The role of non-ferrous metals and alloys in electrical engineering industries in particular relation to cable industries

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SYNOPSIS

The first part of this paper presents the usage of non-ferrous metals in the electrical transmission and distribution field and in winding wires for electrical machinery, equipment and apparatus together with a brief review on the technique of manufacture of electric conductor from copper, copper-cadmium and aluminium wire bars and on the process of sheathing the cables with lead-alloy as practised in this country. This is followed by a discussion on the substitution of the conventional sheathing and conductor metal e.g. lead and copper with aluminium not only for reasons of economy and availability but also because of certain distinct mechanical and electrical advantages. An economic comparison of aluminium and copper conductors on the basis of equal conductivity has been touched upon.

Subject of joining aluminium conductor has been set forth and data of some experiments on ferrule joints made with lead-tin-zinc-solder using an organic flux of reaction type have been provided to establish the fact that joining of aluminium cable is no more a problem.

NON-FERROUS metals in major use in electrical industries are copper, aluminium, silver, cadmium, lead, tin, antimony, zinc, nickel and chromium. Copper, by virtue of its high conductivity second only to silver, and other excellent properties, has always been the ideal conductor material but it is only recently that its position is being challenged by aluminium due to scarcity of copper in the world market and its wildly fluctuating price. As aluminium is a metal whose source is almost unlimited, its use is bound to continue to rise as demand on copper grows with increasing industrialisation and urbanisation of the underdeveloped or developing countries and its source gets gradually depleted with increasing off-take.

In India the change-over to aluminium in electric cable industry is almost complete. Overhead all-aluminium conductor or aluminium conductor steel reinforced for high voltage power transmission and distribution has replaced H.D.B.C. conductor for the purpose almost all over the world. Underground transmission and distribution cables with copper conductors have been partly replaced with cables with aluminium conductors in almost all countries of the world. In India usage of these cables with copper conductor in L. V. range is completely banned since last few years excepting for special usages e.g., in control cables, in cables for collieries where also in a few years time aluminium conductor cables will make inroads as confidence in use of these cables grows. House wiring and general cables rubber or plastic insulated in this country are also now mainly with aluminium conductors excepting for flexible cables where copper still continues to be used by virtue of its better resistance to failure under repeated flexing but here also it is just a question of time when aluminium will catch up with copper. Already a few varieties of flexible cables have been made with aluminium conductors and these are proving no inferior to copper flexibles.

It can boldly be said that in a few more years copper power cables of all categories will be a thing of the past in this country and many other countries of the world. By power cables are categorised here all cables used for transmission and distribution of power including house wiring cables and flexibles for electrical equipments. Auto cables, control and signalling cables for railways and other utilities continue to be in copper but there is no reason why these should not be replaced by aluminium cables.

As to telecommunication cables the trend is to continue with copper cables but here also it must be a question of time when aluminium cables will find favour with authorities, not possibly before copper becomes a scarce metal. The same is the trend with instrument and fittings wire and leads.

Coming now to the winding wires field e.g. windings

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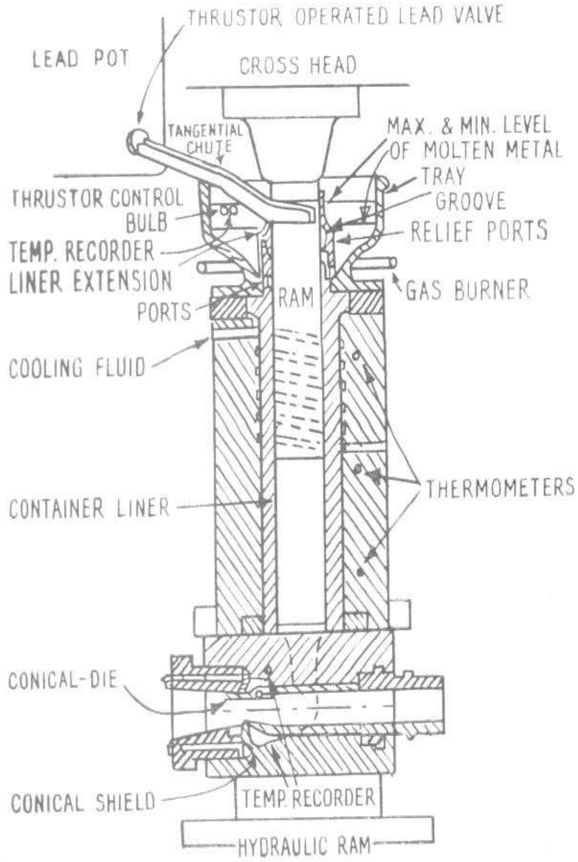
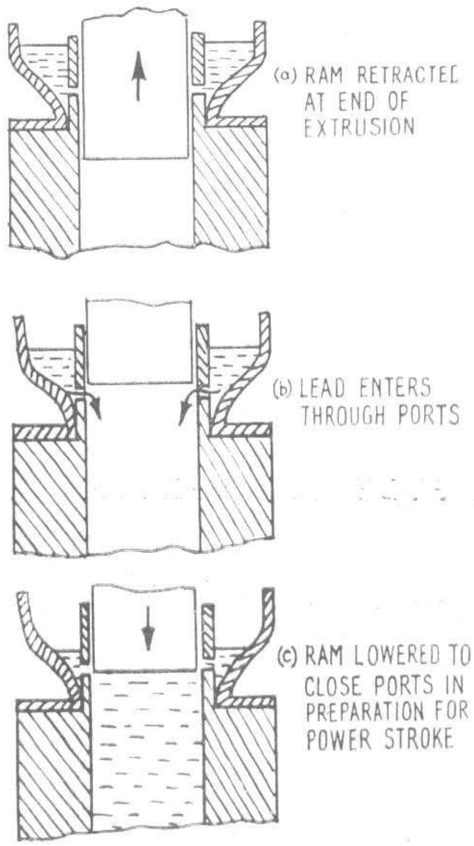


