PROPERTIES AND APPLICATIONS OF ENAMELLED WIRE.

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Enamel lacquer is an excellent insulation material for copper wires because of its high breakdown potential, its high electrical resistance, its slight absorption of water, its unusual thinness and its good mechanical and chemical properties. In this article details are given about these properties of enamel lacquered wire.

Introduction

In electrical engineering the term "enamelled wire" (more accurately "enamel lacquered wire") means metal wire which is insulated by a thin layer of hard baked lacquer. The name often leads to misunderstanding by laymen, who usually think of the glasslike enamel of pots and pans.

The first insulated conductors were made by Faraday when he carried out his pioneer experiments on electromagnetism. According to his diary of 1831 he used "twine and calico". Textiles are thus the oldest form of insulation for wires, and they are still employed on a large scale. Later Werner Siemens used gutta-percha und rubber, which have undoubtedly much higher insulation resistance, but which must be applied in much thicker layers. It is for this reason that insulation materials to be applied in the plastic state, such as rubber, gutta percha and various similar synthetic products of recent years, have no great practical significance for coils and windings. Cotton insulation is also relatively thick, so that the appreciably more expensive silk was often used. The idea, which originated in America around 1900, of applying a thin layer of a lacquer or varnish directly to the copper also was attractive from the point of view of expense.

The idea also was worked out in Germany about 1905. The first task was that of finding a lacquer which was resistant to the chemical influences acting during impregnation and use of the wire, and which in addition was elastic and strong enough for the purpose. Difficulties were encountered at the beginning in satisfying these chemical requirements, since black enamelled wire in particular is made with lacquers having an asphalt base which is not resistant to oil.

In 1906 it was stated [1]) that in Germany copper wire was being made with a coating of cellulose acetate and also of an enamel lacquer. This wire was at first intended for the coils of measuring instruments, etc. but was later available for small machines and transformers.

The early cellulose acetate coatings have almost entirely gone out of use. The lacquers with an asphalt base (for black enamelled wire) have become much less important: all black enamelled wire is not however made with an asphalt base lacquer. Modern enamelled wire is made with the help of oil lacquers. These lacquers consist of mixtures of resins and drying oils (for example wood oil and linseed oil, usually a large proportion of the former in order to produce quick drying, chemically resistant lacquers). Kienle and Adams [2]) give as an example the following composition: 60.5% wood oil, 18.3% raw linseed oil and 21.2% resin neutralized with lime; these components are heated together $1^1/_4$ hours at 270°C, then cooled to 160 ° C and mixed with 10 % benzine and 90% solvent naphtha. It is therefore a very "oily" lacquer, and the oils are already partially polymerized by heating. Of course every manufacturer of enamelled wire uses his own lacquer, the composition of which is usually not published. Artificial resins are also often used in these lacquers.

In the manufacture of enamelled wire a small amount of such a lacquer is applied to the surface of a bare copper wire. This may be done by drawing the wire vertically out of a lacquer container. The wire is then passed through an oven in which the lacquer is "baked". In this process, the polymerisation of the drying oils, which has already begun during the heating of the lacquer, is continued by the oxygen of the air. A strong, cohesive, insoluble layer is the result.

The resins provide for greater hardness of the coating, the (highly polymerized) oil content is responsible for the great elasticity. There is as yet no absolute certainty about structure of the polymerized oils. The properties of the polymer indicate a rubberlike structure, that is a network of quite large molecules are joined to each other at relatively few points. In oil lacquers this structure gives a practically insoluble whole, a fact which indicates very strong, probably chemical bonds at the few points of contact of the large molecules. The pres-

[1]) Electrotechn. Z. 27, 16, 1906.

[2]) R. H. Kienle and L. V. Adams, Ind. Eng. Chem. 21, 1279, 1929.

ence of the "rubber structure", however, includes the posibility of the swelling of the polymer in liquids whose molecules have the tendency to penetrate between those of the polymer. It may in general be said that great elasticity is very often accompanied by a tendency to swell in suitable liquids. This tendency is very slight with enamel lacquer, but is not entirely absent. Particularly in the case of an insufficiently baked lacquer coating is it noticeable (for instance in the presence of melted beeswax and also benzine at room temperature), it is at a minimum with a normally baked lacquer coating.

