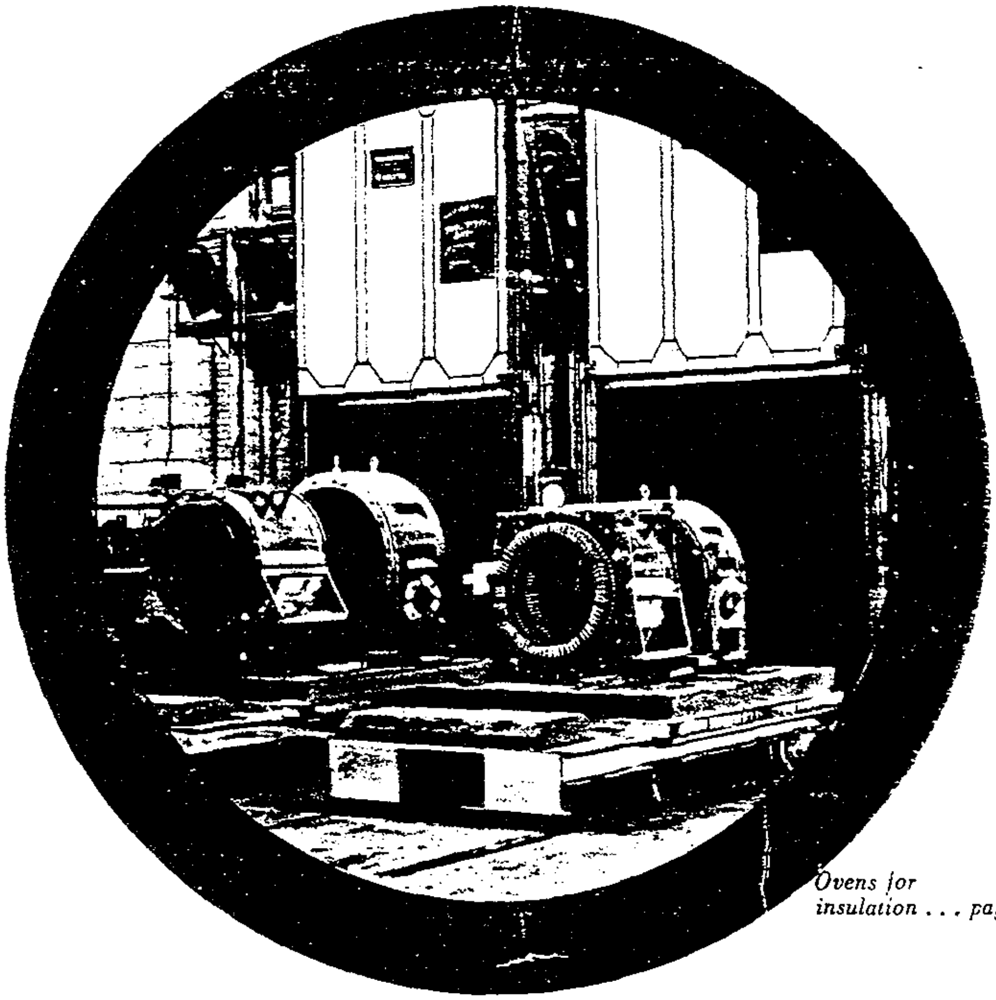
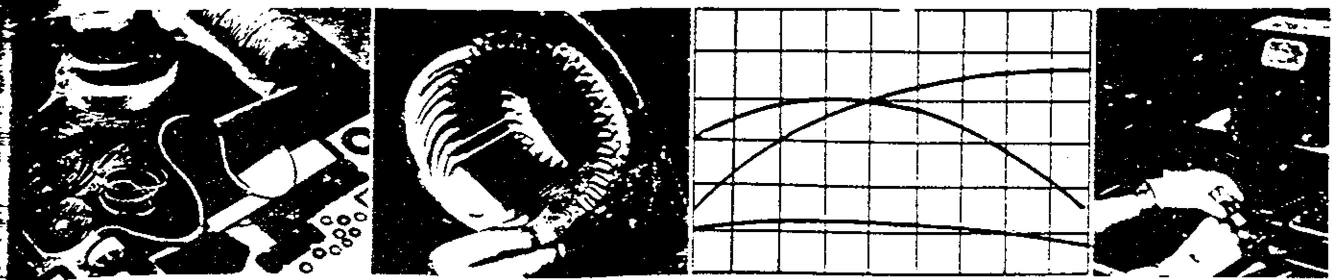
June 1956

