is most important. Some, such as the time that the wheel remains useful, or wheel life, have been mentioned earlier. Production per wheel or per dress is a common basis for testing. Any reduction in dressing time, which is nonproductive time, is also a desirable factor to consider. For example, if one wheel will grind 20 pieces before it needs dressing and another wheel will grind 25, the second wheel has a substantial edge.

In fact, if your criterion is the number of good parts that the wheel produces before it reaches stub or discard size, then the dressing procedure must be kept to a standard. Wheel dressing is essentially induced wear to uncover new and sharp grain, so it does not take a very much longer time per dress to increase wheel wear substantially.

Wheel Dressing and Truing

Dressing and truing may easily be the two most confused terms in the grinding wheel business, and both affect performance. They are done with the same tools, and in the same manner. Only their objectives are different. *Dressing* is an operation done to restore or sharpen a grinding wheel face (or side); any shaping or squaring or restoring of the concentricity of the wheel as it is mounted is a bonus. *Truing* involves establishing or restoring concentricity of the mounted wheel, or shaping or forming its grinding face; any sharpening of the wheel face during the process is accidental. But a wheel that has been trued (i.e., made concentric with the machine spindle) is likely to be dressed; the reverse is less likely to happen. The confusion is not lessened by the fact that any forming of the wheel face is commonly called "form dressing" rather than "form truing."

For another distinction, truing is done only when a wheel is mounted (or remounted) on its machine spindle or other mounting device, because the wheel must be concentric (true) with the machine mount, not with itself. If the wheel-holding device is rigidly held to the wheel, then the wheel may be removed and replaced on the machine as many times as need be without re-truing. But if the wheel is freed from its holder, as happens when it is removed from a machine spindle, then it must be trued again ~~with~~ when it is replaced.

Ideally, it would seem desirable to use a wheel so closely adjusted to the application that the force of grinding would be enough to pull dull grains out of the wheel face, but such a close specification is difficult to find. Most likely, the wheel would wear faster than is economical or, if the job involved a long pass across the piece-part surface, faster than is desirable for flatness. In this kind of flat grinding, if the wheel wears too fast, the finish end of the pass will be higher than the beginning end, and the piece-part will not be flat. On the other hand, a wheel that is too hard, in terms of grade, will not wear; it will hold the grains after they have become dull and stopped cutting. Longer wheel life is not desirable either. The usual compromise is to get a wheel that is a little harder than the ideal, and dress it as needed to maintain its cutting ability.

Before discussing the tools for dressing, a quick consideration of the conditions that the operation corrects is appropriate. One is the condition mentioned earlier, where the grains in the wheel face are retained after they become dull and are no longer cutting. In such a condition, the grains have the additional negative action of rubbing and heating up the piece-parts, which is also undesirable. If the operation is done with a grinding fluid or coolant, heating is reduced, but not eliminated. And because heat is inherent in a grinding operation by its nature, additional heat, with its negative effects, is not needed. The smooth wheel face is called *glazed,* and can be corrected only by dressing the dulled grains from the wheel face.

The other wheel-face condition that hinders cutting is *loading,* which occurs when bits of the work material become lodged in the wheel face. (Fig. 3-22). This does not happen when the wheel face is sharp, and it is retarded when there is sufficient coolant under enough pressure to remove chips from the wheel face. As grains become dull, loading becomes more likely, and so does glazing, but the two conditions do not necessarily go together.

Fig. 3-22. The dark spots on the wheel face are loading from bits of work material picked up by the wheel. Glazing shows up as a smooth, shiny surface on the wheel face. (*Bay State Abrasives, Dresser Industries.*)

If loading occurs when the wheel is fresh and sharp, a poor selection of wheel has been made. It is preferable to change to a more open wheel without delay.

There is one circumstance where dressing is done intentionally to dull the grain. As has been noted, sharp abrasive grain cuts and dull grain polishes, thereby producing a better finish. So in cases where it is more economical to rough and finish the piece-parts with the same wheel, this can be done by intentionally dulling the grain in the wheel face with the dressing tool after the rough cuts have been made. With skillful dressing it is possible, according to at least one expert, for a coarse-grain wheel—say 36 or 46 grit—to produce a finish like that customarily associated with a 240 grit size wheel.

The principal concern of management, however, is frequency of wheel dressing rather than methods. It's an old truism of abrasive use that more abrasive is dressed away than is ground away. Like most old truisms, it has more than a grain of truth. But it must be kept in mind that dressing time is not productive time (except when dressing is automatic and done while the wheel is grinding), that abrasive grain dressed away is lost, and that excessive dressing is a waste of time and abrasive.

Tools and Equipment for Dressing

The tools are the same whether the operation is truing or dressing, and so are the procedures. It is the purpose that differs. Dressing, as was stated earlier, is primarily a sharpening of the wheel's grinding face. Truing involves the additional aim of ensuring that the grinding face is concentric with the center of the spindle on which the wheel is mounted. Truing is most important in the operation of diamond and CBN wheels, where anything beyond a minimum of dressing is extremely expensive.

Tools for dressing fall into four categories: mechanical, diamond, crushing, and abrasive. Diamond dressers are the most widely used, and come in a variety of styles.

Mechanical Dressers. These are most frequently spurlike metal "stars" which are mounted loosely on a pin in a holder, though there are other designs. When the dresser is held against a rotating wheel, the spurs rotate and pick out of the wheel face both dulled grains and bits of work material. These dressers are used primarily on rough grinding wheels. (Fig. 3-23.)

Diamond Dressers. Diamond dressers, which are by all odds the most numerous type, range from the traditional hand-held type to mounted dressers (Fig. 3-24) to the form dresser (Fig. 3-25).

The original diamond dressers were mostly large stones which were not, obviously, of gem quality. The high cost of stones and the size of the loss if one came loose or were otherwise misplaced, has caused a major switch to a cluster type of smaller diamonds imbedded in a matrix. The clusters probably do as good a job as the large diamonds, and are certainly less vulnerable to loss. Diamonds are also mounted on simple swing-type fixtures to dress either a convex or concave radius on the periphery of a wheel. On reciprocating-table surface grinders, a diamond is often mounted on the

Fig. 3-23. Mechanical dresser in use. Such a dresser is for use on coarse-grit wheels for rough grinding. (*Desmond-Stephan Mfg. Co.*)

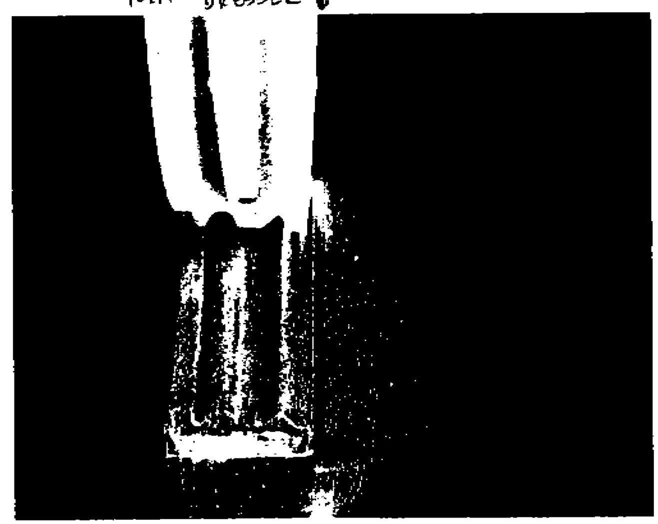


Fig. 3-24. Closeup of a diamond dresser, of which there are many styles, because diamonds are used for almost all precision dressing. The diamond (or sometimes a cluster of diamonds) is in the point, up against the wheel face. (*Desmond Stephan Mfg. Co.*)

magnetic chuck. And the form dresser shown (Fig. 3-25) could also be so mounted.

The diamond dresser is usually traversed back and forth across the face of the wheel. If the traverse is slow, the diamond tends to cut the grain and leave it partially dulled, producing a wheel face more adapted to finishing than to cutting. A faster traverse produces a sharper, faster-cutting wheel. Ability to dress the wheel properly is one of the marks of a skilled grinding-machine operator.

Crush Dressers. Crush dressing is a technique which involves pushing the grinding wheel into the formed dresser with such force that the face of the wheel actually takes on the shape of the dresser. (Fig. 3-26.) This means that the machine must be rigid enough to withstand substantial force, a factor that eliminates many of the lighter-built machines from consideration.

