FRANKLIN INSTITUTE

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BAKELITE, A CONDENSATION PRODUCT OF PHENOLS AND FORMALDEHYDE, AND ITS USES.

BY

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[Bakelite is a liquid compound of phenol and formaldehyde which on solidification resembles amber in appearance and when used in combination with wood, paper, asbestos, graphite and other substances produces a solid non-resistant, non-inflammable insulating material which promises to have many applications in various industries.]

It has long been known that formaldehyde may react upon phenolic bodies in various complex ways resulting in products very unlike in chemical and physical properties. Some of these so-called condensation products are soluble in water; under some conditions they become crystalline, under others amorphous and resin-like.

The product to which the name "bakelite" has been applied is of the latter type. It is a most inert body being infusible and insoluble in all ordinary solvents and capable of withstanding the action of almost all chemicals. It resembles, somewhat, in some of its properties, amber, hard-rubber, and the celluloids.

The history, the chemical considerations, and the experimental investigations, that led to the production of a material of commercial value have been described at length in previous papers and, therefore, will not be considered at this time.* The mode of preparation, however, having an intimate relation to its possible applications, must be briefly reviewed.

The preparation of bakelite may be carried on in a single operation or in several stages, each stage furnishing a product having distinct properties. Ordinarily three stages of transfor-

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mation are employed in each of which the material acquires distinct properties. In these successive forms it may be designated respectively, bakelite *A*, bakelite *B*, and bakelite *C*. The preparation of these condensation products *A* and *B*, and their ultimate transformation into *C* for technical purposes, constitute the bakelite process.

Bakelite *A* is prepared by adding to about equal amounts of phenol and formaldehyde a small quantity of an alkaline condensing agent and gently heating. The mixture separates into two layers, the upper, a supernatant aqueous solution; the lower, a layer of heavy liquid which is bakelite *A*.

There may be thus obtained, at will, either a thin liquid called *thin A* or a more viscous mass, *viscous A* or a *pasty A* or even, if the reaction be carried far enough, a *solid A*.

The condensation agents best adapted to the reaction are alkaline salts, or salts, which in hydrolyzing split into weak acids and strong bases such as sodium acetate, the alkaline carbonates, borax, sodium sulphite, etc. These must be employed in relatively small quantities to secure the desired results. Acid condensing agents may also be employed but these result in the formation of soluble and fusible resins while the bases yield an insoluble and infusible product. Moreover, as there may remain in the final product traces of the condensing agent, the advantage of employing a base rather than an acid is obvious.

At ordinary temperature, *A* may be liquid or viscous or pasty or solid. It is soluble in alcohol, acetone, phenol, glycerine and similar solvents. It is also soluble in NaOH. Solid *A* is very brittle and melts if heated. All varieties of *A* heated long enough under suitable conditions, will change first to *B* and finally into *C*.

B is sold at all temperatures, brittle and somewhat harder than *A* at ordinary temperatures. It is insoluble in all solvents but may swell in acetone or phenol without entering into complete solution. If heated it does not melt but softens decidedly and becomes elastic and somewhat rubber-like and on cooling becomes again hard and brittle. Further heating under suitable conditions changes it into *C*. Although infusible, *B* can be molded under pressure in a hot mould to a homogenous coherent mass which can be further changed to *C* by the proper application of heat.

C is infusible in all solvents, unattacked by acetone, indifferent to ordinary acids or to alkaline solutions and yields only to the action of boiling concentrated sulphuric acid and to nitric acid. It does not seriously soften if heated and the temperature may with safety be raised to 300° C. At much higher temperature it chars without entering into fusion.

Bakelite *C* is an excellent insulator both of heat and electricity and has a specific gravity of about 1.25. It is very hard and cannot be scratched with the finger nail, in which respect it is far superior to shellac or even to hard rubber and celluloid but lacks the great elasticity and flexibility of hard rubber and celluloid, and this is its most serious drawback.