1 *General arrangement of cable press fitted with Glover tray*



2 *Sequence of operations for cable press fitted with Glover tray*

for transformer, electric motors, etc., for field and electro-magnetic coils, copper is still the predominant electrical conductor metal. Only recently, say from 1965, due again to high price and scarcity of copper, there has been a tendency to look for substitution with aluminium and development work is going on to use aluminium in electric motors and transformers only, though the use of aluminium windings for transformers is by no means new. In the first world war the German Electric Co. constructed a number of 60 000 KVA, 110 kV transformers with aluminium windings, and during the 1939–45 war, between five and seven thousand aluminium wound transformers were made in France, Italy, Switzerland and Germany. In both the cases, of course, aluminium was used because copper was unobtainable, but they demonstrated that aluminium wire of the same shape and size could be substituted for copper wires to produce satisfactory transformers.[1]

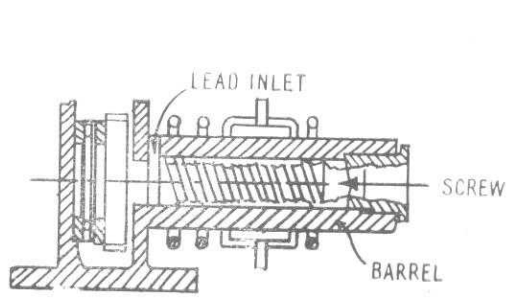
Raw copper and aluminium

Raw metals are generally available to the industry in the form of billets called wire bars.

Copper

The wire bar specification is BS 1036 applying to electrolytic copper wire bars. IS–191 of Indian Standards Institution closely follows this. BS–1036 specifies a minimum copper content of 99·90 per cent with electrical conductivity (minimum) of 100·00 per cent on wire prepared in the manner specified. With the quality of copper available now electrical conductivities of 100·8 per cent to 101·6 per cent are more common. Some brands of copper contain small quantities of selenium, silver or other elements, which have varying effects on electrical conductivity and on annealing temperatures.

Most of the copper is obtained as nominal 265 lb (120·2 kg) wire bars from Northern Rhodesia. Substan-



3 *General arrangement for continuous extrusion* tial amount also comes from Canada and South America. The standard wire bar is horizontally cast with a rough set surface on the top. These horizontally cast bars serve the most general purpose requirements but for special jobs e.g. conductors for enamelling, for coaxial cable, and for superfine wire production, vertically cast wire bars or skalped wire bars are helpful because the horizontally cast bars contain higher amount of oxides on the set surface which persist in the finished product.

Wire bars used generally are 4 in. (10·16 cm) square in section and weigh 265 lb or 275 lb (120·2 kg or 124·7 kg). Copper-cadmium bars are invariably cast vertically and are 4 in. × 4 in. (10·16 cm × 10·16 cm) in section and 4 ft (121·9 cm) in length. Chemical composition and physical constants of material are in line with IS.2665.

Aluminium

Aluminium wire bars available have not any segregated oxide surface and are 4 in. (10·16 cm) square in section and weigh 32–40 kg (70 to 88 lb) approximately ; governing material specification is IS. 2067.

Production of rod

Copper

Rods are produced generally by the hot rolling process. Rod rolling mills are not many in India, and all are non-automatic type. The Indian Cable Company have the largest rolling mill, the output of which is approximately 6·5 tonnes per hour.

Copper bars are preheated in a push-through type oil fired horizontal furnace at a temperature of 840°±10°C.

The atmosphere in the furnace is kept slightly oxidising in the heating zone.

To obtain due dimensional accuracy and high quality surface finish oval square oval square system of pass progression is followed and 18 to 20 passes are given to get finished rods of 1/4″ (6·35 mm) diameter from standard wire bar weighing 265–275 lbs (120·2 kg to 124·7 kg).

It is the general practice that six passes are given in the roughing train which is a single stand three high mill, passes 7 to 9 (oval-square-oval) are given in the intermediate roughing train, a single stand three high mill and passes 10 to 18 square-oval-square oval excepting the finishing one where it is round are given in the finishing two high mill. Drafting is relatively heavy in the first passes which range from 30 to 50 per cent and reductions taper off to about 12 per cent in the final pass.

The test for controlling rod quality is the twist test which readily reveals any rolled-in fins. Copper-cadmium bars are preheated in the furnace at about 820°C and hot rolled in the same way as copper excepting that a break is made in the hot rolling process, allowing the metal to cool sufficiently to acquire some degree of cold work during the process.

Aluminium bars are preheated in the furnace at about 390°± 10°C and are hot rolled in the same copper mill almost in the same way. Generally 18 passes are given when rolling from 4 in. (10·16 cm) square to 3/8 in. (9·525 mm) diameter. The breakdown practice consists of 10 passes through a heavy 3 high mill, passes 11 to 13 through an intermediate 3 high mill and passes 14 to 18 through 2 high finishing mill. To avoid the production of finned rods oval-round system of pass progression is followed from the intermediate roughing mill.

Aluminium rods are also produced straight from ingots/billets by continuous casting and rolling process. In this process molten metal is poured into a rotary casting wheel, which produces solid rod and the rod is immediately led into a train of rolling mills which reduces its section. This is known as the 'Properzi' process.