Many installations, for instance, horizontal-spindle, reciprocating-table surface grinders, have two crush rolls. One is mounted on one end of the table as the work roll, which dresses the wheel during production. The other, called the "master roll," is on the other end of the table. When the work roll becomes worn, as it does eventually, the operator simply moves the wheel to the master roll for redressing and then regrinds the work roll to shape.

Crushing produces a wheel face which is very sharp and free-cutting. Such a face enables the wheel to cut parts from a casting or other blank without prior machining. In fact, this one-step machining to a finished part is an example of the many parts which can be produced in one setup

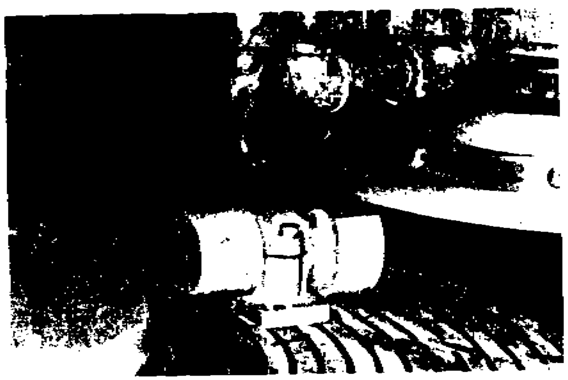


Fig. 3-25. Diamond dressing block to form a bonded abrasive wheel by cutting the grains. Such a block can be mounted on the magnetic chuck of a surface grinder. (*Engis Corporation.*)

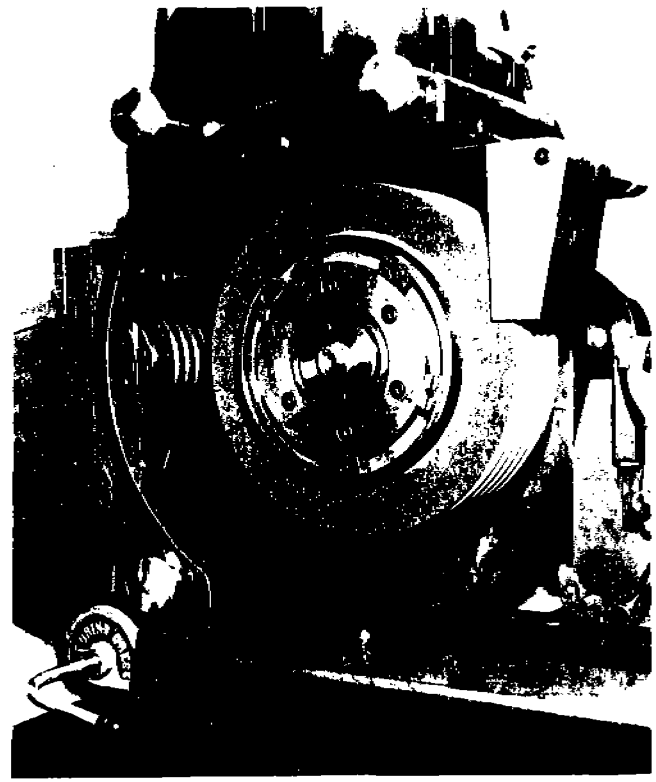


Fig. 3-26. Crush dresser mounted behind the wheel. For dressing, the wheel is fed back into the roll with considerable pressure, enough to break down and sharpen the grains. (*Bendix Corp.*)

without any intervening transportation or other costs. Labor time is usually lower too.

Abrasive Wheel Dressers. Some abrasive wheels, usually vitrified silicon carbide, are sometimes used on cylindrical and centerless grinding wheels which are large enough that a diamond might leave dressing marks that would spoil the part surface. An abrasive wheel as a dressing tool is effective, leaves a sharp wheel face, and requires only a little skill. Abrasive wheel dressers are also used on diamond wheels—a case of the inexpensive softer wheel cutting the expensive harder wheel—but there is usually only a little diamond to be removed anyway. Considering the price of diamond, it is usually more advantageous to have the operator take some extra time to mount the wheel true in the first place, rather than to remove abrasive later to true the wheel, which is a necessity with both silicon carbide and aluminum oxide wheels.

Wheel Surface Speed

"Surface feet" and the abbreviations "sfpm" or "fpm" are the abrasive wheel industry's methods of identifying a very important concept: the speed at which a point on the surface of a grinding wheel is traveling. It can be considered comparable to miles per hour in rating automobiles. Its importance stems from two limitations: first, any grinding wheel has to attain some minimum speed in order to cut efficiently; and second, exceeding the established safe speed limit is a safety hazard for the operator, and very likely for the people in the area around the grinding machine. The safe, efficient operating rate for any grinding wheel is between these limits.

An important consideration is that most grinding machines are designed with a fixed spindle speed (rpm) in mind, although some can be furnished with a variable speed spindle. Usually the spindle speed and the size of the grinding wheel are factored in so that the wheel's surface speed is in bounds. However, with wheel wear, there is a reduction in wheel speed, which is a factor in determining the diameter at which the wheel should be discarded. The basic formula is

$$\frac{\text{Diameter (inches)} \times 3.1416 \times \text{rpm}}{12} = \text{sfpm}$$

Thus, a 20-inch wheel running at 1240 rpm would be traveling at about 6500 sfpm, the generally accepted safe speed for a vitrified wheel. But if the wheel wears to 16 inches in diameter, and the spindle speed remains at 1240, the wheel is traveling at only about 5200 sfpm, which is safe enough but probably inefficient.

SUMMARY

Bonded abrasive wheels and other shapes together constitute an efficient, adaptable, and often less-expensive means of machining a range of materials from most of the soft metals to most of the hardest materials known. Furthermore, these wheels will remove stock effectively at a much faster rate than they are usually given credit for. For some shops, grinding is used only when there is, say, about 1/8 inch of stock to be removed; with

more stock, the tendency is to mill or turn the parts. However, others routinely grind stock up to 1/2 inch.

It is somewhat odd that grinding wheels, which are the preferred stock-removal tools in foundries and steel mills where stock must be removed efficiently and cheaply from castings and billets or blooms, and which are also the preferred if not the only method for producing very close-tolerance dimensions and super-quality finishes, have not made more headway in the middle ground where they compete with cutting tools. But that is the case, and one of the objectives of this book is to attempt to change this.

4

Coated Abrasive Products

In the coated abrasives business, two of the three major suppliers are also principal suppliers of abrasive grain, whereas the third is much more noted for its expertise in applying adhesives to backings. An interesting highlight of the fact that coated abrasive products have three principal components—abrasive and a backing material held together by an adhesive.

The idea of gluing abrasive grain to a backing is not new, as the now-outdated but still frequently used terms "sandpaper" and "emery cloth" suggest—outdated terms because there is no sand used today for coated abrasives and only a little emery. The first combinations of these three basic components—abrasive, backing, and adhesive—may very well have taken place before 1800. The first known magazine article about coated abrasives dates from about 1808, at least three decades before the patenting of the first grinding wheel in 1842.

The development of coated abrasives for the machining of metals was delayed for years because of the lack of waterproof adhesives (which meant that belts and other shapes could not be used with coolants) and the lack of stability and rigidity in the machines. Coated abrasives on light-duty machines became established for woodworking. But their use in the machining of metals spread rapidly with the introduction of waterproof adhesives and the design and manufacture of more-massive and more sturdily built machines with power on a par with the power used for abrasive wheels.

So today coated abrasives, mostly belts, may be regarded as capable of a wide range of processing from cleaning eggs to machining metals such as cast iron and aluminum; as well as some much harder, more rugged jobs such as steel-mill billet cleaning, descaling, and conditioning. The grain on

a belt cuts material. (Fig. 4-1.) This discussion will be much more concerned with the middle part of the range, where abrasive belts are providing increased competition with both cutting tools and grinding wheels.

BELTS, CUTTING TOOLS, AND WHEELS

A coated abrasive belt is a length of coated abrasive material spliced together on the bias to make as smooth a joint as possible. (Fig. 4-2.) It is mounted over two and sometimes more pulleys—one called the contact roll or wheel, which forces the belt against the work; and the other an idler pulley, or sometimes the power pulley, depending on the design of the machine. (Fig. 4-3.) The contact roll can also be the driving roll. When the belt is used to machine parts, it makes chips such as those illustrated (though one-twentieth the size shown or smaller). It is their chip-making ability, which they share with grinding wheels, that makes belts competitive in machining.