PLAINTIFF'S EXHIBIT
E-35

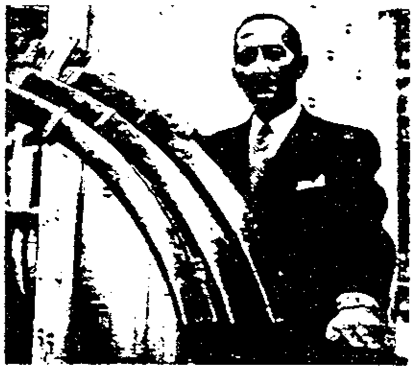
# Insulation



Ovens for insulation . . . page 7



# Basic Insulating Materials



*Fifth of a series of monthly articles on insulation engineering fundamentals by Graham Lee Moses, Manager, Insulation Development Section, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania. Mr. Moses is widely recognized as a leading authority on insulation and is the author of more than 100 technical articles and papers as well as a book on electrical insulation. He has figured importantly in many insulation developments.*

There are a number of basic material components which are used either separately or as combinations in composite insulation products. The solid, non-resinous materials will be described individually in this article. Later articles will present information on liquid and resinous materials and composite products made from them.

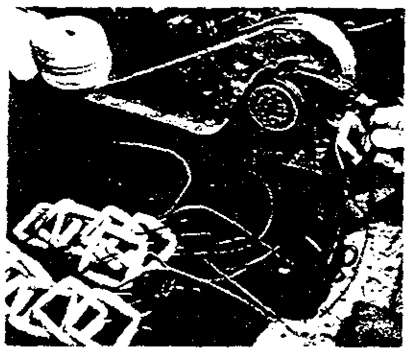
### Cellulose

Cellulose is a most important component of many forms of electrical insulation. In some electric equipment, it forms the major insulation while in many other kinds, it is an essential but minor component used in connection with a wide variety of other materials. Cellulose is used in the form of papers, yarns, cloths, and pressboard. The cellulose used in the electrical industry is mainly derived either from wood or cotton linters. Less important sources include flax, hemp, rice, and numerous other plant stocks. Old rags and rope are important secondary sources of cellulose. Wood contains from 40 to 60 percent cellulose, while cotton contains up to 90 percent. Cellulose consists of carbon, hydrogen, and oxygen in repeating polymeric units of a chain-like construction. It is frequently described as being a natural high polymer.

Cellulose has some very unique and desirable properties which include strength, flexibility, and elasticity. It is low cost and its good electrical and physical properties make it a most useful insulation when properly fabricated and impregnated. The processing is important since cellulose is a "thirsty fiber" and is highly moisture absorbent. Before it can be depended upon as good electrical insulation, it must be carefully dried and impregnated with oils, resins, or varnishes. Paper is the preferred form over cloth where dielectric strength is the primary consideration. The closely matted fiber structure of paper, when suitably impregnated, acts as a barrier to the free movement of ionic charges. On the other hand, where great mechanical strength is the primary consideration, the relatively stronger cotton cloths are more desirable.

It is important to consider the disadvantages that are inherent in cellulosic materials. These include: (a) low thermal stability, especially at elevated temperatures; (b) moisture sensitivity; and (c) the need for impregnation with a liquid or resin to obtain acceptable electrical properties. Moisture sensitivity is perhaps the greatest limitation, consequently cellulosic materials should never be used in important electrical applications without very thorough pre-drying followed by thorough impregnation. Impregnation does more than seal the fibers against moisture absorption. By replacing the air normally in the fiber interstices, the dielectric strength of all insulation is materially improved. For example, impregnated paper and pressboard is often found to have short time 60 cycle dielectric strength as high as 1,000 volts per mil with impulse levels several times that value. The poor thermal stability of cellulose poses a much more difficult problem. Therefore, cellulose is not usually employed where Class A temperatures of 105° C hot-spot are exceeded except for very short periods, usually intermittent, of operation. The thermal degradation of cellulose begins with the loss of some of the chemically combined water which embrittles and weakens the fibers. Then carbon dioxide and carbon monoxide are given off. All of these products of thermal degradation are objectionable. The water is harmful electrically and the oxides of carbon pose toxicity problems. Furthermore, the residual carbon is an excellent conductor and only a small amount of decomposition in cellulosic insulation locally can destroy the effectiveness of a piece of electrical equipment.