Processing of rolled rods

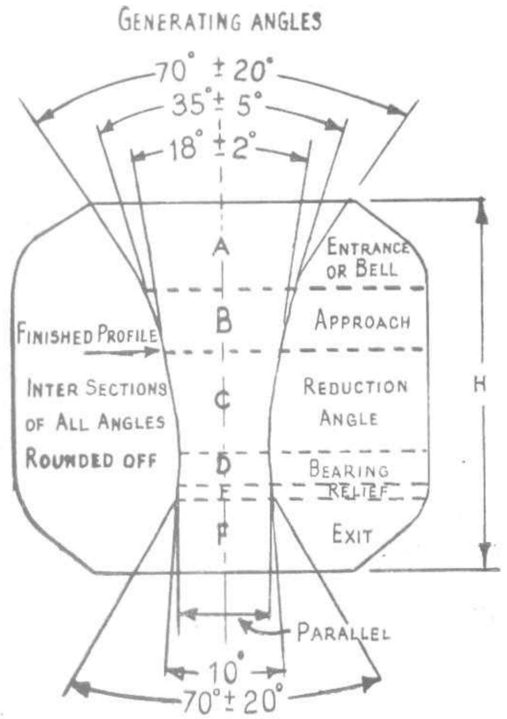
Prior to wire drawing copper and copper-cadmium, hot rolled rods are pickled in sulphuric acid (10% acid in water W/V), followed by washing, and a dip in soap water to remove last traces of acid and to protect the rods against staining on storage. For copper conductors, for enamelling and for coaxial cable etc. which demand superior surface finish on wire it becomes necessary to shave the rods. In shaving operation a depth of cut is usually given 0·004″ to 0·006″ (0·102 mm to 0·152 mm) radially and with the removal of top layer from the rod some ferrous inclusions which are present in rolled rods are also removed. Aluminium rods do not require any such treatment, prior to drawing down to wires.

Wire drawing

Both non-slip and slip type machines of different makes are used for breakdown drawing of wire rods.

Non-slip type machine is an assembly of 5 to 9 single block machines synchronised electrically to operate together in tandem. The blocks not only draw the wire but have arrangement to accumulate the wires between stages and this permits considerable variation in drafting and eliminates the phenomenon of wire slip on the drawing block whereas slip type machines operate on the principle that there will be some slip during drawing and to reduce the amount of slip and stop breakages drafting must be accurate. Drawing blocks of the non-slip type machine are water and air cooled.

In non-slip type machines as there is a provision of accumulation of wire at each stage this has the advantage of providing a margin of safety when breakage of wire occurs at any stage. Non-slip type machines are simpler in design and cheaper than slip type machines but non-slip type machines are slower in speed and they operate at about 3 000 ft (914·4 m) per minute with reduction of about 33 per cent at each stage. These machines are used mostly for aluminium drawing for sizes up to ·081″ (2·06 mm). Tandem slip type machines of 5 to 11 dies suitable for producing wires of about 0·128″ (3·25 mm) dia. down to ·056″ (1·42 mm)



APPROXIMATE VERTICAL HEIGHTS

A + B + C = 2/3 H

D + B + F = 1/8 H

C = DIAMETER AT D

D = 30 PERCENT OF DIAMETER

E = 10 PERCENT OF DIAMETER AT D.

4 *Diamond die for copper (as per B. S. 1393-1947)*

diameter at final process are normally used. These machines are run at speeds from 1 500 to 5 000 ft (457·2 m to 1 524 m) per minute and draftings employed are within 40 per cent area reduction and heavy draftings are given only in the first few passes.

For intermediate, fine and superfine wire drawing operation, say to draw wires of sizes below 0·056″ (1·42 mm) down to and including ·020″ (0·508 mm) for intermediate, below 0·020″ (0·508 mm) down to and including ·0048″ (0·122 mm) for fine, and below ·0048″ (0·122 mm) for superfine it is the general practice to use slip type machines capable of giving 13 to 21 reductions, a reduction of about 20 per cent in area is given for intermediate and fine and 16 per cent in the case of superfine wires at each stage. Drawing speeds are generally 2 500 to 5 000 ft/minute (762 m to 1 524 m/minute) for intermediate and fine, and 3 500 to 6 000 ft/minute (1 066·8 m to 1 828·8 m/minute) for superfine wires.

For superfine wire drawing machines each and every moving part, speed compensating device for winding on spools etc. should be of the highest degree of sensitivity to avoid breakages of the wire during drawing.

Use of carbide dies is limited to the drawing of heavy sizes of wire and diamond dies are used for all the sizes of wire below 0·056″ (1·42 mm) diameter. It is again common practice to use diamond die at least at the final stage in drawing heavy sizes of wire also.

An emulsion of rape seed oil in water or soluble oil in water is used as a lubricant for drawing of copper and copper-cadmium alloy wire, fat content of which varies between 6 and 10 per cent for heavy, 4-6 per cent for intermediate, 2-3 per cent for fine, and 1·5-2 per cent for superfine sizes of wire. Mineral oil (viscosity Redwood I at 140°F-500 to 600 secs) is used as a lubricant for drawing heavy and medium sizes of aluminium wires but soluble oil is used for drawing fine wires.

Weight of the copper wire coil or spool from different types of machines are generally fixed according to the demand or for easy handling of the packing for subsequent processing which ranges generally between 60—500 kg for heavy, 10 kg—120 kg for medium, 10 kg—30 kg for fine and 5 to 10 kg for superfine sizes of wire.

Rectangular conductor

Process for manufacture of rectangular conductor is the same for both copper and aluminium where the rods are first drawn through T. C. dies in a single block machine to get the required sizes of inlet rod for the manufacture of the strips.

Following three methods are generally adopted to process the drawn rod to rectangular conductors :

Rod is flattened between two rollers and either

(i) passed through edge forming rolls
or
(ii) drawn through holes of a steel plate
or
(iii) drawn through T. C. dies

For correct radius of corner and better surface finish the last method is preferred. Highly viscous petroleum oil is used as a lubricant for drawing the strips.

Interstage annealing becomes necessary in the manufacture of thinner strips. Strips are generally packed in 20-40 kg/coil for aluminium and 100-240 kg for copper on coils/drums.