Fig. 4-1. Photomicrograph (20×) of swarf ground with a coated abrasive belt shows that the individual grains cut like turning tools or milling cutters. The precise orientation of the grain on the backing improves the belt's cutting ability. (*Norton Co.*)

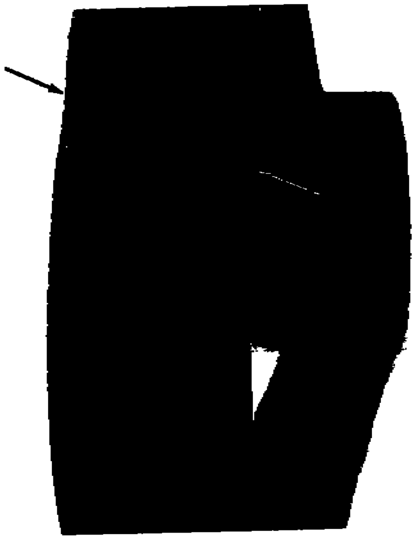


Fig. 4-2. Spliced belt, with arrows showing the two ends of the splice. Joint is virtually smooth, so that it will leave no marks on the finished surface. (*3M Company.*)

Belts vs. Cutting Tools

The theoretical case concerning abrasive belts and cutting tools can be stated very quickly. On the surface of a 4- × 96-inch long 50-grit belt there are about 500,000 abrasive grains. At average belt speed, each of these will come in contact with the work more than 600 times per minute. At each contact, each grain theoretically removes a minute chip of the work material. This makes a potential stock-removal capability of some 300 million chips per minute. Obviously not all the grains remove chips; but if it is assumed that only a million tiny chips are removed per minute, while a much larger single continuous chip is removed by a lathe tool, then it is possible that the million tiny chips outweigh the one large chip. A similar analogy applies to milling cutters or planing and shaping tools.

Belts vs. Abrasive Wheels

The principal advantage of belts over wheels is the belts' ability to grind in one pass, widths up to 48 inches without lengthwise splicing—and wider widths with splicing. (Fig. 4-4.) Moreover, it is very easy to set up several belt grinding heads on the same machine, so that the piece-parts are

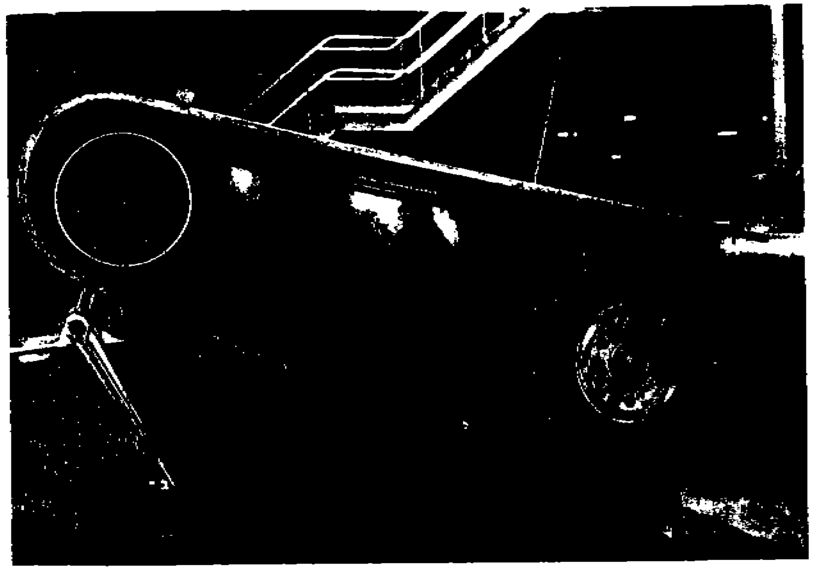


Fig. 4-3. This is the simple contact wheel-idler pulley setup which is the basis of all coated abrasive belt machine design. The contact wheel, at the right, is usually larger and is serrated. Some machines may have two or more idler pulleys. (*Hitchcock Publishing Co.*)

roughed and finished in one pass as they go under the heads on a conveyor belt. Belts, however, can remove significant stock. (Fig. 4-5.)

Belts are rarely dressed; for the most part they are used until worn and are then discarded. On a multihead machine as described above, a belt might be moved from the first head to the last before being discarded. So the comparison is between dressing time and belt-changing time, and such a comparison often favors belts.

On the other hand, belts are pretty much limited to straight-line rather than form grinding, although some contouring is possible with formed contact rolls. And it is generally held—even though abrasive belt proponents would argue the question—that belts cannot achieve quite the precision that is possible with wheels. There is some "give" in the backing material and some in the contact roll, which makes the contact more spongy than that of a vitrified grind wheel and probably a little less precise. However, belts routinely can attain closer tolerances than can metal cutting tools. And if the contact roll is made of steel rather than the usual hard rubber, the precision of the operation is enhanced. Finally, though belts do not have to be dressed as a general rule, they do have to be changed more fre-

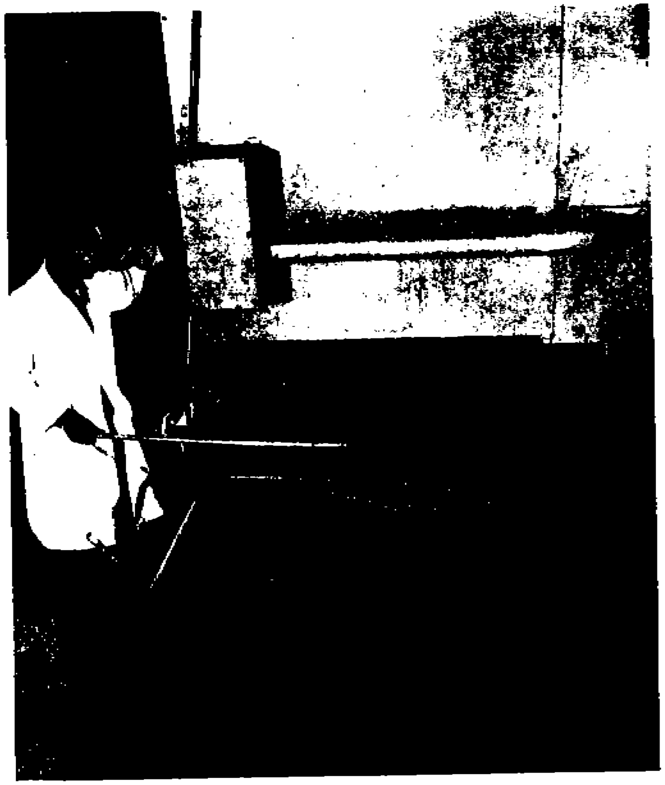


Fig. 4-4. Final polishing and oiling of stainless steel plate. Plate is 58 inches wide. (*Hitchcock Publishing Co.*)

quently than grinding wheels, because there is essentially a single layer of abrasive grain on any coated abrasive belt.

No Standard Marking System

A few of the coated abrasives manufacturers have worked up consistent marking systems of their own, though none can compare with the range of the standard marking system for grinding wheels. Nor is there an equal need for one. The total number of companies making grinding wheels, including those making diamond and CBN wheels, probably totals close to 100; the corresponding total for belts is approximately six. The com-

Fig. 4-5. The shower of sparks demonstrates the stock-removal ability of belts on cast iron. Removal rate is 1/2 cubic inch per minute. (*3M Company.*)

parative capital investment needed for the latter explains the difference, at least in part. The coated abrasive "making" machine is a large investment indeed. At any rate, there is plenty of space on the back of almost any piece of coated abrasive to print all the explanation that is needed, this reduces the need for a code.

Abrasive Types

For all coated abrasives virtually all the abrasive grain is either silicon carbide or aluminum oxide, augmented by a little natural garnet or emery for woodworking, and with minute amounts of diamond or CBN. Around 1935, about half the product was coated with natural abrasive and half with manufactured abrasive. Twenty-five years later, the manufactured abrasive share had risen to about 70 percent; and 20 years later, by 1978 or 1979, to over 90 percent. In fact, since most of the garnet- and emery-coated product goes into sheets for home workshops and do-it-yourself projects, industrial usage must be approaching 100 percent manufactured grain.