Cellulose fills an important place in electrical insulation in spite of these limitations. Its physical strength, ease of fabrication, convenience of use, and adaptability to commercial processes make it a highly desirable material not only by itself, but for use in combination with higher temperature classes. Small percentages of cellulosic material are permitted under AIEE standards in both Class B and H insulations, with the provision that it must be used only for structural purposes where its degradation does not seriously impair the ability of the composite insulation system to perform its intended function.



*Cotton tape used to insulate field coils. Portable Electric Tools, Inc.*

### Asbestos

Asbestos is a fibrous mineral sometimes called "serpentine" and "hornblende." It exists in many forms in varying physical and chemical properties. Chrysotile and Amphibole are the more important commercial types from which asbestos insulation is fabricated. The first is essentially a compound of silicate of magnesium, iron, calcium, and frequently some manganese. The second is similar except that it usually contains aluminum in addition. Commercial asbestos fibers obtained from different parts of the world will vary in chemical composition as well as in chemical and physical characteristics. For example, they differ considerably in flexibility and the contained waters of crystallization, physical properties, and color of the fibers. The nature and quantity of contaminants such as particles of iron oxide will be different as well as their ability to withstand acids and heat. Most asbestos fibers are heat resistant, but contain small amounts of hygroscopic moisture (usually about 2%). When they are dehydrated by excessive heating, they are embrittled and fragile. All asbestos fibers are poor electrical insulators unless they are thoroughly dry and protected against re-absorbing moisture.

Chrysotile asbestos from Canada is well suited for spinning because of the fineness of the fibers, good tensile strength, and flexibility. It may contain a considerable number of magnetic oxides of iron particles which are conducting and may cause electrical failures under certain conditions. It is susceptible to attack by sulphuric acid and hydrochloric acid. It is capable of withstanding temperatures up to 300° C without loss of strength. Above 400° C, as much as three percent water of crystallization may be lost in one-half hour. At 600° C and above, practically all its water of crystallization will be lost and it will become weak and brittle. Arizona Chrysotile asbestos contains considerable less magnetic oxide of iron and is used for certain electrical grades of asbestos paper. While it can be spun into yarn, it is weaker and more brittle than the Canadian type.

Amphibole asbestos is a much more heat resistant type; it may withstand temperatures as high as 1,000° C without serious degradation. It is relatively resistant to hydrochloric and sulphuric acids. The electrical resistance of Amphibole may be improved by treating it with boric acid solution with distilled water.

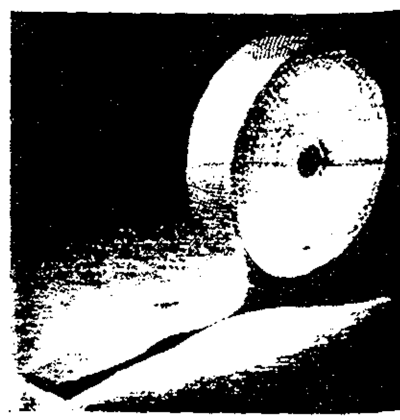
Crocidolite asbestos from Africa is different in chemical composition from either of the other types of asbestos described and is much more resistant to sulphuric acid, but harsher and more brittle than Chrysotile.

In recent years, improved mechanical and chemical processes have made asbestos fibers available in more desirable forms. They are now used in smaller dimensions with tremendous reductions in the number of impurities and conducting particles compared to what was feasible in the past. These purified fibers are combined with binders and fillers by new paper making processes. The resulting paper-like materials have many uses in electrical apparatus. These asbestos papers compare favorably with cellulosic paper in thickness and flexibility. They can also be treated with organic and silicone resins which improve their electrical properties. Asbestos in these forms is mainly used for wire covering and for insulation between the turns of strap coils.