The application of fluid lacquer and the subsequent baking are repeated a number of times (sometimes 6 or even as many as 30 times), until the desired thickness of insulation has been reached. This is done by leading the wire as it comes out of the oven back to the lacquer container and so on.

The application of enamelled wire has become progressively more important in the last few decades. Not only thin and very thin wire (up to 25 microns core diameter; 40 micron wire is used to a large extent at present for high tension transformers) but also the thick kinds (for instance 3 mm core diameter) are at present employed everywhere for transformers, motors, coils, low current cables and connections (telephone installations). The product has at present almost a monopoly in the radio industry (transformers, coils, so-called stranded or "litz" wire), in other branches (motors, power transformers) it is steadily gaining ground. The reasons for this increasing application are the following:

a) The enamel coating has a very high breakdown potential.

b) It has a very high electrical resistance and the dielectric losses are not high.

c) The enamel is an unusually watertight material.

d) The insulation layer is unusually thin.

e) The mechanical properties of the coating satisfy rather high requirements.

f) The enamel coating is very resistant chemically.

We shall examine these characteristics one at a time in order to build up as complete a picture as possible of the final product.

a) Breakdown potential

The breakdown potential of the enamel layer itself may be said to be very high: namely of the order of 10^6 volts/cm for layers from 5 to 20 microns thick.

The breakdown potential of the insulated wire exhibits quite wide variation; the reason for this is that the condition of the metal surface exerts a tremendous influence on breakdown. This phenomenon, which is theoretically perhaps not entirely unexpected with such thin insulating layers, results in the fact that the condition of the bare wire is actually at least as important as that of the insulating layer.

The high breakdown potential of the material is not completely manifested in the finished product because of this influence of the metal surface. Nevertheless the breakdown potentials attained, compared with the thickness of the insulation, are still very high, as may be seen from the table below, in which several of the standard specifications of various countries are noted.

Breakdown potentials (in volts eff), minimum requirements according to the standard specifications of different countries for enamelled wire of various diameters and with an alternating voltage of 50 c/s.

Diameter of wire	Standard thickness of of enamel coating (approx)	Standard Specifications			
		DIN Germany	C 31 France	C 8.7 U.S.A.	BSS 156-Engl. (1936)
mm	microns				
0.1	6	350	150	200	200
0.5	16	500	400	700	1000
0.1	22	750	550	800	1200

The breakdown potential of the various standard specifications are not entirely comparable because the methods of determination differ rather widely. The American and English specifications determine the breakdown of two enamelled wires against each other, the others of one wire against polished metal. Division by two of this "double breakdown" in order to obtain a figure comparable with the other requirement is not permissible, because of the fact that the breakdown found as an average with enamelled wires with different thicknesses of insulation is far from proportional to the thickness of the insulation. This latter fact is again explained by the above-mentioned influence of the metal surface.

Wire with twice the standard thickness of coating exhibits about three times the normal breakdown potential [3]).

Fig. 1 which reproduces the result of a large number of determinations of breakdown (DIN method) on two different lots of enamelled wire of the same kind, gives an idea of the relatively wide

[3]) By the term breakdown value is meant the voltage which is withstood by 80% of the samples tested, in agreement with the German standard specifications.

variation which occurs as a rule in the determination of this property of enamelled wire. The small difference in the average thickness of the enamel layer found in samples which broke down

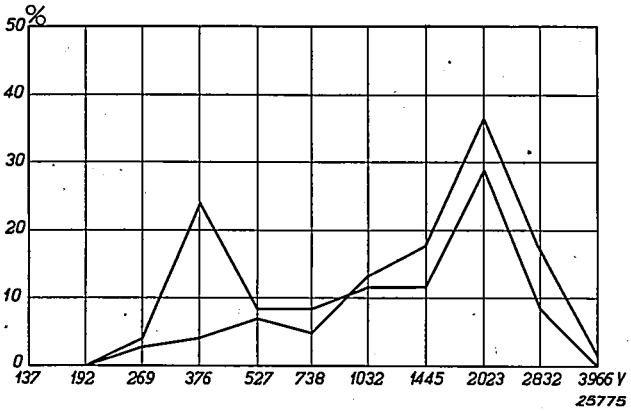

Fig. 1. Statistics of the breakdown potentials measured on two spools of different manufacture (about 60 measurements per spool). The wire was enamelled wire of 0.4 mm core diameter. The thickness of a single layer of lacquer was about 13 μ.