Aluminum oxide intended for coated abrasives is more elongated and pointed or sharp than is grain for wheels. As has been mentioned, the process for making coated abrasives permits orientation of the grain with its long axes at right angles to the backing, but the molding process for wheels does not include grain orientation. Aluminum oxide is a little softer but tougher (i.e., less likely to fracture under pressure) than is silicon carbide, and it is a more effective abrasive on all ferrous metals (except perhaps cast iron), on alloy steels, on tough bronze, and on hard woods. It is available in all grain sizes, generally from 600 (fine) to 12 (coarse). The size designations have the same general meaning for coated abrasives as they have for bonded.

Silicon carbide is regarded as a harder and sharper, though not tougher, abrasive than aluminum oxide. These qualities make it superior for use on low-tensile metals, glass, plastics, fibrous woods, leather, and other comparatively soft materials. It penetrates and cuts fast under light pressure, which is beneficial for polishing or other cosmetic surface treatments where appearance is more important than close tolerances. Silicon carbide is available in the same range of sizes as aluminum oxide, 600 through 12.

Backings

There are four general groups of backings used for coated abrasives: paper, cloth, vulcanized fibre, and combinations of these laminated together. Various weights of cloth are the most-used industrial backing.

Paper backings as a group are the least costly. They are generally used when strength or pliability of the backing is not critical—with sheets, for one example. The weight of the paper per ream (480 sheets of 24 × 36-inch paper) is indicated by a standard letter on the back of the sheet. The lightest, A weight, is 40 pounds per ream. C weight paper is 70 pounds; D weight is 90 or 100 pounds; and E weight, the heaviest, 130 pounds. Paper belts, which are used in some woodworking applications, are almost always E weight. A-weight paper may be called finishing paper, and C and D weight papers are sometimes termed cabinet papers.

Cloth backings are generally made from a specially woven type of cotton cloth. The two most common types are drills, marked with an X on the back, and jeans, marked with a J. Both have a twill weave. The principal difference is that drills are made from heavier threads, though there are fewer of them per square inch than there are for jeans, so that drills are the

heavier and the stronger of the two. Drills are preferable for heavy work with coarse abrasives; jeans are better when more flexibility is needed.

The strength of the backing for belts, particularly, limits the pressure that coated abrasive belts will stand without tearing. And pressure, as has been mentioned earlier, is a key factor, along with speed, in the stock-removal capacity of any abrasive tool, whether wheel or belt. The consensus is that cloth belts have been pushed about to the limits that they can take; and that further increases in ability to withstand pressure will come from synthetic backings.

The problem is that heavier cloths, which are quite readily made, cannot also be made flexible enough to bend around the contact roll and the driver and possibly idler rolls that are the basic elements of any coated abrasive belt grinder.

Vulcanized fibre is a very heavy, hard, and strong backing, of limited flexibility, used principally for resin-bonded discs on heavy duty sanders, and in a thinner version for drum sanding. (In drum sanding, a woodworking application, a sleeve of coated abrasive is slipped over a round, expandible holder, so that the assembly resembles a single-layer abrasive wheel.) Belts are preferred in metalworking and, for that matter, in most woodworking, because the abrasive, as a result of the length of the belt, has more of an opportunity to cool off between passes across the piece-part(s). Vulcanized fibre is made by impregnating cotton rag base paper with zinc chloride and then vulcanizing five to seven sheets together by heat, before the backing is coated with adhesive and abrasive.

Combinations may be either paper and cloth laminated together or laminated fibre and cloth. Both backings are sturdy and shock-resistant, though not particularly flexible. The first combination is used mainly on high-speed drum sanders; the second is an alternative to fibre backings for sanding discs on portable sanders.

Adhesives

The obvious function of any adhesive is to attach the abrasive grain to the backing. In the manufacturing process for coated abrasives a continuous strip of backing 52 inches wide moves through each step of the way—back-printing, coating with adhesive (the "make" coat), coating with abrasive, a second coating (the "size" coat) of adhesive—until the strip is wound up as a "jumbo roll" about three feet in diameter and trimmed to 48 inches width.

If the product is intended for dry use, as, say, in most woodworking applications, then the adhesive can be glue—straight animal-hide glue, which is the traditional adhesive. With coolants, the adhesive can be one or another of the resins, which are basically liquid phenolics. For special uses, the two may be combined, either glue over resin or resin over glue. Resins, particularly, may be modified to provide shorter or longer drying times, greater strength, more flexibility, or other desirable properties.

METHOD OF MANUFACTURE

In the manufacture of coated abrasives as outlined above, the key step is probably the application of the abrasive, which may be done by pouring the grain in a controlled stream from above, or, as is more likely the case today, passing the strip of backing over a pan of abrasive with the adhesive-coated side down, and at the same time passing through the abrasive an electric current which causes the abrasive grains to project themselves upward along and parallel to the lines of force, so that they embed themselves point up in the adhesive-covered backing. This grain orientation produces a very sharp, fast-cutting abrasive tool.

The amount of abrasive grain deposited on the adhesive-covered sheet can be controlled to amazing accuracy by adjustment of the abrasive stream and manipulation of the speed of the sheet of backing. Of course, once these two factors are established for any one jumbo roll of backing, they are not modified during the coating of the roll.

There are two variations of coatings—closed and open. A closed coat is one in which the abrasive grain completely covers the coated side of the backing. This is generally preferred for severe service. An open coat (Fig. 4–6) is one in which individual grains are spaced out to cover from 50 to 70 percent of the surface. An open-coated abrasive is more flexible than a closed-coated product, and it is less likely to become clogged or loaded with bits of the work material.

From the making unit the product is carried by a festoon conveyor system through a drying chamber to the sizing unit, where the size coat of adhesive is applied. The two films of adhesive unite to anchor the grain securely. Following a second trip on a longer festoon conveyor through a drying and curing chamber with closely controlled temperature and humidity, the product is wound into jumbo rolls for storage and conversion to marketable forms of coated abrasives. (Fig. 4–7.)

As the coated abrasive sheet is unrolled from the jumbo roll it is quite stiff, because it is made up of two coats of adhesive applied over a strip of cloth, paper, or fibre. So the first step in converting it to marketable forms is to flex it, that is, to break the adhesive in a controlled process so that it won't break in a haphazard and uncontrolled fashion later. Flexing may take two forms, single and double. Single flexing involves break lines at 90° to the edge of the roll. With fine grits, the break lines are usually close

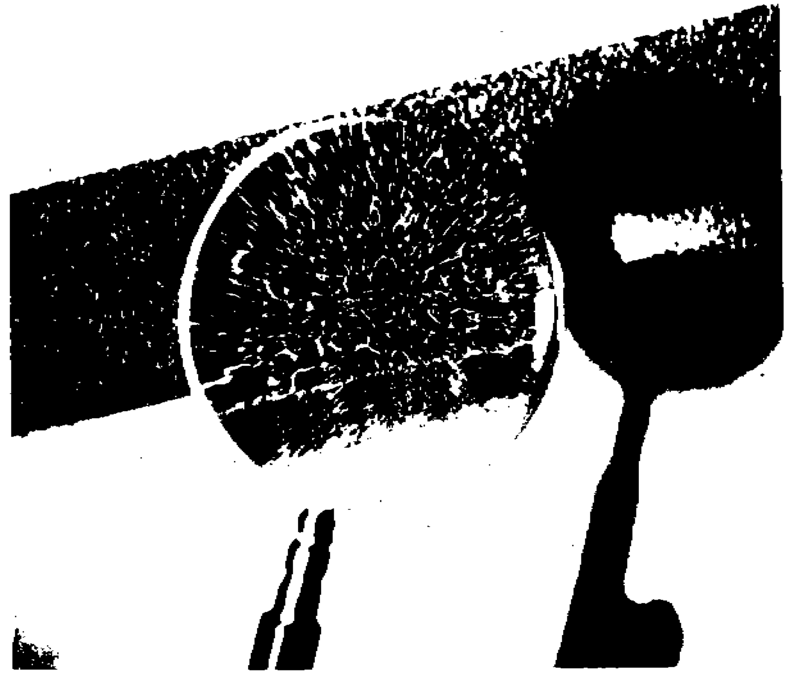


Fig. 4-6. Magnification emphasizes the backing showing through on this open-coated strip of coated abrasive. Coverage is 50 to 70 percent. (*3M Company.*)

together, thereby providing a softer flex. With coarse grits the break lines are farther apart, thus making a stiffer flex. This procedure leaves the sheet stiff in the crosswise direction, but with lengthwise flexibility that enables the sheet to conform to the arc of a drum or pulley without random, harmful cracking. The single flex is sometimes done at an angle other than 90°, but this is not common.