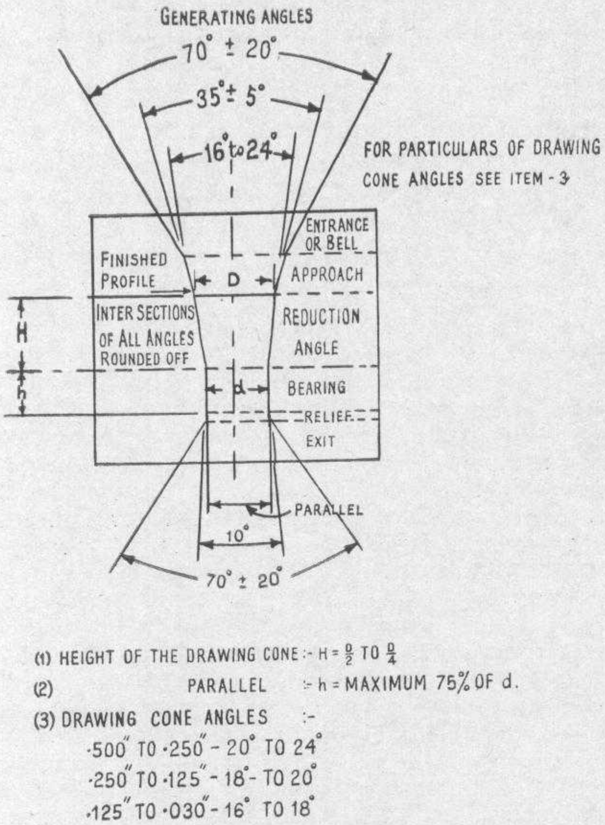
Wire drawing dies

Profiles of diamond dies followed are as recommended in British Standard Specification 1393. However the diagrams (Figs. 4 and 5) shall give a clear picture on diamond and tungsten carbide dies for drawing into various sizes of wire.

Dies shall be checked at regular intervals to see that 'ringing' of dies is avoided and these shall be removed by light polishing whenever such minor defect is observed.

Annealing

Annealing is an essential part for the manufacture of



5 *T. C. die for aluminium*

copper conductors. The conductors are annealed in various types of batch annealing furnaces at different temperatures ranging between 250° and 450°C depending on the sizes of the conductor. It is very important to maintain an inert and controlled atmosphere in the furnace to avoid tarnishing and fine wires sticking between layers. Vacuum type furnaces have also been introduced in some plants where better annealing condition can be maintained without trouble.

Aluminium conductors are used in different tempers and for general cables it is used either in 'H', or 3/4H temper but where the question of flexibility comes it does need be annealed and in that case the conductors are annealed at temperatures ranging between 250° and 350°C depending on the sizes of the conductors in the same way as followed in the case of copper. Though it is not essential to maintain inert annealing atmosphere as for copper it does help to avoid thickening up of the inherent oxide layer on aluminium.

Tinning

Copper conductors need be tinned where the insulant is rubber in order to prevent the deterioration of rubber insulation due to the catalytic effect which copper has upon the oxidation of the rubber.

It is the practice to use untinned conductors for cables which use paper, thermoplastic or newer type of insulants other than rubber but tinned conductors are sometimes used in plastic insulated cables because they facilitate soldering operations for termination.

Tin is normally applied by hot dip process by passing the copper conductor after pickling and fluxing through a bath of molten tin. Thickness of tin coating is generally of the order of a few microns e.g. 0·5 to 2 microns.

Sheaths

Paper insulated power cables, dry core telephone cables, coaxial telecommunication cables, etc. must have metal sheathing, lead and its alloys are still the materials most commonly used for this job.

Lead extrusion press in current use in this country is vertical ram press with Glover tray.

To feed, the press lead or its alloys are kept in molten condition at 440°±10°C in the melting pot which is connected by a pipe to the tray.

In the ram press metal is charged into the tray which is virtually an elaborate form of tundish, the general arrangement being illustrated in Fig. 1.[2] The sequence of operation is shown diagramatically in Fig. 2.[2] As the ram passes the ports on its return stroke (Fig. 2) metal flows into the container in which a vacuum exists due to the sealing action of the molten metal in the tray. When the container is full, the ram is lowered until the ports are again closed in preparation for the extrusion of the next charge ; clearly, the tray must contain sufficient molten metal to fill the container without exposing the ports and thereby allowing air to enter the container. Care is also taken to ensure that the level of the metal in the tray never rises above the liner extension. In this way, the possibility of carrying oxide down into the container on the face of the ram is avoided. One further precaution taken is to ensure that metal enters the tray tangentially to the metal surface in order to avoid any danger of air or oxide being driven down into the body of the metal. The risk of oxide inclusions being present in a product from a press fitted with a Glover tray is extremely remote and the quality of the product is undoubtedly high. Some data on extrusion conditions (pressure and temperatures) are given as a general guide.[2]

	Gauge reading		True extrusion pressure	
Material	T/in²	(Kg/mm)	T/in²	(Kg/mm²)
Unalloyed lead	1·5–2·0	(2·4–3·15)	19–25	(29·9–39·4)
Alloy 'E' (0·2% Sb + 0·4% Sn)	2·0–2·5	(3·15–3·9)	25–30	(39·4–47·2)
Alloy 'B' (0·8% Sb)	2·5–3·0	(3·9–4·7)	30–37	(47·2–58·3)

Alloy 'E' may be extruded at virtually the same rate as pure lead by a small increase of pressure but the extrusion rate of alloy 'B' even with a greater increase in pressure is about 60 per cent of that for pure lead.

Except at the die-block, extrusion temperatures are not changed with the material being extruded. Normal values are about 130°C for the press container and 400°C for the metal in the melting pot.

Whatever the metal extruded, the lower half of the die block is generally maintained at about 20°-25°C higher than the upper half. For pure lead and alloy 'E', typical die block temperatures are about 150°C (upper) and 170°C (lower) and for alloy 'B', these values are increased to about 160-165°C (upper) and 180°-185°C (lower).