The method was that of the DIN: the wire was wound a bare polished cylinder of 30 mm diameter, and one end was weighted with 50 grams. A sinusoidal alternating voltage of 50 c/s was then applied between the copper wire and the cylinder, and gradually increased from 0 to the breakdown potential. E_{eff} was measured. The breakdown values found were then divided into groups in such a way, that each group begins with a voltage 1.4 times as great as the initial voltage of the previous group. The percentage of the total number of measurements in each group is plotted.

at widely different potentials, illustrates the fact stated above, that the thickness of the layer of lacquer is by no means the only factor which determines breakdown.

A comparison of the breakdown value of enamelled wire with that of ordinary kinds of wire insulated with textiles is of little value, considering the fact that the textile insulation of these wires, when tested in the unimpregnated condition, has a breakdown potential which is lower than that of the layer of air situated between the textile fibres. The spark travels along the fibres; a breakdown of the insulation material does not take place. This is also shown by the fact that the same breakdown potential may be measured repeatedly at a single point. For example, a wire of $^1/_2$ mm core diameter double covered with cotton (thickness of insulation 120 μ) has a breakdown potential of about 350 volts against a polished cylinder. If a textile wound coil is impregnated, the breakdown potential is somewhat higher, but is entirely dependent on the quality of the impregnation.

b) Insulation resistance and dielectric losses

The enamel layer itself has a very high resistance. With 1000 volts direct voltage on a meter of enamelled wire of $^1/_2$ mm diameter, immersed in mercury, a resistance of 10^{12} ohms is found if the enamel layer has no faults. With standard enamel wire, however, several faults per 10 m are permissible. Such faults are not usually "bare places" while the English expression "pinholes" is also incorrect, but they are spots with an unusually low breakdown potential. If there is such a spot on the wire immersed in mercury, breakdown occurs far below 1000 volts. Another kind of fault which may influence the insulation resistance under certain circumstances is demonstrated by immersion of the wire in water: in this case several otherwise entirely invisible faults are found to exist where the insulation resistance is lower. This holds however only for standard enamelled wire; with extra thick (so-called double-enamelled wire) these faults are practically non-existent. This latter fact, even more than the higher breakdown potential, explains the reason for the increasing demand for extra insulated wire. The "faults" in the insulation described here are of absolutely no importance in the employment of the wire for ordinary coils and transformers because of the fact that with the small number of permissible faults it practically never occurs that two of them lie next to each other. There is a possibility that the faults might be of importance in special applications such as for unimpregnated coils to be used in a moist environment or very low power connections (telephony). In such a case it is better to make sure by using wire with an extra thick enamel layer.

The dielectric loss angle δ, measured at radio frequency, is small (tan δ = 0.015), and keeps

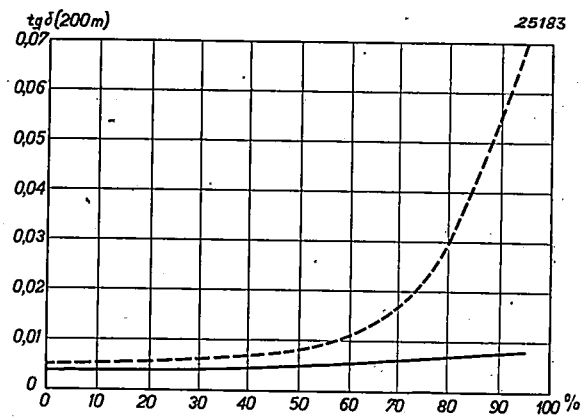

Fig. 2. Dielectric losses (tan δ) measured at 200 m wave length between two insulated wires with 0.5 mm core diameter, which were twisted together with a pitch of 2.6 cm, as a function of the relative humidity of the surrounding atmosphere. The wires were kept in this atmosphere until the losses had become constant and they were not removed from it for taking the measurements.