### Fiber Glass

Glass is an excellent electrical insulation, but in the forms commercially available before 1935, it was not suitable for the insulation of coils and wire, such as used in electric machinery. In plates, moldings, and castings, glass appears to be a hard, brittle, vitreous material and has very definite and rather narrow limits as to where it can be used as electrical insulation. With the commercial production of glass in thin flexible monofilaments, a vast new field was opened to its use as electrical insulation. Fiber glass has many very desirable characteristics. It possesses great physical strength, moisture and chemical resistance, and outstanding thermal endurance. The science of spinning glass into threads for textiles is not very new as patents date as far back as 1890 covering the insulation of magnet wire with glass fibers. The mass production of thin glass monofilaments in flexible form made the present widespread use of fiber glass insulation possible.

It was early found necessary to develop a special formulation of glass called "electrical grade" for use in the

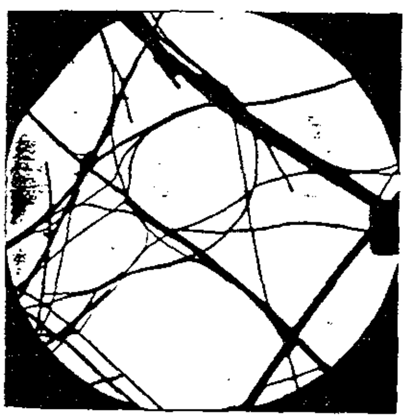


*Fiber glass woven into tape form.*

ers employed as electrical insulation. two major forms of fiber glass ns used for electrical insulation are "continuous filament" yarns and "staple fiber" yarns. The contin filament yarns are the most comonly used for both wire and cable ulations and for woven fabric products.

For continuous yarns, the filaments mechanically drawn from molten glass and can be compared in appearance to natural silk or linen. Staple fiber yarns are produced from short length glass described as "slivers" and are made by drafting and twisting these slivers together in a fashion similar to the production of cotton yarns. The individual sliver fibers usually have a length of about nine inches and may be as long as fifteen inches. The staple fibers are produced by the gas blast drawing of molten glass which are then collected on a drum and spun into yarns. Since glass fibers abrade themselves in their raw state, it is necessary to add a small amount of lubricant to the fibers to permit their subsequent processing without damage. The lubricants added to glass fibers correspond to the natural oils present in organic fibers in minimizing friction between fibers, thereby reducing fiber breakage and abrasion.

Staple fiber and continuous filament glass yarns are made with fibers of several different diameters, but with relatively good control of the specific diameters. Various types of yarn differ in the number and diameter of the individual filaments used in their construction. Woven products have different characteristics of strength, flexibility, and fuzziness depending upon the type of filament, number of filaments in individual yarns, and the weaving and braiding processes. Larger diameter filaments can be produced at a higher rate and are hence lower in price than the finer filaments. However, very thin fabrics may require the use of the finest filament sizes in order to have thinness, flexibility, and strength. The yarn characteristics and their effect on cost must be considered in the proper selection and application of fiber glass yarns and woven products.



*Electron micrograph of glass fiber paper developed by National Bureau of Standards.*

Fiber glass has many excellent characteristics which make it desirable for use as electrical insulation. These can be summarized as follows:

1. Excellent thermal endurance. Since glass is inorganic and unaffected by normal operating temperatures in electric machines, the basic fibers have no established temperature limit. The limit of operating temperature of finished products is dependent upon the type of resinous treatment employed.

2. Moisture resistance is outstanding as water is not absorbed into the structure of the filaments. Water will collect on the faces and between the filaments and its exclusion is a problem of selection and application of resinous treatment.

3. Great chemical resistance is inherent in electrical grade fiber glass. No other fibrous material has comparable general chemical resistance.

4. Superior mechanical strength is comparable with that of steel on an individual fiber basis. This permits the use of thinner fabrics where physical strength is the primary consideration.