Continuous extrusion

In continuous machines, lead/lead alloys are fed on to a screw which revolves in a closed barrel. There is a clearance between the screw and barrel so that the arrangement may be regarded as a screw revolving in a lead/lead alloy cylinder which is threaded on its inner surface. Since the position of the screw relative to the barrel is fixed, once the frictional resistance between the lead and barrel opposing forward travel is overcome, the lead shell moves forward in the manner of a nut which is held on a rotating screw. The arrangement is indicated in Fig. 3. Temperature of the extrudate is about 50°/60°C higher than that of the ram press product. When operating successfully, there is little question of the excellence of the product as regards cleanliness, uniformity of structure and consistency of dimensions.

A disadvantage of a continuous machine is considered to lie in the difficulties with alloy extrusion where segregation of the alloying elements is a problem. The selection of an ideal cable sheathing alloy is extremely complex. Briefly the alloys shall have the following properties :

- (i) A good creep resistance which might permit their use, without reinforcement, on cable operating under low internal pressure.
- (ii) A good creep ductility which is maintained at low rates of sheath expansion.
- (iii) An estimated thirty to forty year life when subjected to bending cycle of the order of one cycle per day.
- (iv) Good fatigue resistance.
- (v) There is no significant change in properties with time after manufacture.

None of the alloys used commercially has all the qualities to be merited as an ideal cable sheathing material but from the service performance point of view it has been seen that alloy 'E' and alloy 'B' can serve most of the requirements of cable sheaths. Alloy 'E' is suitable for general use where a moderate amount of vibration is expected and the conditions where a sheath is required to possess long-time creep ductility. The fatigue limit is about twice that of pure lead and since extrusion is simple, alloy 'E' has found wide application.

Alloy 'B' must be considered if there is any suspicion that continuous abnormal conditions of fatigue may be met in service. There is an age-hardening of the alloy but attainment of equilibrium is a lengthy process and a considerable time may elapse before changes are complete.

Fatigue resistance of alloy 'B' is about thrice that of pure lead and it has been admitted that to-date alloy 'B' has proved to be one of the most satisfactory high-strength alloys in service, creep and fatigue resistance of unalloyed lead are low and structural stability is also low with tendency to form coarse grain ; so pure lead is used as a sheathing material in the conditions where a sheath is not supposed to stand the above mentioned abuses but is only for a sheath as an impervious layer preventing access of moisture to the cable insulation.

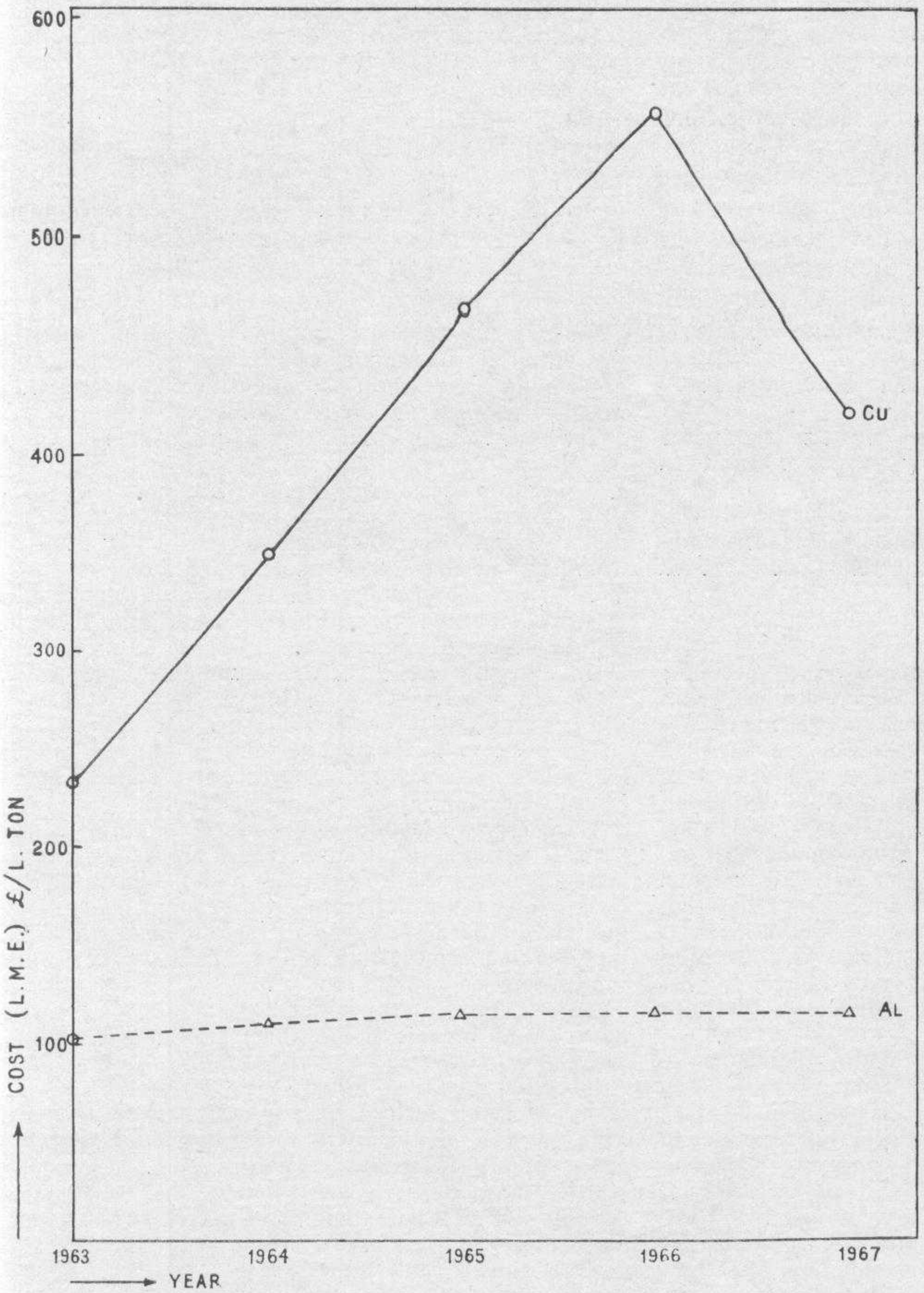
The greatest single incentive for considering aluminium conductors in any form is the prospect of economic advantage which is based upon the substantial differential in prices of aluminium and copper. Since last three decades a very wide fluctuation of copper price has been noticed, the only stable period in the recent price history of copper was during world war II when prices were fixed. In contrast, the price of aluminium has been quite stable and has not fluctuated widely due to variations in supply and demand.