——————— enamelled wires

---------- wires wound twice with silk.

the same value after long continued storage of the wire in a humidity chamber or moist room. If it is measured while the wire is in an atmosphere of definite relative humidity, the loss angle of enamelled wire is found in practice to increase slightly with the moisture content of the air. *Fig. 2* gives a clear picture of the very favourable behaviour of this material compared with silk. Double silk covered wires and enamelled wires, both with $^1/_2$ mm cores, were twisted together for this purpose with a pitch of 2.6 cm.

The insulation resistance and the dielectric losses are of particular importance when the wire is to be used for cables and for the wiring of apparatus. The application is of great and increasing importance, particularly in telephony. For wiring, enamelled tinned wire is usually used, since tinned wire is more easily soldered.

The dielectric constant is about 3.2, a relatively low value. This is an advantage for the purpose of telephony.

c) Resistance to water

Enamel laquer is an electrical insulation material with an extremely small attraction for water. Because of this characteristic its electrical characteristics remain practically unchanged in very moist surroundings. The insulation value given above of more than 10^{12} ohms may also be measured in water after 48 hours immersion. For wiring in moist surroundings or in a tropical climate enamelled wire is therefore the most suitable. Coils and motors wound with enamelled wire are found to suffer much less from moisture than when wire insulated with textiles and the like is used.

It might be thought that the same resistance to water and moisture could be obtained by soaking paper or textile insulation in impregnating lacquer, that is, also in an oil lacquer, and then baking the whole. This impregnation gives reasonably satisfactory results, but the watertightness of enamel lacquer is not even approached. As an example of this we give the following results of measurements on bifilarly wound coils of 300 double turns with 0.35 mm diameter core, wound on a central core of 3 × 3 cm.

Insulation	Resistance at	
	45% rel. humidity	60% rel. humidity
Enamel lacquer	2×10^{10} ohms	2×10^{10} ohms
Cotton, well impregnated	10^7 ohms	5×10^5 ohms

In the first place the smaller resistance to moisture of the impregnated insulation may be ascribed to the textile or paper fibres which pass straight through the layer of impregnating materials and take up considerable water. In the second place to the fact that baking in this case is carried out at about 100 ° C compared with 300-400 ° C in the case of enamelled wire. In the third place the absorption of water depends also upon the kind of oil in the impregnating lacquer. It is much less for example with wood oil than with linseed oil.

As an example of the second and third points, the table below gives the absorption of water by films of linseed oil and wood oil after 21 days immersion in water [4]) compared with that of a film of enamel lacquer kept for 21 days in an atmosphere saturated with water vapour.

Absorption of water by			
Linseed oil		Wood oil	Enamel lacquer
Dried at room temp.	Dried at 70°C	Dried at room temp.	Baked at 300-400°C
150%	30%	≦ 45%	$1^1/_2$%

In judging these figures it must be kept in mind that the thin films here investigated generally have a higher absorption of water than thick or massive pieces of the same material. Hartshorn, Megson and Rushton [5]) thus found with a film of artificial resin 0.165 mm thick an absorption of water of 3 per cent, while a film 0.675 mm under the same conditions only absorbed 1.94 per cent.

In spite of the slight permeability to water of the enamel layer it is often of importance to impregnate coils which are intended for use in moist surroundings. The purpose of this operation is then, in addition to obtaining a mechanically strong unit, to prevent the penetration of macroscopic amounts of moisture into the coil.

d) Thickness of insulation, "space" factor.

The unusually thin insulation of enamelled wire offers great advantages to the electrical engineer. The "space factor", that is the percentage of the cross section of a wound coil occupied by copper, is at present an important quantity for the constructor, now that every effort is being made to

[4]) W. Rinse and W. H. G. Wiebols, Verfkroniek, **10**, 231, 250, 1937. Ind. Eng. Chem. **29**, 1149, 1937.