5. Improvement in space factor for insulation is attainable because of the improvements in physical characteristics. This is often a distinct economic advantage in comparison with both cellulose cloth and asbestos cloth.

No new material such as fiber glass is completely free from limitations. It is desirable therefore, to understand some of the problems which face the insulation designer and must be considered in its use.

1. Glass filaments without any lubricant or resinous treatment are abrasive and may cut each other under physical pressure or movement. To handle them successfully in textile operations, a small amount of lubricant must be immediately applied to the filaments as they are formed. With this lubrication, such glass fibers can be handled very much as conventional textile materials are fabricated. However, if the lubricant is destroyed, the glass filaments will readily abrade. The abrasion resistance of woven fabrics is very greatly improved further when the fabrics are treated with varnishes. In some cases, it is necessary to remove the initial lubricant from the filament of a fabric in order to apply certain types of resinous treatment to the cloth. Heat cleaning and chemical cleaning of the glass fabrics are frequently employed before glass cloths are coated with silicone varnish. This is important, for the original filament lubricants do not have comparable thermal stability to the silicone varnishes and processing varnishes over these lubricants may result in an inferior product.

2. Glass fabrics must be recognized as primarily providing spacing insulation just as cotton cloths do. There is no inherent dielectric barrier effect in the glass cloth. Like cotton cloth, fiber glass cloth can only become a dielectric barrier when it is suitably impregnated and coated with a resin. Thus the dielectric barrier action of fiber glass fabrics must be attributed to the resin treatment selected and the technique of processing used. Furthermore, the thermal endurance of such a fiber glass cloth is likewise dependent upon the resinous treatment and not upon the glass fabric itself. Therefore, in all glass cloth for high temperature insulation, care and thought must be given to the type of treatment and processing.

## Synthetic Textiles

Recently, numerous synthetic fiber textiles have been introduced as electrical insulation. These are either continuous monofilaments of resins, or short fibers made of resins, that are spun into threads and woven into fabrics. They have the dielectric limitation of all fabrics—not being dielectric barriers unless varnish coated. Thermally, these materials lie between cellulosic fabrics and glass fabrics, and depend on the nature of the resin coating more than upon their own characteristics for their life expectancy.

## Mica

Mica includes several forms of mineral silicates which were crystallized during their formation under tremendous pressure while cooling very slowly from the molten state. There is preferential orientation of the crystalline structure producing thin parallel laminae. Mica derives its outstanding electrical and physical properties from the existence of these laminae which permit its fabrication into these exceptionally thin, flexible, elastic members. The mineral mica is found in many forms and qualities, and exists in many parts of the world mixed with clay, feldspar, and quartz. Of the seven recognized varieties of mica, only muscovite and phlogopite are of industrial importance, especially in electric equipment. Muscovite mica is commonly called white or ruby mica and is found in a coarsely crystalline intrusive igneous rock known as pegmatite. Phlogopite is commonly referred to as amber mica and occurs in somewhat similar rock except that it is associated with limestone and is basic in chemical reaction. India is the primary source of muscovite mica for commercial use in electrical insulation. There are considerable deposits of muscovite in the United States, Mexico, and South America. Phlogopite is a hydrogen potassium magnesium silicate. Both contain water of crystallization with about 4.9% in muscovite and 3.2% in phlogopite.