Double flexing involves breaking the sheet at two 45° angles to produce a criss-cross pattern of break lines, which makes the sheet flexible in almost any direction. Double flexes are required on coated abrasives intended for the sanding of shoulders and other contoured work. Triple flexing is a combination of the two; it makes the sheet extremely flexible for the sanding or grinding of very irregular contours.

Because any flexing breaks the continuity of the bond, it tends to decrease the durability of the product. For that reason, flexing should be held to a minimum (which for most industrial applications is a single flex)

Fig. 4-7. Jumbo rolls of coated abrasive in storage. Each roll contains about 50 linear yards of product which is approximately 50 inches wide. (*3M Company.*)

so that the belt will conform to the arc of the contact roll or wheel and the other pulley(s) in the system. Minimum flexibility consistent with operating requirements is always the economical selection.

Slitting and Other Cutting Operations

Some coated abrasives are sold to consumers in the original 48-inch-wide, 50-yard-long jumbo rolls, but most are sold in narrower slit widths, as, for example, stock intended for belts. The slit rolls are produced on a machine that uses circular knives against a hardened steel roll and then rewound to the desired length. Most of the 50-yard rolls are continuous strips, though

difficulties in manufacturing sometimes make it necessary to produce rolls made up of two or three lengths; but if this is the case, an extra length is included for each short piece, so that where a 50-yard continuous length is required, the roll can be spliced so smoothly that the joint is virtually invisible.

For continuous belts in any desired width and length, slit rolls of the proper width are cut to length, including an allowance for the joint overlap or splice. Most belts are spliced at a 45° angle, though narrow belts are spliced at a more acute angle, and wider belts at a greater angle. At the joint, to avoid a bump which would ruin the piece-part surface, the two angle-cut ends of the belt length are skived, that is, the layer of abrasive is removed from one end of the length and a minute layer of backing is removed from the other end, so that when the two overlapped ends are joined, the belt is of correct length and the joint is little, if at all, thicker than the belt. For coarse-grain belts where the prime objective is to remove stock, only one end may be stripped of abrasive (single skiving), because the surface will not be affected seriously by a poorer finish and because the whole strength of the belt is needed to withstand the high pressures in such operations.

Sheet and Disc Cutting

Standard sheet sizes (usually 9 inches × 11 inches) are cut on a ream cutter, which is a combination of a slitter and a flying knife. Discs are cut on a punch press with a die or dies. The operation is usually done on a complete length, as a jumbo roll or a slit roll is unwound ahead of the punch press. Each disc with its center hole and any required radial slits is punched out in one operation for standard diameters.

ELEMENTS OF BELT GRINDING HEADS

Basic Design

Coated abrasives are used in many forms: sheets for sanding; discs with stiff backs to be used on portable grinders for rough applications, such as weld grinding; discs adhered to backing plates for wood sanding; small strips wound up and glued together like mounted bonded wheels; and continuous-belt grinders on which the work is either pressed against the belt backed up by a contact wheel or a flat platen between the pulleys or simply held against the belt without any backing (slack-of-belt grinding). But the major industrial grinding-head design is one in which the belt passes around two or more pulleys, with one of them, known as the contact roll or wheel (depending on its width), forcing the belt against the piece-parts. Or, as with a floorstand or backstand grinder—two terms of the same machine—the piece-part is forced against the contact wheel by the operator.

This basic assembly of drive pulley and contact wheel can be augmented by one or more idler pulleys around which the belt can pass. The whole idea of belt grinding, as opposed to drum sanding where the sleeve of coated abrasive is fitted snugly around a head, is that the travel time of the belt between contacts with the work gives the belt time and opportunity to dissipate grinding heat. A drum sanding head provides no such opportunity. So it is not uncommon to have more than two pulleys for the belt, but two would be considered the norm. (Fig. 4–8.)

Contact Wheels or Rolls

It should be clear by this time that effective stock removal with abrasive belts requires some kind of backup for the belt, and that the backup is usually a contact wheel or roll, though it could be, as noted above, a flat platen. Usually the platen is located between pulleys mounted one above the other, and there is frequently a horizontal work rest to help support the piece-parts.

The contact wheel is generally a grooved solid rubber tire (Fig. 4-3) vulcanized to an aluminum wheel or a metal rim mounted on a hub. (There are also sewn-cloth contact wheels, but they are primarily used for polishing operations without close tolerances or significant stock removal. (Fig. 4-9.)

Rubber contact wheels have become popular because of improved methods of bonding the rubber to the metal and because of improved

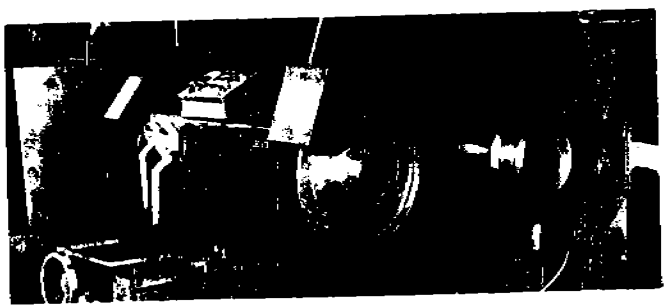


Fig. 4-8. Another view of the belt system, with the guard raised so that the contact wheel and backstand idler can be seen. In operation, of course, the guard is closed. (*Divine Brothers Co.*)

Fig. 4-9. This operator is polishing pistol frames with a 4- × 148-inch belt running over a compressed canvas contact wheel. (*Norton Company.*)

methods of controlling the hardness or density of the rubber. Hardness (durometer) of the rubber, along with the serrations, determines the cutting rate of the belt—other factors being equal. For a given grain size, a hard wheel makes the belt remove more stock than a soft wheel; and the harder the wheel, the faster the cut and the coarser the finish. So changing to a harder wheel has approximately the same effect as changing to a coarser grain size. In any multiple-stage operation, where two or more grinding heads are used, the hardest contact wheel that will conform to the surface and also produce a finish that can be blended in by the subsequent grinding is the one to be used.

Rubber contact wheels are manufactured in densities from extremely hard (90A durometer) to extremely soft (20A durometer). Wheels in the range of from 70A to 90A durometer are primarily for stock removal. Medium wheels (40A to 60A durometer) are for the type of operation involving some stock removal but primarily a good commercial finish. Soft wheels (20A to 30A durometer) are used for fine polishing and limited contour grinding. There is a third factor, however, that may sometimes come into consideration—the speed of the belt, and consequently, of the contact wheel. Increasing this speed will cause the contact wheel to act harder than it does at normal speed. And since most coated abrasive grinders are designed to run at a constant speed, adjusting speed might well be regarded as a measure to be used only in emergencies. The normal optimum approach is to select a contact wheel in keeping with production requirements, and with the grinder running at its normal speed.

The serrations or cross slots in the contact wheel also affect its action, and the aggressiveness of belt action and the coarseness of the finish increase as the size of the angle increases from a minimum of 15° to a maximum of 90°. At the maximum, 90°, there will be a very aggressive abrasive action, and subsequent coarse finish, along with a noise that sounds like a siren, which would probably be unacceptable as a working condition. There may also be an unattractive scratch pattern on the work.

Serrations produce alternating lands and grooves across the face of the contact wheel, and thus the ratio of the width of the grooves to the width of the lands, the depth of the grooves, the shape of the lands, and as mentioned, the hardness of the rubber in the contact wheel are all factors in determining the cutting action of the belt. The serrations also provide an easy means of controlling the breakdown of the abrasive grains to ensure renewed sharp grain edges. Beyond that, the flexing action of the belt as it passes over the lands and the grooves provides chip clearance and prevents the chips from loading the belt.

