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Letter
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ARTIFICIAL ABRASIVES AND ABRASIVE PRODUCTS

The abrasive industry supplies: (a) abrasive-coated paper and cloth for surface finishing; (b) unbonded abrasive (referred to as "abrasive" or as "grain") for grinding, polishing and lapping with loose grain, and for set-up wheels used in surface finishing; and (c) bonded abrasives (referred to as "abrasive products") in the form of wheels or other shapes to be mounted in suitable machines for grinding and finishing.

Manufacture of Abrasive Grain

Silicon carbide (SiC) was first made in 1891 by E. G. Acheson (1856-1931), who called it "Carborundum", which term has been registered as a trade-mark by one of the several concerns producing this material. The natural mineral is known as moissanite. The crystals, when free to develop, usually form hexagonal plates of limited transparency. The average index of refraction is 2.65, character uniaxial positive, density 3.1, thermal expansion coefficient 4.7 $\times 10^{-6}$ per °C, and hardness 9.5 in Mohs' scale. It is characteristically brittle. In nature it has been found in the meteoric iron of Canon Diablo, Arizona.

Silicon carbide is made in resistance-type electric furnaces. The usual furnace is a brick container which may be 45 ft long by 10 ft wide, and 10 ft high. Such a furnace produces 8 to 10 tons of total silicon carbide (97 1/2% SiC) per furnace heat. In most furnace operations, unreacted material is returned to the furnace for 'refurnacing'. A new mix, several of which are required to load a furnace, may consist of approximately 10,000 lbs of silica, 6,000 lbs of low ash petroleum coke, 1,200 lbs of ordinary wood sawdust, and 160 lbs of sodium chloride. The sawdust lowers the density and provides a structure sufficiently porous to permit the escape of the large volume of reaction gases.

After careful mixing of the ingredients, the charge is packed around a starting resistor of granular coke approximately 3 ft wide by 1 ft high. At the start of the heat, a relatively high voltage (about 300) is necessary because the internal resistance of the furnace is high. As the temperature rises, the internal resistance of the furnace falls and the voltage required may fall below 100. A heat is completed in about 36 hrs and the power consumption will be about 4 to 5 kw-hr per pound of usable material.

Published temperature measurements on commercial furnaces have shown that the core temperature may rise as high as 2600°C (4710°F), where some of the silicon carbide formed is decomposed into graphite. The limiting lower temperature of the outer zones of the ingot which will produce suitably crystallized silicon carbide is around 2200°C (3630°F). The essential reactions in the furnace may be represented by the simple equation $SiO_2 + 3\ C = SiC + 2CO$.

Artificial corundum or "fused alumina" (alpha - Al_2O_3) -- Production in quantity from bauxite was made possible by the patented process of Chas. B. Jacobs, dated 1897. His patent followed closely on the patents of Werlein in France (1894) and Hasslacher in Germany (1896) for its production from emery or from the purer African ore. Artificial corundum is known commonly as "Alundum", which word also is a registered trade-mark of one of several manufacturers. It crystallizes in the trigonal system, and the crystals are described as uniaxial negative in character, average index of refraction 1.76+, density 4, and hardness 9+. The average linear thermal expansion coefficient is about 8.0×10^{-6} per °C.

Artificial corundum is produced in steel-lined, watercooled furnaces of the arc type. An average furnace, 7 1/2 ft in diameter and 6 ft high, will hold sufficient charge in the fused state to produce a "pig" weighing 6 to 10 tons. About 24 hrs, and energy at the rate of from 500 to 800 kw, are required to fuse this amount of material.

Calcined bauxite is used customarily as the source of alumina for the manufacture of abrasive grain. A typical calcined bauxite will contain from 75% to 80% of alumina as charged to the furnace, the impurities being 2% to 5% of TiO_2, 4% to 8% of SiO_2, and 8% to 12% of Fe_2O_3. Variable amounts of coke and of iron borings are added to the charge to aid in the reduction and in the separation of the impurities. The coke reduces the impurities (mostly oxides of silicon, iron and titanium) and these, together with the iron added to the batch, form an impure magnetic ferro-silicon which settles to the bottom of the melt. The product contains about 95% of alumina.