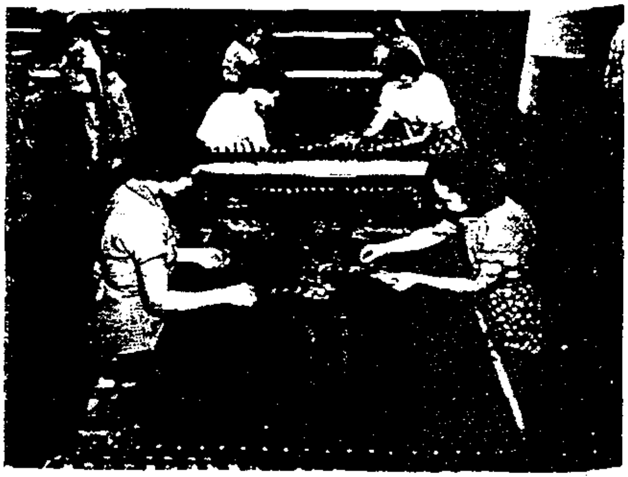
Mica is a unique material which has great value as electrical insulation because of its electrical, mechanical, and chemical properties and *the form in which it is available as an engineering material*, i.e., thin flexible films of high dielectric strength and great thermal stability. It is one of the earliest materials used for insulation in the electrical industry and has maintained its position under severe competitive conditions against the inroads of other natural materials and many modern synthetics. Mica splittings have high dielectric strength and low dielectric loss combined with very high surface and volume resistivity, being infusible and non-inflammable. Mica is one of the very best insulating materials in thermal endurance. When heated beyond its safe temperature limit (well above 500°C) mica dehydrates and subsequently calcines, thus becoming opaque and silvery and losing its mechanical strength and dielectric properties.

Chemically, mica is relatively inert as it is unaffected by conventional solvents, water, alkalies, and acids (except sulphuric and hydro-fluoric acids). Mica should be protected from many oils as they may be absorbed into the laminae and produce further separation and splitting. Mica possesses high shear and tensile strength in a direction perpendicular to the laminae, but is weak in the opposite plane and may easily be split into very thin flakes and platelets. Electrically, mica owes its outstanding properties to the form in which it occurs in nature which permits fabrication into thi flexible splittings with intrinsical high dielectric strength. As it occurs nature, mica is a crystalline structu capable of being split into thin di lectric barriers which lend ther selves to processing into composi insulating structures. These composi insulating products made of mic splittings frequently have dielectr strengths equal to 10 or more time the breakdown strengths of the equiv lent air spacing. Such high dielectri strengths can be maintained through out severe thermal aging when the mic splittings are properly combined wi suitable backing and bonding m terials.

The name mica is often applied all of the various forms of mica wheth thin flexible splittings, thick films, o powder. The simple term mica is al frequently extended to cover mic products which contain any of the forms in combination with the paper cloths, resin films, and bonds. It therefore desirable to differentiate be tween the various forms of mic materials as well as the products usin them when using the term "mica".

Mica was synthesized during Worl War II, but the cost is excessive fo most uses. Furthermore, there is n economical trained labor for splittin it in the Western Hemisphere. It i being used in special capacitors, an in mica-filled glass molded part where a rigid, brittle structure i acceptable.

Three processes have been develope for making paper-like sheets from



*Left. Raw mica splittings being inspected before any processing. Right. Book form mica splittings being fabricated into flexible mica wrappers.*

mica platelets using essentially conventional paper making machines. The platelets are produced by three different systems:

(a) Hydraulic pulsing jet.
(b) Mechanical grinding and roasting to partial dehydration.
(c) Grinding, chemical treatment, and roasting to a higher level of dehydration.

Usually the platelets are 0.0003 inches thick or less, and less than 0.1 inch in their largest dimension. Until resin treated, these are very fragile and difficult to handle. Their physical and electrical characteristics are completely dependent upon the resins used for bonding and coating. Products made from mica papers are now in commercial production; and are undergoing trial use in service and functional evaluation in numerous laboratories.

## Summary

The basic solid insulating materials reviewed herein have individually peculiar characteristics which make them well suited to specific uses and limit their use in other applications. None of the materials discussed are precisely interchangeable. In substituting one for another, their advantages and disadvantages must be considered carefully, and weighed in the light of engineering objectives and economic considerations.

Processing of the materials into their simplest commercial form is of great importance, but fabrication into finished insulation products and combination with resinous treatments is usually even more significant in producing the best insulations.

The early predominance of insulating materials is giving way, since insulation systems as a whole are now considered the major factors in electric equipment design.

*Article No. 6 to appear next issue*

## *One-Sided Conversation*

The defendant acknowledged that he hadn't spoken to his wife in five years, and the judge put in a question.

"What explanation have you?" he asked severely.

"Your honor," replied the husband, "I didn't like to interrupt her."

—*Reichhold Chemicals, Inc.*