Bakelite *A* heated above 100° C. without any precaution produces a spongy mass of *C* due to the evolution of gases from the decomposition of the condensation product. This is entirely avoided by heating the product in a bakelizer, a closed vessel subjected to an air pressure of 50 or, better, 100 lbs. per square inch and a solid homogeneous mass of bakelite *C* of the exact shape of the recipient is assured.

Instead of pouring liquid *A* into a mould to form an object of the desired shape of solid bakelite, it may be applied as a coating to an object of different material, such as wood, which, after treatment in a bakelizer, acquires a hard brilliant coat of bakelite, superior to any varnish or the most expensive Japanese lacquer. Better still, by using a more liquid form of *A*, soft wood may be impregnated with it resulting, after bakelizing, in the equivalent of a very hard wood, proof against dry rot, dilute acids, water, and steam. Indeed, in this application to the transformation of cheap soft woods with a material having the properties of the most expensive hard wood, the process promises most fruitful results.

As a binder for all inert filling materials such as sawdust, woodpulp, asbestos, bakelite has a wide field of application. Among the more impressive applications of this class may be mentioned its use in the manufacture of grindstones and again in the manufacture of oilless bearings of which the aggregate is graphite. Mixed with fine sand or slate dust it can be applied in the form of a dough to the inside of metallic pipes, containers or pumps, which, after bakelizing, produces an acid-proof lining very useful in chemical engineering. Among other applications

may be named, steam and acid-proof valves and steam packings, phonograph records and the thousand and one other articles of domestic and industrial utility now made of hard rubber, celluloid or kindred substances.

In the electrical industry bakelite has already received the test of some actual use. There too its possible applications are numerous. Armatures and field coils of dynamos and motors instead of being treated with ordinary resinous varnishes can be impregnated with *A*, which treated in a bakelizer becomes a solid, infusible, insulating mass. This may ultimately permit an increase of the allowable overload in motors and dynamos by eliminating the possibility of the melting or softening of such insulating varnishes as are now used. This part of the subject has not, as yet, received more than preliminary investigation, and, for the present, may be dismissed for a consideration of what has already been achieved in the production of moulded insulators, which have been manufactured successfully for several months.

The element of time is a most important feature in moulding operations. To insure economy of manufacture, the moulds whose first cost is generally high, must remain in use not longer than a determinate time for each piece moulded. For that reason the methods that are employed require the use of the mould for the very minimum of time.

As stated above the use of bases permits the production of a variety of *A* that is solid though still fusible. This is as brittle as ordinary rosin and can be pulverized and mixed with suitable filling materials. A mixture of this kind is introduced in a mould and subjected to pressure at a temperature ranging from 160° to 200° C. The bakelite *A* melts, impregnating the filler and at the same time is rapidly transformed into bakelite *B*. The latter, as has been noted, is infusible and the object moulded can therefore be expelled from the mould without changing its form after a very short time and the mould can now be refilled. The moulded articles now in condition *B*, may at any convenient time be placed in the bakelizer without the use of any moulds and finally transformed into bakelite *C* of maximum strength, hardness, and resisting power.

For electric insulators which are subjected to high temperatures, mineral fillers such as finely ground asbestos, clay or mica should be used. If the temperature specifications are not im-

portant, organic fillers like woodpulp or ground sawdust are available and furnish suitable moulding compositions of which the insulating coefficient is frequently higher than that of asbestos.

Not enough experience has yet been gathered to determine the relative merits of porcelain and bakelite-asbestos or bakelite-mica insulators for high voltage insulation. But for insulation in third-rail systems where the vibration of passing trains is very destructive to the porcelain, bakelite-asbestos has indicated decided superiority after several months of continuous service as well as by direct laboratory tests. Besides greater strength it has shown more regularity in manufacture and allows more accurate moulding, permitting closer designs with a smaller margin of safety. It has the further merit that there is no difficulty whatever in imbedding metallic parts like bolts, cores, screws, washers or reinforcing members in the moulded mass.

The tables which follow are condensed from some comparative results communicated by users of bakelite who previously had acquired great skill in the manufacture of other excellent insulating compounds.

MECHANICAL STRENGTH TESTS.