Belt Tension, Belt Speed, and Power Requirements

The tension on the belt, its speed, and the power requirements for abrasive belt grinding are all items of importance, because they affect the efficiency of the method and, in some measure, part of its costs.

Actual tension on a belt can range from a low of 4 to 5 pounds per inch of belt width ("inch of belt width" is one of the common denominators of belt comparisons) to a high of 35 to 40 pounds. The lower range is used for contour polishing and similar applications, with the belt at reduced speed. In such circumstances it is preferable to use just enough tension to keep the belt from "walking" sideways on the contact wheel when the work is applied. It is also preferable for the belt to have 100° or more of uninter-

rupted wrap around the wheel before it comes in contact with the piece-part.

With harder contact wheels and heavier pressure on the piece-part, higher belt tension is needed. Unless steel contact wheels are used, high pressure deforms the contact wheel at the contact point, a condition which may cause the belt to pucker up ahead of the contact area if the pressure is high enough. Particularly if belt tension is insufficient, this puckering can cause premature "shelling," or stripping, of the abrasive, which in turn makes it necessary to discard the belt before its time. On the other hand, excessive belt tension can reduce some of the beneficial effects of the contact wheel.

Belts do operate at various speeds, of course, and like grinding wheels they have safe maximum limits, as indicated by the manufacturers. It is worth noting, though, that they have proved safe at a maximum practical speed of 10,000 sfpm, which is approximately 50 percent above the general safe maximum for vitrified bonded wheels, and about on a par for the general safe maximum for unreinforced resinoid wheels. Much of what is true about the effects of wheel speed and pressure on the work for wheel grinding is also true for belt grinding. And pressure of the work on the belt has the further beneficial effect of promoting breakdown of the abrasive grain and keeping the belt sharp.

Power requirements per inch of belt width range from 1/2 to 7 horsepower, with the lower end for very light work such as deburring, and the upper limit for operations requiring heavy stock removal. Probably most operations fall into the range between 1 and 3 horsepower, although the recent trend has been toward higher horsepower, because most experts agree that the majority of belt grinders, just like most hard wheels grinders, are underpowered for the most-efficient operation. As belt speed is increased, horsepower should be increased proportionately. The benefits of high-speed operation cannot be realized unless the horsepower available in the machine will maintain speed under load.

CONTACT WHEELS

Storage

Poor storage practices can do more damage to contact wheels than almost anything that can happen to them while they are in use. For example, on any operation involving the use of two or more contact wheels, it is usual to lean the extra wheels against the machine, a practice which can put the wheel into a permanent and undesirable set: it can produce both an out-of-round and out-of-balance condition that can mark the work, tire the operator, and shorten belt life. The best practice is to hang the out-of-use wheels on pegs through their center holes at locations convenient to the machine(s). Failing that, they should be stored flat on their sides.

Contact Wheel Selection

The selection of a contact wheel for a given application is obviously a job for someone with technical knowledge and a familiarity with the job, but the reader should have some understanding of the generalities on which the selection is made. Following are a series of statements that hold true for most of the grinding applications that use coated abrasive belts and contact wheels. Some of these have been indicated before; one or two of the ideas are new. Belt grit size is presumed to be a constant.

1. The harder the wheel, the faster the cut and the coarser the finish.
2. The smaller the wheel diameter, the faster the cut and the coarser the finish.
3. Finish and rate of cut go together. Coarse finishes accompany a high rate of cut; fine finishes, a lower rate of cut.
4. High speeds usually produce better finishes, except with soft wheels, for which speeds of 5,500 sfpm harden the wheel and make the finish coarser.
5. Higher groove-land ratios on serrated wheels increase the rate of cut and produce a coarser finish.
6. Serrated wheels reduce belt glazing and loading and give longer belt life than do smooth-faced wheels.
7. Hard contact wheels increase the stock-removal capacity of a belt, other factors being equal.

As Fig. 4-10 and 4-11 illustrate, the basic contact wheel-and-idler pulley (also sometimes called a backstand) is used on many different types of machines. The combinations can sometimes get rather complicated, but they can be used practically anywhere that a peripheral grinding wheel can be used, as is illustrated with the floor backstand grinder, the surface grinders, or the centerless grinders. In a centerless setup it is not uncommon to team up a belt abrasive grinding head with a rubber-bonded regulating wheel. And there are numerous such combinations of wheels and belts, some developed in-house and some developed by machine builders, to take care of special situations.

But while belts are probably the most-used coated abrasives, they are not the only ones. Stiff, heavy-coated abrasive discs (Fig. 4-12) compete with various kinds of grinding wheels on portable grinders. But one of the more

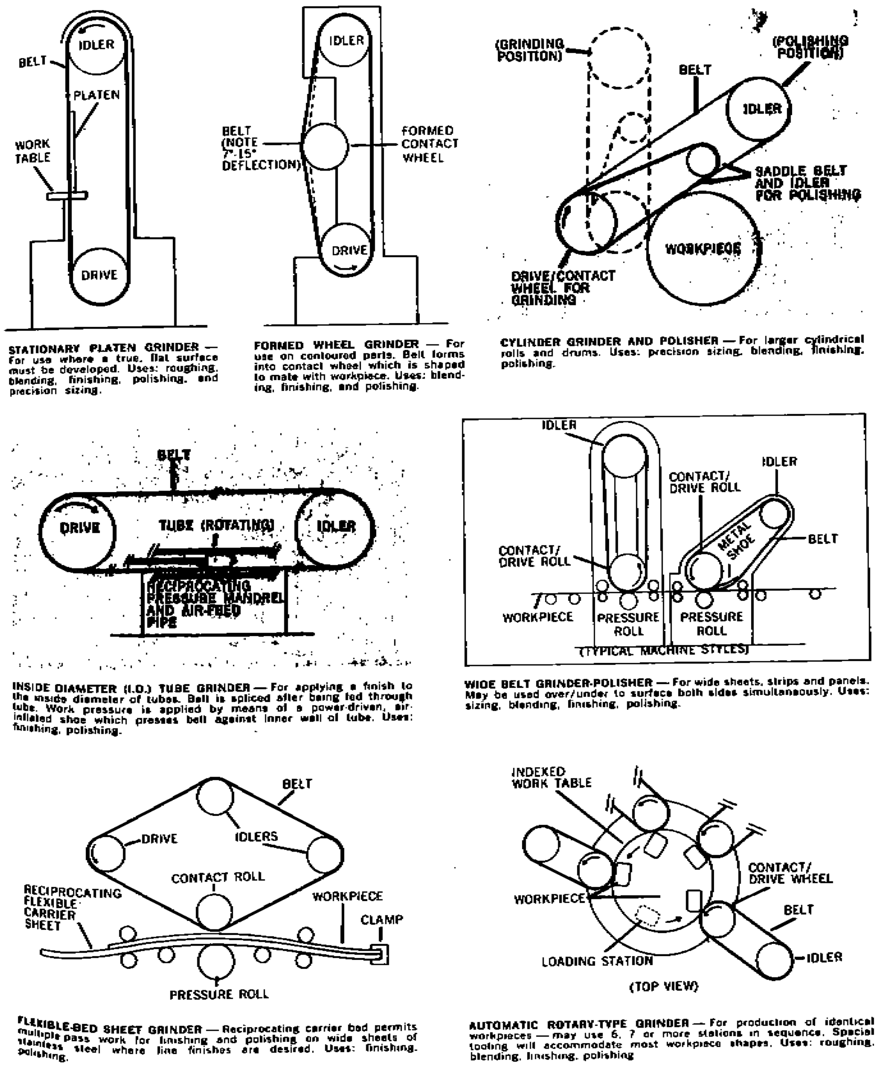
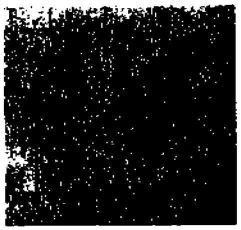
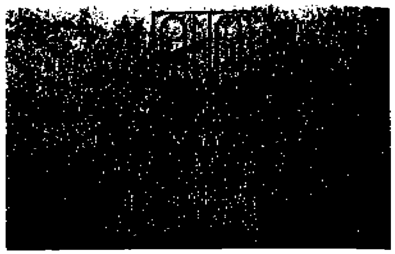


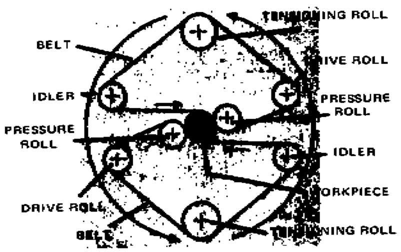
Fig. 4-10. Variations in belt machine design. (*3M Company*)



FLOOR BACKSTAND GRINDERS — For use on workpieces that can be carried and handled properly. This machine is basically a conversion of a floor lathe or polishing jack to abrasive belt use by means of a backstand idler pulley. Uses: roughing, blending, finishing, polishing.