Another incentive for aluminium is its light weight. Where light weight of cables or electro-magnetic coils is essential, aluminium is especially attractive.

In winding wire field a strong incentive for aluminium is that it has better heatshock properties and may be operated at high temperature without oxidizing or flaking. The natural oxide film on the surface of aluminium protects the underlying metal from further oxidation and coils of aluminium wire/strip can be successfully operated at temperature in excess of 400°C. Today aluminium has established its position as a conductor not as a substitute for copper but as an attractive alternative on its own merit.

After world war II shortage of lead gave a chance to aluminium to be tried as an alternative to lead for cable sheathing. Aluminium cable sheaths were first used commercially in great Britain in 1948 and since then extensive trials have been carried out and several thousand miles of cable with Al-sheath are already in service. In western countries aluminium has been recognized as a general purpose sheathing material and has proved its superiority over lead in many respects.

The advantages of aluminium are primarily that it is considerably lighter and stronger than lead. In the case of power cables, the saving in weight varies from about 60 per cent for small cables to 30 per cent for large cables with an average of about 35 per cent for unarmoured and 25 per cent for armoured cables. Another disadvantage of lead is its softness and lack of mechanical strength. Bare lead sheath easily gets damaged during transit or installation and additional protection and mechanical strength have



6 *Copper and aluminium costs on conductivity basis*

often to be provided by steel tape or galvanised mild steel wire armour. Except in special circumstances, armour is not necessary with aluminium, and this is another factor in further reducing weight and cost of cable.

A further disavantage of lead is that it is liable to fracture by vibration but aluminium is several times stronger than the hardest lead alloy and failure is not expected. Lead has some advantages over aluminium ; lead can be cut and plumbed easily and ordinary bitumen and hessian servings are quite adequate to protect the lead sheath from the different forms of attack which can occur underground whereas aluminium needs a completely impervious serving e. g. extruded plastic covering etc.

The great difference between aluminium and lead is in electrical conductivity. Although the higher conductivity of aluminium is not of very great importance for power cable sheath it is advantageous in high frequency coaxial telecommunication cables, where the sheath is an integral part of the cables as losses are kept to a minimum.

As aluminium has greater conductivity than lead, the tendency is for sheath losses to be higher ; although this does not affect multicore cables to any significant extent, the ratings of single-core cables are somewhat reduced, particularly with the usual method of bonding for earthing at both ends.

Where the rating of lead sheathed cables is governed by a maximum permissible operating temperature of lead without armour, and a higher temperature is allowed for an armoured cable, it is reasonable because of the extra strength of aluminium to permit unarmoured aluminium sheathed cables to operate at the higher temperature.[3]

The main methods of aluminium sheathing are :

(a) Drawing the cable into an oversize aluminium tube which is subsequently swaged down to fit the cable.
(b) Forming a sheath around the cable from aluminium strip which is seam welded longitudinally. The sheath is then rolled down to fit the cable.
(c) Direct extrusion.

The main driving force to switch over from copper to aluminium is the substantial difference in prices of aluminium and copper which is shown in Fig. 6

The curves plotted in Fig. 6 are on the basis of equal conductivity. While the electrical conductivity of E. C. grade aluminium is only 61% that of copper, the density is only 30%, accordingly 0·485 lb (0·22 kg) of aluminium will be required for one pound (0·45 kg) of copper as a conductor for equal conductivity. Price spread between the two conductors as it stands now is sufficient to justify the increased covering costs resulting from the larger cross-sectional area of equivalent aluminium conductors and thus aluminium has firmly established its position as conductors for most types of cables and wires.

The problem associated with joining aluminium to aluminium or to other electrical conductors are well known but the method of joining has been made much easier as a result of the successful introduction of fluxes and solders intended for soldering aluminium conductors and also with the development of some recent techniques e. g., cold welding, shielded inert arc welding, ultrasonic methods of jointing, high temperature soldering and mechanical jointing, etc. which assure high quality and long life in aluminium jointing when properly applied. The detailed summary of the different techniques is not within the scope of this paper. We shall deal with the process of jointing of stranded aluminium conductor by soft soldering method.

Soldering is the operation of joining metals by adhesion of a low melting point alloy run between the mating faces without any distortion or fusion of the parent metals. Solders for aluminium are broadly divided into two groups namely, soft solders and hard solders. Indian standard, to specify composition of solders for aluminium and to define soft and hard solders, is in the draft stage—soft solders are those alloys which have melting points well below 300°C and hard solders are those having melting points above 300°C and generally below 500°C. The solder composition can be broadly divided into :

(i) Tin base (soft solders)—Tin-zinc or tin-lead-zinc alloys.
(ii) Zinc base (hard solders)—Zinc-silver, zinc-aluminium or zinc-aluminium-copper alloys.

Tin-lead-zinc solders are normally used for soldering the stranded aluminium conductors of electric cables because they have short pasty ranges suitable for making wiped joints on lugs and ferrules.

The essentials for ensuring good joints are :

1. Proper design of the joints which have long solder interfaces and which are subjected to shear stresses rather than peeling ones in service.
2. Use of right type of solder and flux.
3. Thorough cleanliness of the surfaces to be jointed.
4. Complete removal of the oxide film from the surfaces of aluminium.
5. Effective wetting of the aluminium surfaces by the solder.

