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ABRASIVES AND ABRASIVE PRODUCTS

The abrasive industry supplies material for two major operations: One is for grinding and polishing with unbonded abrasive, or with so-called "set-up" wheels carrying abrasive bonded with glue, the wheels being made in the user's plant; the other operation requires the preformed shape. The unbonded materials are referred to as "abrasive," or as "grain," and the bonded shapes "abrasive products."

Manufacture of Abrasive Grain.

Prior to 1934 there were only two artificial abrasives, silicon carbide and corundum, and these will probably continue to predominate in the field for some time.

Silicon carbide (SiC) was invented in 1891 by E. G. Acheson (1856-1931) and is known universally as carborundum, although the term originated strictly as a trade name. Scientifically the compound 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, and hardness 9.5 in the Moh scale. It is characteristically brittle.

SiC is made in furnaces roughly 45 ft. long by 10 ft. wide by 10 ft. high, producing from 8 to 10 tons per heat, and sells at about 15 cents per pound. The charge consists of 56% glass sand, 35% low ash petroleum coke, 7% sawdust, and 2% NaCl. This charge is packed around a conductor of granular coke approximately 3 ft. wide by 1 ft. high. The heat is started with a current of about 6000 amps at 230 volts and, as the temperature of the charge is increased, the amperage is built up to 10,000 at about 150 volts. Operating temperatures will range from 1900 to 2100°C, although the center of the furnace is above 2200°C as evidenced by the formation of graphite. Reactions are completed in 36 hours and, during that time and in that portion of the furnace where proper temperatures were obtained, the sand and coke are assumed to gassify and combine, while the NaCl forms volatile chlorides with impurities and escapes through the pores left by the burned sawdust. A good grade of SiC will contain approximately 69.6% combined silica, 0.1% free silica, 29.4% combined carbon. The following equations presumably represent the reactions:

$$SiO_2 + 2C = Si + 2CO$$
$$3\ Si + 2CO = 2SiC + SiO_2 \text{ vapor.}$$

Artificial Corundum (alpha - Al_2O_3) produced 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. It is known commonly as alundum, a trade name practically as well established in the language as is carborundum.

It is supposed to crystallize in the rhombohedral system, the crystals are usually described as uniaxial negative in character, average index of refraction 1.76 +, density 4, and hardness 9 +, and the average linear thermal expansion about 8.0×10^{-6}.

It is produced in steel-lined, water-cooled, 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 8 to 10 ton. About 36 hours are required to fuse this amount of material and the current consumption is about 5000 amp at 100 volts.

Typical bauxite averages about 50% Al_2O_3 and 8% SiO_2. It is calcined to remove the chemically combined water and about 5 parts are mixed with 2 parts of iron turnings and 1 part coke. 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 ferrosilicon which settles to the bottom of the melt.

The cooling of the "pig" must be controlled very carefully to give the type of crystal growth productive of the most advantageous 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.

Corundum made from bauxite contains, on the average, 95% Al_2O_3, 3% TiO_2, 1.5% SiO_2 and 0.5% Fe_2O_3. These impurities are probably in solid solution. The material is characteristically tough, presumably caused by the titanium.

Another material of greater purity (about 99% Al_2O_3) and decidedly more brittle, may be prepared by refining the mineral corundum, using the same type furnace.

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

Boron carbide (B_4C) is an artificial abrasive which is new in the industry. It was brought out by The Norton Company laboratories in 1934. However, it has 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} or just a little lower than that of SiC.

It is made in the resistance type furnace similar to 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, 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.--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; (b) to prevent breaking down the grain by combination of the fluxes with the silica. An average bond would contain about 45% feldspar, 20% flint, and 35% clay, while a typical bond for the aluminous grain would be about 25 percent feldspar, 25 percent ordinary clay, and 50 percent "slip clay."

The bond, grain, and water is 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 heated with the greatest care. Periodic kilns require about 100 hours to reach the maturing temperature (1250°C 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 two weeks. Modern tunnel kilns have decreased this time to 5 or 6 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 the pressed process, or a combination of rolling and pressing. By careful control the pressing of wheels 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 make this the more desirable method.

The vitrified bond does not differ essentially from that used in the casting process, and the entire procedure is practically 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.), ZnO, and silicate; formed in hardened steel molds by tamping, or pressed under 1 or more tons per square inch pressure (similar to the pressed vitrified process); dried; and matured in ovens at from 200 to 240°C in about 20 hours. In this bond the ZnO enters into combination with the sodium silicate to form an insoluble compound, the composition of which may be 1 ZnO 1 $Na_2O.2SiO_2$.

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 colanders 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 in 8 to 10 hours. 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 artificial 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, mixed with rosin or similar adulterants, and with sulphur, talc, plaster or some other fine grained friable filler; the "gooey" mass is then cooled and crushed. In the second step the coated grains are placed in steel moulds of the proper size for the wheel to be made; again brought to a sticky condition by heating; pressed under about 1 ton per square inch; and finally "cured" at about 180°C, the total heating and cooling cycle being 40 to 50 hours. (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 a bakelite 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 polymarization and is still thermo-plastic) 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.

Having coated the grains they are next compressed in appropriate steel moulds under pressures from 1/2 to 2 tons per square inch, and cured. The curing requires 2 days (heating and cooling) and the maximum temperature is about 200°C. During this curing the bakelite is heated sufficiently to cause transition from the "B" to the "C" stage, but higher temperatures would cause charring and must be avoided.

There are dozens of additional bonds (hydraulic and oxy-chloride cements, and many combinations of varnishes, shellacs, bituminous materials, vitreous enamels, etc.), but they cannot be considered as more than oddities.

All in all, there are 5040 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 1400, each of which the producer must be ready to duplicate in quantities of one or of one thousand.

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