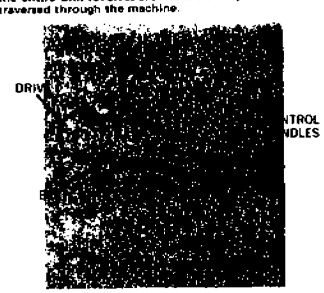


CONVEYORIZED GRINDER — For use on flat surfaces, including large sheets and panels, where a succession of abrasive grades is used. Uses: simultaneous roughing, blending, finishing, polishing and precision sizing.



PLANETARY GRINDER & POLISHER — For use in grinding and polishing cylindrical, oval and some tapered stock in continuous or cut lengths. Note that the entire unit revolves around the workpiece as stock is traversed through the machine.

CENTERLESS (O.D.) GRINDER — For cylindrical shaped workpieces such as rod or tubing of varying diameter and length, often requiring precision finishes. Uses: roughing, blending, finishing, polishing and precision sizing.



SWING GRINDERS — For use on larger workpieces that cannot be brought to a floor grinder. Available in 1-15 H.P. ratings. Uses: roughing, blending, finishing.

SURFACE GRINDER — For high volume stock removal operations. This machine features rotating fixture tables which are plunged vertically into an abrasive belt with extremely high pressure. This produces high stock removal rates and a flat surface. Note that the revolving turret creates a load-unload station while the alternate fixture table is in a grind cycle. Uses: heavy stock removal.

Fig. 4-11. Variations in belt machine design. (*3M Company*)

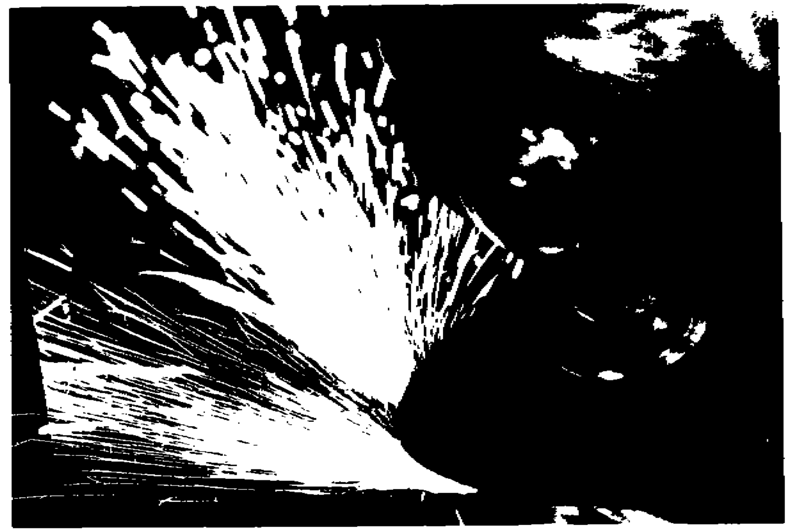


Fig. 4-12. Portable grinding with a stiff coated abrasive disc cemented to a rubber backup pad. Note, however, that the pad does bend. (*Hitchcock Publishing Co.*)

useful recent developments is what is often termed a "flap wheel (Fig. 4-13.)" This is simply a number of partially slit sheets of coated abrasive clamped in a rotary holder, which can be mounted to revolve so that the abrasive strikes the work. The abrasive action depends on the grain size, the stiffness of the backing, and the rotating speed of the backing. Coarse-grained, stiff sheets rotating at high speed are effective in descaling or removing rust. Finer-grit and more flexible sheets at medium speed can be used for polishing contoured or formed parts. Sometimes slit sheets are used in a holder to polish grooves or slots.

WHEEL AND BELT GRINDER COMPARISONS

After having considered both grinding wheels and coated abrasives—principally belts—as forms of abrasive cutting tools, it is time to make some comparisons of the machines on which they are used, which are for the most part not too much different in design, although they may look considerably different to the layman because of the extra pulley(s) which are a requirement for any grinder using abrasive belts. It has been pointed out that grain orientation is much better on belts than it is on wheels, because

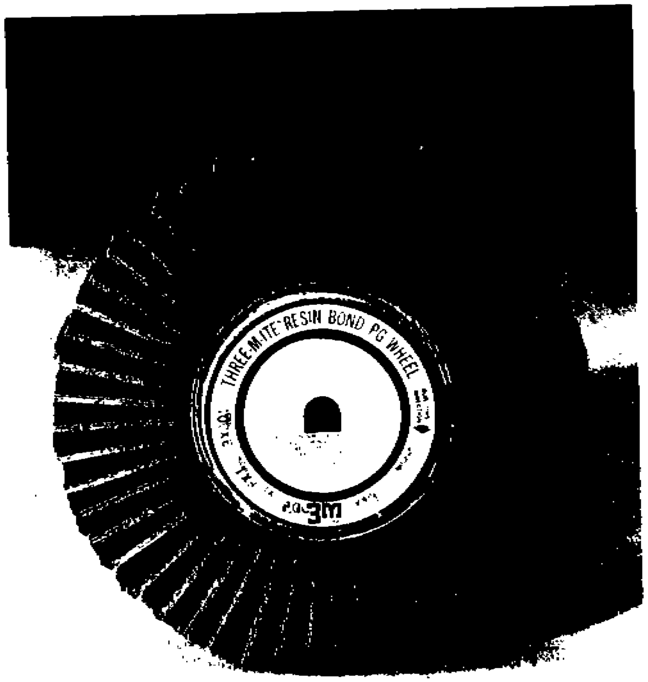


Fig. 4-13. Coated abrasive "flap" wheel. Each set of three sheets has a sponge backup. With 100-grit abrasive, this wheel is probably for a semifinal finishing operation. (*3M Company.*)

the molding process for wheels does not at present make orientation possible. In terms of machine tool "rake," a metal cutting tool may be anything from positive to negative. The grain in a grinding wheel has only random rake, since the cutting angle of each grain depends on how it is positioned in the mix. But coated abrasive grain in general have various degrees of negative rake.

Peripheral or Side Grinding

Bonded abrasive wheels are designed generally for grinding on either the periphery or the side (rim). Of the grinding wheels definitely designed for side grinding or grinding on the flat, like type 2 cylinder wheels and types 6

and 11 cups, to mention the three most-used shapes, the area for grinding is usually small in relation to the outside diameter of the wheel. Segments in a chuck or holder for vertical-spindle surface grinding have greater area for flat grinding. And a bonded abrasive disc might be considered as a type 1 straight wheel without any center hole, although it may have bolt holes in a pattern on its flat sides for attaching it to a backing plate.

Belt grinding, at least all precision belt grinding, is peripheral grinding very similar to wheel peripheral grinding. But there is very little if any precision disc grinding with coated abrasives which is on a par with rim or side grinding with wheels. Belts have a somewhat higher surface speed than vitrified wheels—about 10,500 sfpm as compared with 6,500 sfpm for vitrified wheels or 9,500 for resinoid—and they have a much thinner layer of abrasive—essentially a single layer rather than the many in a conventional wheel. And belts must have the extra pulley(s), though that has been no barrier to rather frequent conversions of, say, cylindrical or centerless grinders from wheels to belts. The converted grinder may look a little odd, but it works.

Width of Grinding Surface

Comparative width of the grinding surface is another important consideration. Peripheral wheels for either surface grinders or cylindrical grinders range in width (thickness) up to about 6 inches for surface grinding and 4 inches for cylindrical. For centerless grinding, both the grinding wheel and the regulating wheel are wider, up to about 20 inches for standard wheels. Of course, on a centerless grinder, the duration of the grind depends on the thickness of the wheel, whereas both peripheral surface and cylindrical wheels can be traversed across the surface of the piece-part. Each passage of the wheel across the piece-part is known as a "pass"; it is of utmost importance that the passes overlap without marks of any kind. And it should be obvious that with a wide piece-part and too soft a wheel, there is a distinct possibility that one end or side of the piece-part will be higher than another, because of wheel wear as it moves across the work.