The cooling of the "pig" must be controlled carefully to produce the type of crystal most advantageous to the desired fracturing during the later crushing processes. The wheel manufacturer, for example, desires a grain roughly cubical in shape but with sharp, jagged edges. The manufacturer of coated paper and cloth, on the contrary, desires a grain like a spear point in order to produce a sharper, cleaner-cutting surface.

Another abrasive of greater purity (about 99% Al_2O_3) and decidedly more brittle, may be prepared by refining the mineral corundum or by fusing purified bauxite in the form of Bayer alumina, using the same type furnace.

Grain intended for the polishing trade is given a final roasting at about 650°C (1200°F) to maintain the "capillarity" of the grain. This is a surface quality which, if not maintained, seriously impairs the adhesion of the glue to the grain.

Boron carbide (B_4C) is an artificial abrasive which is relatively new in the industry. It was brought out by the Norton Company laboratories in 1934. However, it had been known for many years that a carbide of boron could be made in small quantities and that it had desirable properties. In citing Moissan's original work, the International Critical Tables give the formula as B_6C. Its hardness is greater than that of silicon carbide, but less than that of the diamond. The density is 2.52, and the coefficient of linear thermal expansion 4.5×10^{-6} per °C or just a little lower than that of SiC.

B_4C is made in the resistance-type furnace similar to that used in the SiC process, and the raw materials are coke and dehydrated boric acid. Norton Company literature states that the maximum temperature in the furnace is about 2750°C (4980°F), under which condition carbon replaces oxygen in the boric oxide and the resultant combination fuses and recrystallizes to form the abrasive B_4C.

Manufacture of Abrasive Products

There are four main classes of bonds - (vitrified, silicate, rubber and resin) and two general processes - (casting and pressing).

Casting. -- Although once an important method of fabrication, casting has been largely replaced by the pressing process. The cast (or puddled) wheel is made with the vitrified bond using either SiC or Al_2O_3 grain. For the SiC, a bond relatively low in fluxes is used, probably for two principal reasons: (a) to maintain a low thermal expansion approaching that of the grain; and (b) to prevent the grain being attacked by combination of the fluxes with the SiC. An average bond would contain about 45% of feldspar, 20% of flint, and 35% of clay, while a typical bond for the alumina grain would be about 25% of feldspar, 25% of ordinary clay, and 50% of "slip clay."

The bond, grain, and water are thoroughly mixed in especially designed blungers, and in the deflocculated condition to facilitate removal of air bubbles. After thorough mixing, the batch is flocculated, in order to produce sufficient "stiffness" to keep the grain in suspension, and run into sheet iron forms set on plaster slabs, proper allowance being made for shrinkage during drying and later forming. The blanks are next dried, preferably under automatically-controlled humidity and temperature, and then "shaved" to their approximate final shape and size on modified potter's wheels. Special contours, recesses, etc., are made at this time.

To duplicate wheels of certain cutting qualities, and obtain freedom from internal stresses, it is of paramount importance that the blanks be matured with the greatest care. Periodic kilns require about 100 hrs to reach the maturing temperature (1250°C, 2280°F, or higher) following as closely as possible an established heating schedule, and the cooling is carried out with equal care. Consequently, the wheels are in the kiln about 2 weeks. Modern tunnel kilns have decreased this time to 3 or 4 days, partly because of closer temperature control and partly because of the reduction in "kiln furniture."

After removal from the kilns, the wheels are finished to size. This is accomplished with hardened steel conical cutters, and softer wheels may be ground with other wheels of harder grade. Arbors and faces are turned concentric (when necessary, the arbors are lead-lined) and the wheels are tested for static and dynamic balance before their final "speed test" prior to shipment.

Pressing. -- Vitrified, silicate, rubber and resin-bonded products are made by pressing, or a combination of rolling and pressing. By careful control, the pressing process may be utilized to produce rather nice gradations of structure which are not possible by casting. Also, the time saved in drying and machining to size makes this the more desirable method.

The vitrified bond does not differ essentially from that used in the casting process, and the basic procedure is the same except that pressing is substituted for the time-consuming steps of casting, drying and shaving.