No.	Name of piece.	Bakelite.	Remarks.
2	Square tube Thickness .103 inches...	Transverse strength, 6-inch centres, 1850 pounds	Asbestos hard-rubber composition 1700 pounds.
8	Rail insulator	Ultimate strength compression 96,000 to 110,000 pounds Ultimate strength tension, 3200 to 5500 pounds Impact test, no limit found for same blow as porcelain was submitted to	Porcelain 45,000 to 85,000 pounds. Porcelain 1400 to 2300 pounds. Porcelain 38 to 100 blows.
9	Cup piece, hollow cylinder 3 inches high, 1½ inches diameter, .045 inch thick	Ultimate compressive strength 2550 pounds	Loaded on top.

HEAT TESTS.

No.	Name of piece.	Bakelite.	Remarks.
10	Valve interior	At 265 pounds, steam about 460° Fah. for one hour	No effect on the composition.
11	Packing nut graphite composition	Tight at 65 pounds, steam 200 r. p. m.	Could turn 3 inch shaft by hand.

ELECTRICAL TESTS.

No.	Name of piece.	Bakelite.	Remarks.
1	Spool	Punctured at 16,000 to 18,000 volts	Asbestos hard-rubber composition punctured at 4000 to 8000 volts.
2	Square tube Thickness .103 inch	Punctures at 21,000 volts.....	Asbestos hard-rubber composition punctured at 17,000 volts.
3	Washer Thickness .062 inch	Punctured at 20,000 volts.....	Asbestos hard-rubber composition punctured at 11,000 volts.
4	Dises of various compositions Thickness .0625 inch Thickness .162 inch Thickness .165 inch Thickness .375 inch	Punctured at 45,000 volts..... Punctured at 31,000 volts..... Punctured at 22,000 volts..... Punctured at 42,000 volts.....	These tests are still unfinished and were made on various bakelite compositions. None on pure bakelite.
5	Disc Thickness .095 inch	Punctured at 18,000 volts.....	Asbestos hard-rubber composition punctured at 1500 volts.
6	Cup insulator Thickness .375 inch	Punctured at 42,500 volts.	
7	Line insulator	Arc to pin, dry at 50,000 volts	Used on 11,500 volt line.
8	Rail insulator	Resistance dry, 5625 megohms Resistance wet, 0.5 to 65 megohms (These tests are only approximate in megohms) Arc over hook bolt to rail 27,000 volts	Porcelain resistance dry, 4550 megohms. Porcelain resistance wet, 0.2 to 10 megohms. Porcelain arc over 26,400 volts.

NOTE.—All of the bakelite insulation shows an unusual uniform resistance at varying temperatures from 0° to 300° Centigrade and does not soften at much higher temperatures. Most of the insulation contained about $\frac{1}{3}$ bakelite and $\frac{2}{3}$ finely divided asbestos.

SMOKE PREVENTION.

REPORT BY THE UNITED STATES GEOLOGICAL SURVEY.

Among the recent discussions of the smoke nuisance and waste, and their remedies, is a report of the United States Geological Survey numbered Bulletin 373, by D. T. Randall and H. W. Weeks, entitled "The Smokeless Combustion of Coal in Boiler Plants."

The burning of coal without smoke is a problem that concerns the Government directly because of the advantages of smokeless combustion in boiler plants installed in public buildings and on naval vessels, and the Survey's technical experts have therefore made careful and thorough tests to determine the conditions necessary to prevent smoke.

Studies were made in thirteen of the larger cities of the country, more than 400 plants have been examined. The report gives in detail the results of the observations made at these plants, together with the results of smoke tests and observations made at the Survey's fuel-testing plants at Norfolk and St. Louis.

The conclusions reached show that in properly constructed plants smoke prevention is possible and is economically desirable, though in ordinary boiler furnaces only coals containing large percentages of fixed carbon can be burned without smoke except by expert firemen. Of the existing plants some can be remodeled with advantage; others must continue to burn coals that are high in fixed carbon or to burn other coals with inefficient results and more or less smoke. To replace these inefficient plants with new, well-designed equipments is the only remedy for the loss and the nuisance they occasion.