For belts, width is not a real problem until the belt becomes wider than 48 inches, the usual width of a trimmed jumbo roll of product. Probably most belt grinders use belts that are 12 inches or less in width. Incidentally, machines using 12-inch belts are very widely used. Machines using belts wider than 12 inches are often called wide-belt machines, with the width frequently determined by the width of the product being ground. One of the strengths of belt grinding, as was said before, is its ability to grind or polish wide work in one pass.

Work-Holding

Comparative methods of holding and/or conveying the work during processing should be mentioned, even though they will be discussed in more detail in connection with the various types of grinders. For cylindrical and centerless grinders, the work-holding mechanisms are the same; whether the machine uses a wheel or a belt is immaterial. However, for flat grinding with wheels, the choice is generally some kind of metallic magnetic chuck or workholder with sufficient strength to hold the piece-parts under wheel pressure. The magnetic chuck either rotates or reciprocates to being the work under the grinding wheel; and on high-production machines it is possible to design a grinder with an indexing work table with two or sometimes more chucks, so that while one chuck load is being ground, another may be unloaded and reloaded.

This machine design is made on the assumption, of course, that the grinding cycle is long enough to permit the second chuck to be unloaded and reloaded. If the grinding cycle is too short—and if production is high enough to warrant a custom machine—it is certainly possible to design a three-chuck grinder which with two operators would permit unloading, grinding, and loading cycles to be carried on simultaneously.

With belt grinders, high production is usually associated with conveyor belts that carry piece-parts from one grinding head to another, or perhaps a single-head with the conveyor to carry parts under it. With this setup, whether the machine has one head or several, all the human power needed is someone to load the parts; a tote box can be located at the end of the conveyor so that the ground parts fall into it. This applies whether there is one head or several. Under each head there is a backup roll sometimes called a "billy roll," or sometimes a pressure roll, or a platen (the functions of the three are identical) to ensure adequate pressure on the abrasive belt and the workpiece. And a variation of this is to have two heads mounted in a vertical plane with each other, one above a continuous sheet of steel or other metal, grinding and or polishing both sides of the sheet at the same time as the sheet is unrolled from one reel and rolled up on another after passing between the heads.

Nor is it uncommon to have, for example, a belt centerless grinder using a rubber-bonded abrasive wheel for regulating. And since the only function of the regulating wheel is to keep the piece-parts from spinning, it would certainly be possible to put more than one regulating wheel on a longer-than-usual spindle, in line with a wider-than-usual belt. (Two straight wheels cemented together for grinding would certainly leave marks on the work, but for regulating that should be no problem.) It might even be possible to have an automatic abrasive vibratory finishing unit into which

the piece-parts could fall at the end of the conveyor, and thereby rough, finish, and deburr the piece-parts from one loading without any intermediate handling.

STORAGE OF COATED ABRASIVES

Grinding wheels are relatively unaffected by atmospheric conditions and require care in handling and storage primarily to prevent chipping through contact with other grinding wheels or with anything that might chip or crack the wheels. But for coated abrasives, the backings and sometimes the adhesives are sensitive to climatic conditions and will gain or lose moisture in accordance with the temperature and the relative humidity of their surroundings. High moisture content is particularly bad for glue-bonded products. Moisture causes the bond to soften under the heat generated by use, which in turn may allow the grain to shell from the bond and the backing before it is really worn.

Coated abrasives are manufactured to be at their best in heat and humidity most comfortable for human beings; that is 60° to 80°F, at 35 to 50 percent relative humidity. Temperatures above or below these ranges and air that is moister or drier can cause unnecessary trouble for coated abrasives.

The ideal storage room for coated abrasives would be one whose walls are all inside partitions, rather than outside walls. There should be neither steam-heated radiators nor hot-air inlets in the storage; if there must be a heat source in the room, it should be as far away from the coated abrasives as possible and shielded from them. Air conditioning is preferable in any case and, for any plant with a significant inventory of coated abrasives, virtually a requirement. Plants with smaller inventories could easily justify some kind of special cabinet or enclosure for this purpose.

SUMMARY

While coated abrasives cut chips similar to, though of course very much smaller than, those removed by cutting tools, and more similar to those cut by grinding wheels, there are important factors that make coated abrasives, particularly belts, worth considering for many more than their current applications. A cutting tool stays in continuous contact with the piece-part; abrasive grain in a grinding wheel cuts the piece-part intermittently, although with very short intervals between cuts; but a coated abrasive belt, with the same kind of intermittent cut, has much longer intervals between cuts—two or three or more times longer, depending on the length of the belt. This means that the grain in a belt has much more efficient air cooling than does the grain in a wheel. And the use of a coolant on a belt improves the cooling action noticeably.

A cutting tool in one pass across a piece-part cuts a thick chip that is only a fraction of an inch wide. It needs periodic resharpening and adjustment to maintain a flat surface or a consistent cylindrical surface. A grinding wheel cuts a myriad of chips from an area of a piece-part that is approximately as wide as the wheel's grinding face; and particularly if the specification is on the soft side, a wheel needs to be down-fed (or in-fed) to maintain a consistent straight surface. On a wide flat surface, if the wheel wears and there is no downfeed, the part of the surface cut last will be higher than that cut first. Similarly, on a cylinder where there is wheel wear and no adjusting infeed, the end of the cylinder cut last will be larger in diameter than what was cut first. But on the other hand, an abrasive belt will cut its width across the piece-part without significant alteration, because most of the time the belt will be wide enough to cover the whole surface of the work in one pass. And even if it needs more than one pass to cover the surface, the wear is miniscule at best and not unsuitable for most grinding work.

And of course when you consider the amount of grinding work—or metal-cutting work—that has fairly liberal tolerances for dimensions and other elements of its geometry, it's obvious that a great deal of this could be done on coated abrasive belt machines.

Furthermore, when you consider that a belt grinder equipped with a conveyor belt to carry the parts can be loaded manually and unloaded, if they are suitable, by letting them off the other end of the conveyor, there could be a considerable drop in manning requirements. And if the parts can come by chute or similar conveyance from another operation, the labor requirements drop off even more. It does not matter whether in the course of the grinding operation the piece-parts pass under one, two, or even five or six grinding heads. The loading and unloading steps in the process remain the same.

Abrasive belts have suffered even more from misconceptions than grinding wheels. The first belts, like the first wheels, were short-lived, light-duty tools. Unlike wheels, however, belts for many years were not as durable and tough as they should have been; and because lightly-built machines were sufficiently strong for woodworking, where belts were mostly used, there were only rare opportunities to demonstrate belts as metal-cutting tools. As one authority said some years back, "Before World War II, I would have said there were very few areas where belts could compete with wheels. Now I hold that there are only a few areas where they can *not* compete."

5
Flat-Surface Grinding Machines

As was stated in the preface, it is logical and convenient for management to group abrasive machining operations by the geometry of the surfaces they are designed to work on, rather than by, say, stock-removal capacity or the design of the machine. Thus, surface grinders (Fig. 5-1), disc grinders (Fig. 5-2) and free-abrasive or flat lapping machines (Fig. 5-3) will be discussed together in this chapter, even though most other publications on the subject discuss them separately.

From a technical standpoint the customary breakdown makes sense. The specification of abrasives for a wheel surface grinder, a disc grinder, and a coated abrasive surface grinder, for example, could be considered as three different areas of specialization. But specification of abrasives, beyond a very elementary level, is not an objective of this book. It has to be done, of course, but rarely by those to whom this book is addressed.

The broad use of the term "grinding" may also be questioned. It is hardly consistent with the title of this book, nor is it usually applied to fine finishing operations like lapping and honing. However, it has a broader application to surface generating and refining operations with abrasives than any other, and it is for that reason that it is used.

One observation on terminology. For many years the term "lapping" has been applied indiscriminately to any operation involving the use of abrasive grain in oil or some other carrier between two surfaces, one of which is to be finished, regardless of the geometry of the surfaces. It ought logically to be confined to flat surfaces. It has been so restricted here.