The ordinary fluxes used on copper are not suitable for soldering aluminium because of the stable nature of the oxide film.

There are two types of fluxes which are normally used for soft soldering aluminium. Those are named organic and inorganic ; the effectiveness of both the fluxes depends on a chemical reaction between the components of the flux and between those and the aluminium itself within the working temperature of the respective flux which ranges between 250° and 350°C.

Organic fluxes are so called because they are generally based on an organic amine which acts as a carrier for active fluxing agents.

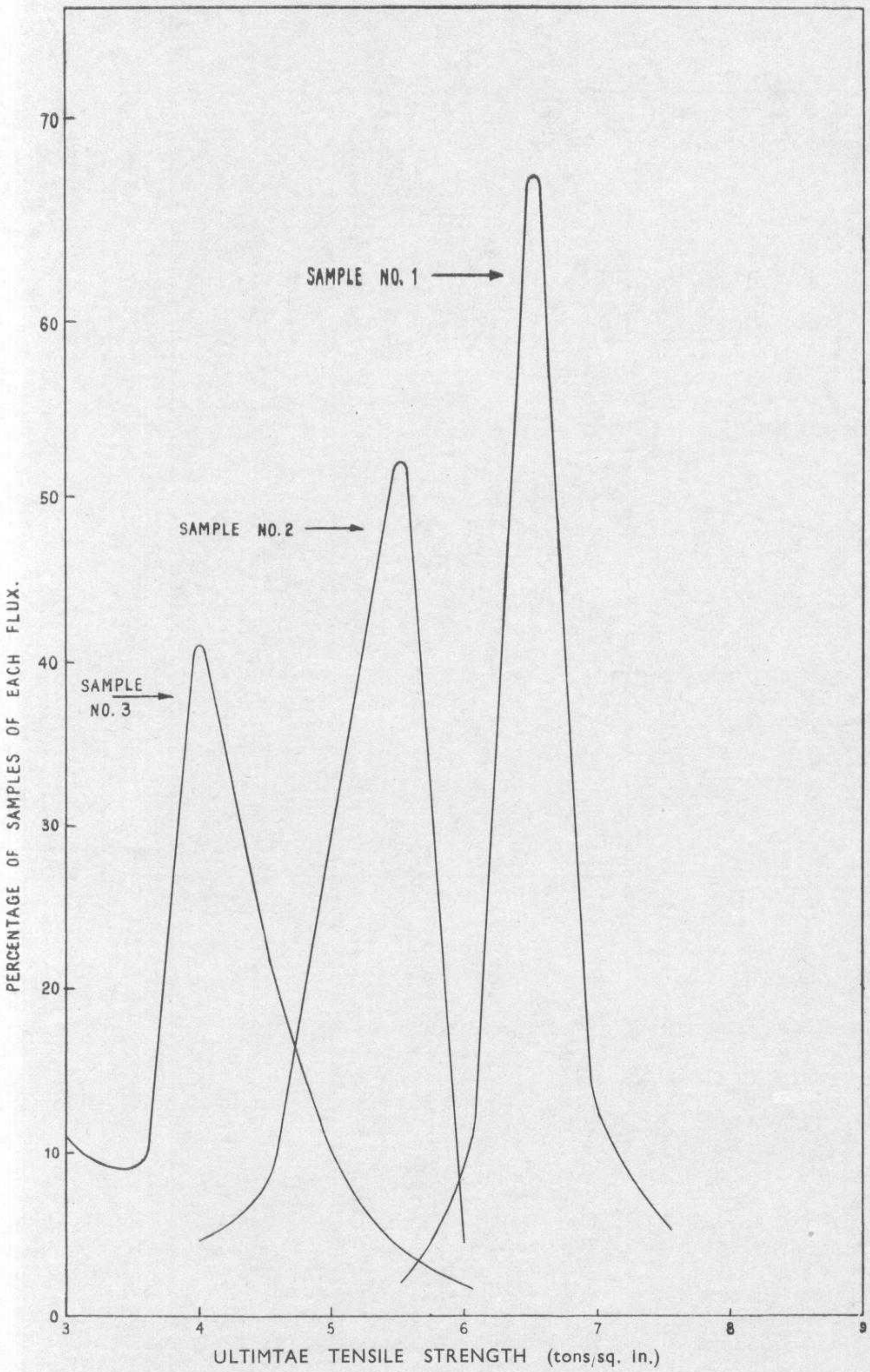
Inorganic fluxes are usually mixtures of the chlorides of heavy metals such as tin and zinc. Between 250° and 350°C such a mixture reacts to form aluminium halides which effectively remove the oxide film. A secondary reaction then takes place whereby the heavy metal deposits out on the aluminium surface. However, organic fluxes are also very effective and leave non-corrosive residues and as such they have become very popular and improved the joint properties made by soft soldering process to a very large extent.

Results on the jointing experiments carried out at the works of The Indian Cable Co. Ltd., Jamshedpur, using 25 sq. mm. stranded aluminium conductor and weekback copper ferrules given below will give a comparison of fluxes for aluminium conductor soldering and also will show the performance characteristics of the soldered joints.

Test arrangements

The conductor used throughout the test was 25 sq. mm stranded aluminium conductor.