[5]) L. Hartshorn, N. J. L. Megson and E. Rushton, Chem. Ind. **56**, T. 266, 1937.

construct electrical apparatus as small as possible.

The space factor is of course dependent on the method of winding, and with completely regular mutual contact of the wires reaches a maximum, which depends then only on the thickness of the insulation. The usual (and in most countries standardized) thicknesses of the commonest wire insulations are given below for wires with core diameters of 1 and 0.3 mm respectively.

Fig. 4 shows a few pieces of standard enamelled wire which have been laid across each other on an anvil and then struck with a hammer. The result gives the impression that the lacquer coating is considerably stronger than the copper beneath it. If, however, the same lacquer films are made on thin copper foil, and the copper is then dissolved in such a way that the enamel lacquer film is not damaged, the stretch of these films by themselves

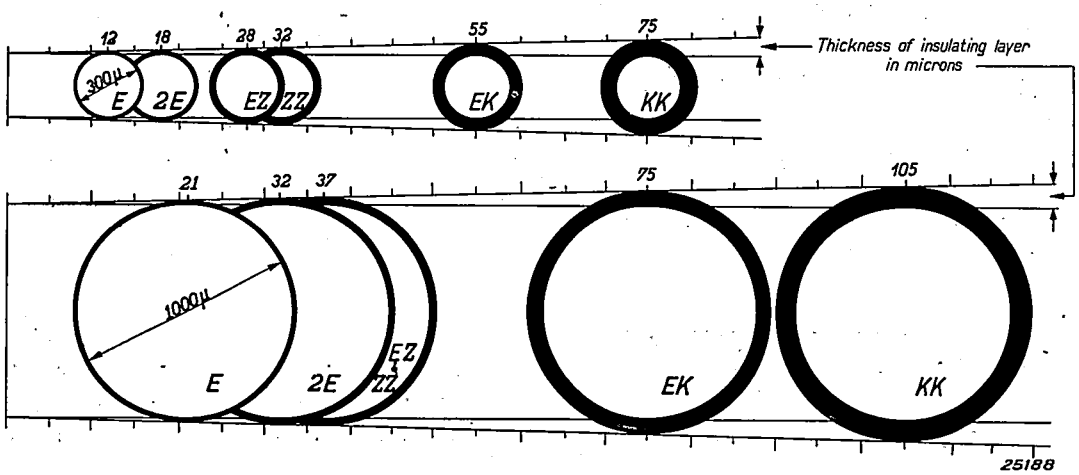

Fig. 3. Thickness of the insulation of ordinary wires for winding.
E = enamelled.
2E = thick enamel layer (twice the normal breakdown potential).
EZ = enamelled and then wound once with silk.
ZZ = bare copper wound twice with silk.
EK = enamelled, wound once with cotton.
KK = bare copper wire, wound twice with cotton.
((In upper right figure) thickness of a single layer of insulation in microns).

e) Mechanical properties of the enamel layer

The mechanical properties of lacquer baked at a high temperature form an interesting subject by themselves. If a piece of enamelled wire is stretched until it breaks, that is, often more than 30 per cent, it is found, except sometimes with very thick layers, that the layer of lacquer is quite undamaged, and that even after this test of strength it can scarcely be removed with the finger-nail.

Most of the wires also easily stand being wound about a mandrel equal in diameter to the wire. In this test the enamel layer is stretched 50 per cent on the outer side. It must, however, be noted that an enamelled wire, which has been wound around a mandrel of such a diameter that the lacquer coating only just remains intact, runs the chance of developing cracks in the coating when the wire is heated in the shape of a spiral (as is done in impregnation). The "critical" mandrel has a diameter 1 to 3 times that of the wire, depending on the material of the wire and the thickness of core and insulation.

is found to be considerably less than that of enamel layers on copper wire. Several stress-strain diagrams determined with a special dynamometer on such membranes are reproduced in *fig. 5*. The membranes which have a stretch of 19 per cent are decidedly soft ("un-cured"), those with 3.5 per cent stretch correspond to the layers which, on copper have a stretch of 50 per cent.