The silicate-bonded product derives its name from the use of sodium silicate. The grain (usually corundum) is uniformly coated with a mixture of filler (flint, feldspar, clay, etc.), zinc oxide, and silicate. The wheels usually are formed in hardened steel molds by pressing under 1 or more tons per square inch pressure (similar to the "pressed vitrified process"), but cylinders and odd shapes are hand-tamped. These formed shapes are dried, and matured in ovens at from 200 to 240°C (390° to 465°F) in about 20 hrs. In this bond the zinc oxide enters into combination with the sodium silicate to form an insoluble compound, the composition of which may be $ZnO.Na_2O.2SiO_2$.

Rubber-bonded wheels are made by thoroughly mixing the grain, pure raw rubber, sufficient sulphur to produce a "hard" vulcanization, fillers, and possibly small additions of special organic chemicals to act as plasticizers and to prevent aging of the rubber. Steam-heated calenders knead the mixture into sheets from which discs of the desired diameter are cut. Thick wheels are made by pressing together a stack of these discs.

The discs, or wheels, are then vulcanized at about 170°C (340°F) in 8 to 10 hrs. The thin cut-off type of wheel, which is made from a single sheet rolled to the desired thickness, is practically ready for shipment when removed from the vulcanizer. Thicker wheels may require some machining to the required diameter and thickness.

Resin-bonded wheels are of two types--natural resin (shellac) and synthetic resin (such as the phenol-formaldehyde condensation products).

The shellac-bonded (or "elastic") product is made in two steps. First, the grains are coated in a steam-heated kneading machine with shellac containing rosin or similar adulterants, and then mixed with sulphur, talc, plaster or some other fine-grained friable filler, after which the "gooey" mass is cooled and crushed. In the second step, the coated grains are placed in steel molds of the proper size for the wheel to be made. They may then be cold-pressed, or again brought to a sticky condition by heating and pressed under about 1 ton per square inch. Final "curing" is at about 180°C (355°F), the total heating and cooling cycle being 40 to 50 hrs. (Small shapes, and thin wheels, may be hand- or machine-rolled instead of pressed, and are cured in less time.)

The second type of resin-bonded product is commonly referred to as a "Bakelite" wheel. To manufacture such a wheel, the grain is wetted with a so-called solvent for the resin and then thoroughly mixed with the powdered resin (which is in an intermediate or "B" state of polymerization and is still thermoplastic) which becomes sticky and uniformly coats the grains. This operation is preferably carried out in an atmosphere of controlled humidity; which observation applies also to the storage of the resin because it is strongly deliquescent and absorbed moisture will affect its properties as well as the qualities of the product.

The grains, having been coated, are next compressed in appropriate steel molds under pressures from 1/2 to 2 tons per square inch, and cured. The curing requires about 2 days (heating only) and the maximum temperature is about 200°C (390°F). During this curing, the resin is heated sufficiently to cause transition from the "B" to the "C" stage, but higher temperatures would cause charring and must be avoided. Experimental work with dielectric heating is meeting with some success.

There are dozens of additional bonds (hydraulic and oxychloride cements, and many combinations of varnishes, shellacs, bituminous materials, vitreous enamels, etc.), but they cannot be considered as more than oddities. Also, the casting process and the shellac bond are rapidly being displaced.

All in all, there are about 5,000 possible or regularly used bond and grain combinations. Fortunately, not every grain size is made in every grade or with every bond. Consequently, the actual number of different wheel compositions regularly passing through the plants of the larger manufacturers is approximately 1,400, each of which the producer must be ready to duplicate in quantities of one or of one thousand.

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REVUE GENERALE DE MECHANIQUE - 6 Av. Pierre, 1-de-Serbie,
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ZEITSCHRIFT VEREIN DEUTSCHE INGENIEUR, V.D.I. Verlag G. mbH
Ingenieurhaus, Prinz-Georg-Str. 77
Düsseldorf, Germany.

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Treasury Dept. Specification No. 371 for Abrasive Wheels.

U.S. Navy Dept. Specification No. 40W-1f for Abrasive Wheels.

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