The solder was INCAB-PARASOL

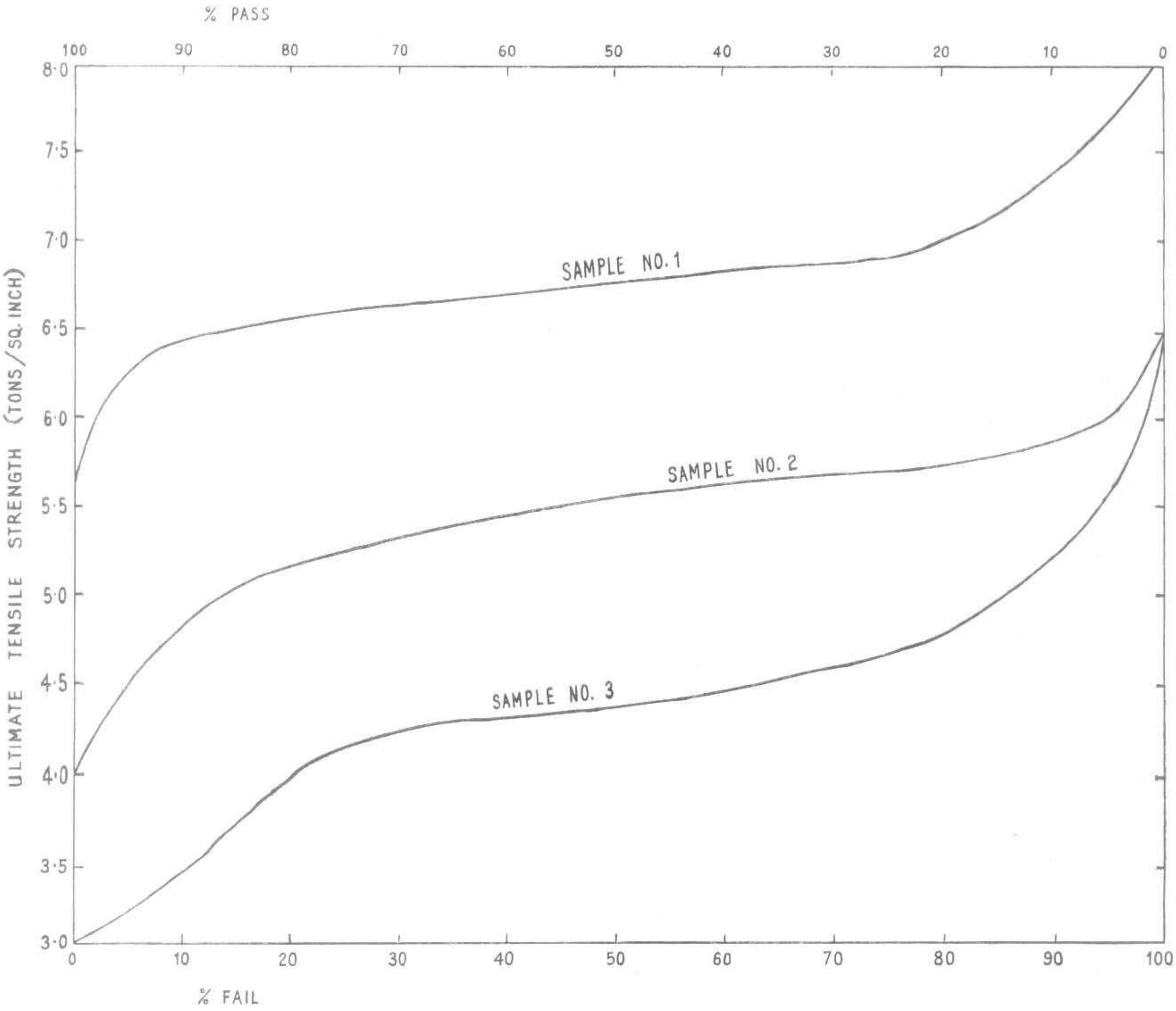


7 *Ultimate tensile strength of the ferrule joint of each sample vs. percentage of total number of sample joints made with each type of flux*

Preparation of samples

Test samples have been prepared by three test jointers in accordance with the standard jointing instructions as laid down below :

1. The conductor ends are cleaned with solvents e.g. carbon tetrachloride.
2. The ends of the conductors are opened with a pointed instrument to help solder penetration.
3. It is important to keep the temperature of the solder in the pot between 315±10°C.
4. Copper week-back ferrules are fluxed and pot tinned in the solder pot. The ferrules must be tinned smoothly and excess metal must be shaken off the ferrules—not wiped.



8 *Probability graph*

5. The conductor ends are preheated by basting with molten solder and flux is applied with a stiff brush, making sure that the flux is pushed inside the strands. On no account must the flux be applied to cold conductor.
6. After the final baste the conductors are tapped to release any surplus material and then the strands are closed with gas tongs.
7. The ferrule is fitted centrally and loosely over the conductor ends with slot upper most and a gap of 1/8″ (3·175 mm) is left between the two conductor ends. A gap less than this will not allow the solder to flow freely.
8. On no account must flux be applied after fitting the ferrule. The result will be flux deposits between couductor and ferrule and thus a weak joint.
9. The next step is to baste and flux until solder runs freely through the ferrule. The ferrule is then tightened up on to the conductors.
10. After closing the ferrule, basting is continued until the solder begins to solidify, when the joint is wiped to a smooth finish with a cloth.

Mechanical testing

The ultimate tensile strength of the ferrule joint of each sample was determined by use of automatic tensile testing machine.

Plotting the results

The results obtained were grouped to the nearest half ton and plotted (Fig. 7) against the percentage of the total number of sample joints made with each type of flux.

The graph shows that the highest percentage of joint samples with Flux 1 had tensile strength in the range of 6·5 t. (almost 67%), about 52% of the joint samples with Flux 2 were at 5·5 t and 41% of the joint samples with Flux 3 were at 4 t.

If we study the probability graph Fig. 8 then some interesting predictions can be made.

If the conductor fractures at 6·0 t then the percentage of joints made with each flux which will reach this point are : Flux 1, 98%, Flux 2, 5% ; Flux 3, 2%.

If 5·5 t which is about 50% of the tensile strength of the normal conductor is considered the minimum acceptable value (an arbitrary) then the percentage of joints made with each type of flux above this value are :

Flux 1, 100% ; Flux 2, 57% ; Flux 3, 6% grade.

A very large proportion of the samples jointed using the Flux No. 3 showed an unacceptably low tensile strength. Flux No. 2 can be used as an alternative to Flux No. 1 although joint strength obtained with Flux 2 was somewhat less.

References

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