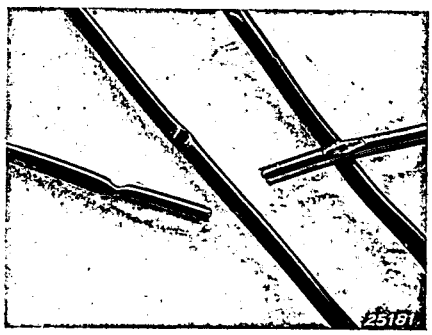

Fig. 4. Several pieces of standard enamelled wire laid across each other on an anvil and then struck with a hammer. The enamel layer shows no injury.

There is therefore no possible doubt that the bond between the lacquer and the copper beneath it is very strong, and that this bond makes possible the great stretch of the layer of lacquer. This also

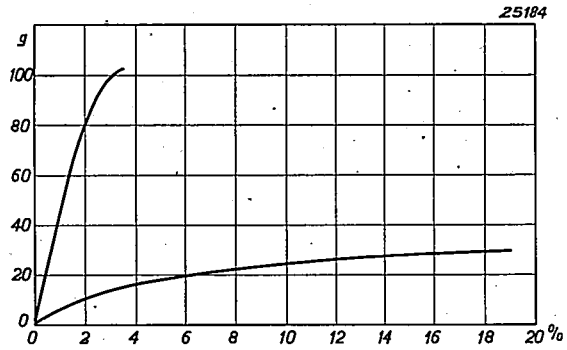

Fig. 5. Stress-strain diagrams of membranes of baked wire enamel. The membranes were baked on copper foil in four steps. each time a given thickness of layer of fluid lacquer was applied and baked a given number of seconds at the same temperature. The copper was dissolved electrolytically. The strips of lacquer film were 5 mm wide and 20 to 30 μ thick. Pieces 5 cm long were stretched about 2.5 mm/min. Upper curve: hard baked, lower curve: soft baked.

explains why thicker kinds of wire, which have thicker lacquer coatings will withstand less mechanical deformation than thin wires; the great elasticity in the thicker layers can no longer be transferred to the metal *via* the bond to the same degree as is the case with thinner layers of lacquer on thinner wires. Wire 2.5 mm thick, for example, with a lacquer coating of 30 microns will not withstand being wound around a mandrel of its own thickness, although the lacquer is in general softer (less well baked) than with wire of 0.2 mm.

The above-mentioned enamelled tinned wire has less favourable mechanical properties with respect to its insulation (mandrel test) than ordinary enamelled wire. The adhesion of the enamel lacquer to tin is much less strong than to bare copper.

f) Chemical properties of the enamel layer

The chemical qualities of the insulating layer, which are important to the electrical engineer, are chiefly stability against aging, sensitivity to temperature, resistance even at high temperature to impregnating substances (paraffin, waxes, asphalts, oil lacquers and other insulating lacquers), to moisture and oils (chiefly transformer and lubricating oil). The requirements of resistance to concentrated alkali and acid solutions, which is still often made, is actually of little importance. The resistance of the enamel to alkalies and especially to acids is high, and can be increased quite easily, although at the expense of the mechanical properties.

The stability of enamelled wire is found to be very high providing the enamel layer has been correctly baked through. In the case of clearly under-baked wire it has sometimes been found after years that the enamel coating had lost some of its elasticity. In the case of standard enamelled wire we have not been able to discover any changes in the course of years.

The sensitivity to high temperatures is slight when the heating is not of long duration. This is obvious considering the high temperature to which the product is exposed during manufacture. No anxiety need be felt for injury to the enamel layer as a consequence of the drying and impregnating of coils at temperatures up to 150 ° C. On the contrary, the heating of enamelled wire from 6 to 24 hours in air at temperatures up to 120 ° C causes a slight further hardening of the enamel layer, which is to be desired for many purposes, and is in fact deliberately brought about by many manufacturers of electrotechnical products.

In the long run the enamel layer has a resistance to high temperature which is as good as, or better than, that of textiles.

The resistance to impregnating materials and lacquers is extremely satisfactory in the case of good modern enamelled wire. Less favourable experiences, which will occasionally be met with in the literature of the last few years, may be ascribed to the fact that the most suitable raw materials were not used for the enamel lacquer.

The so-called finishing lacquer, insulating lacquers which are used cold and only applied to the outside of coils, usually soften the enamel layer temporarily. This is no disadvantage, but serves to bring about a strong adhesion between the dried layer of insulating lacquer. The constructor must of course take this temporary softening into account.

Of the impregnating materials which are applied without solvent (and therefore in a molten state), especially those which contain higher esters have some action on the enamel layer at a high temperature.

Good enamel, however, may be allowed to remain in molten beeswax for 15 minutes or longer at 150 ° C, after which, upon cooling, no depreciation of the enamel can be discovered.

The conducting core

Now that we have studied several characteristics of the layer of enamel lacquer, we shall consider

briefly the conducting core of the enamelled wire.

Very much the largest proportion of enamelled wire is electrolytic copper wire. This copper, which has to be very pure to give the highest conductivity required for electrical purposes, has an annealing temperature below 200 ° C. The annealing temperature of a cold worked metal is closely dependent on the degree of deformation; the cold deformation is very great in wire-drawing, considering that this process is at present always carried out as a continuous operation on drawing machines with 10 or more dies, each of which gives the wire an elongation of from 20 to 30 per cent.

The low annealing temperature, which results in enamelled copper being always soft, is due to this cause.

The tensile strength and elongation attained are approximately as follows:

Diameter of wire	Tensile strength	%
mm	kg/mm²	Stretch
1	23—27	30—40
0.05	27—30	20—26

This annealing of the copper during enamelling is an advantage, in the first place since hard (springy) wire cannot be used for winding coils, and moreover the conductivity of annealed copper is 3 to 4 per cent higher than of copper in the hard state.

With very thin wire, however,the tensile strength of annealed copper is very low for its use in coils. In this case other metals and alloys may be used, although the choice is very much limited by the requirement that the conductivity of the metal chosen may not be very much less than that of copper. Three metals which satisfy this requirement are copper-cadmium (which is also used for overhead high tension lines), silver and copper-silver. The high price of the raw materials silver and copper silver is not all important in this case because of the fairly high cost of working this extremely fine wire. Copper-silver is very strong, but has among other disadvantages a tendency to be corroded by moisture. Copper-silver and silver have little or no stretch in the hard state. They have not reached the annealing point at enamelling temperature. If the material is annealed at a high temperature before enamelling, the advantage of great strength disappears. The absence of stretch is a disadvantage in the use of copper-silver wire on winding machines, since the wire breaks at the slightest irregularity in the winding.

The table below gives a comparison of the properties of thin wire with various core materials.

Core	Diameter of the core	Force at break	Stretch	Specific resist.
	microns	gram	%	ohms mm²/m
Copper	40	36	15—23	0.0175
Copper-cadmium 0.6%	40	56	5—16	0.0183
Silver	40	70	2—3	0.019
Copper-silver	40	138	1—2	0.022

A special use of thin enamelled copper wire is in the manufacture of insulated stranded wires for high frequency purposes.

These wires, which are divided into a large number of thin units in parallel and insulated from each other, are used especially where solid wires would give too much eddy current loss. Because of the fact that very thin wires, sometimes less than 100 μ in diameter, are used, it is clear that a good space factor can only be attained with the use of enamel as insulator.

Various requirements are made in the braiding of these wire, because for example care must be taken that the same wires do not keep to the outside of the strand over the whole length or a large part of the length. The method of braiding is otherwise noticely dependent on the purpose for which the wire is intended. Stranded wires are manufactured in great variety, from very thin for winding small coils, to very heavy interlaced braids with many hundreds of wires for carrying large currents, for instance in transmitter installations *(fig. 6)*.

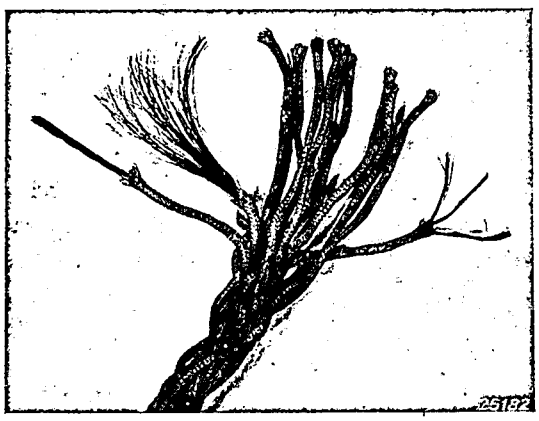

Fig. 6. Heavy stranded wire consisting of 12 bundles braided together. Each bundle is covered with silk and consists of 90 enamelled wires of 0.07 mm core diameter.

In this brief review of enamelled wire in its various forms, the practical applications of the material have not been exhausted. We have confined ourselves to the cases where the enamel forms the only insulation of the wire. Enamelled wire is also employed in combination with the spinning or braiding of paper, cotton, silk or artificial silk about the wire, impregnated or otherwise, or subsequently covered with a layer of lacquer (usually of cellulose derivatives). The discussion of these kinds of wire, however, is outside the scope of this article.

THE COLOUR REPRODUCTION OF INCANDESCENT LAMPS AND "PHILIPHANE GLASS"

by P. J. BOUMA.

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"Philiphane" or "Neophane" glass is a glass which has an absorption band in the yellow region of the spectrum. By using this glass as an envelope for the bulb of an electric lamp, most of the colours, and particularly the blue, are reproduced with greater saturation. The loss of light flux is only slight.

Introduction

As has already been explained in a previous article [1]) the estimation of the quality of colour reproduction of a source of light depends very much upon the purpose for which it is desired to use that source of light.

In some cases it is a question of obtaining light which shall resemble daylight as closely as possible. This ideal may be approached by providing the electric lamp with a blue bulb which makes the spectral distribution of the light more nearly like daylight. Good results may also be obtained with gas discharge tubes in which the line spectrum of a gas is complemented by the continuous spectrum of fluorescent substances.

In many cases however there is no desire at all to imitate daylight, and the requirement is made that the surroundings shall have a pleasant, cosy appearance, that persons shall have a healthy appearance, that certain articles appear fresh and tasteful, etc. We shall concern ourselves here with the question of whether electric light can also be improved in this respect by the introduction of a coloured envelope.

What absorption curves must be considered?

It is clear that large portions of the spectrum must not be weakened to any extent by the bulb. This would cause too great a decrease in the efficiency. Only an improvement of the colour which can be attained with a relatively slight loss of light is to be considered.

The only possibility thus consists of the absorption of one or more relatively small regions of the spectrum. What colours may be considered in this connection?

In general, absorption of a given colour is accompanied by the following two objections:

1) An object which reflects almost exclusively this colour appears too dark.
2) Objects which exhibit the colour under consideration in a less saturated form appear still less saturated.

The first objection holds particulary for the colours at the extremities of the spectrum, thus for red and blue. Very saturated red, for example, can only occur when a material reflects practically exclusively red and orange. The same is true of blue.

For yellow, however, the situation is different. Highly saturated yellow occurs in nature as a rule, not because only a narrow region of the spectrum is reflected, but because red and green as well as yellow are fairly well reflected, and only blue and violet are absorbed to a large extent. Such a phenomenon appears in the case of the yellow "Selectiva" light used for automobile and bicycle lamps. In this case a very saturated yellow colour is obtained by the absorption of the blue and violet only. Strong absorption of the yellow therefore will cause only a relatively slight decrease in brightness of saturated yellows.

The second objection also holds particularly at the extremities of the spectrum: the blue, which is reproduced in electric light in a much less saturated form than in daylight, may certainly not be made still duller. The saturation of the red

[1]) Philips techn. Rev. 2, 1, 1937.