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The Manufacture of Earthenware Ducts

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Earthenware ducts form by far the greater part of the Post Office underground-cable conduit system. Although the basic stages in the manufacture of earthenware have remained unaltered for centuries, the techniques employed have changed considerably, and the methods at present in use for the manufacture of Post Office designs of duct are described.

INTRODUCTION

IDEALLY, an underground-cable conduit or duct should possess the following main properties. It should have a smooth low-friction bore, adequate strength and durability, it should be inert to the cables that it will contain, and it should be easy to lay, with sufficient flexibility to permit deviations in the line of the trench. It should be watertight, or at least resistant to silting, and, finally, its cost should be competitive. The glazed earthenware duct possess most of these properties to a greater extent than any other available conduit at a comparable price. For this reason the Post Office has been using earthenware ducts for over half a century as the main basis of its underground-cable conduit system.

The present form of duct, with a moulded-earthenware socket and Stanford-composition spigot and socket linings (Fig. 1), has been used for most of this time. Such

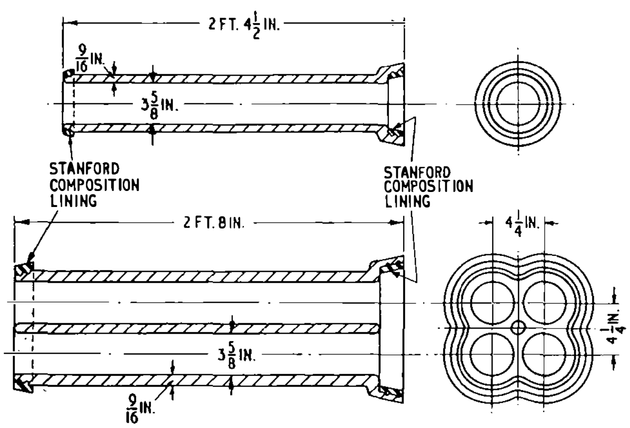

FIG. 1—POST OFFICE TYPE DUCTS

changes as have been made have been of a dimensional nature dictated chiefly by current requirements and economics. As with any design used in great quantity for many years, over-familiarity tends to lead to exaggeration of known shortcomings, and this is true of the earthenware duct. The fact remains, however, that throughout this time there has been no serious competitor, and due to the nature of the raw material alternative designs present considerable problems. Currently, some 4,000 bore-miles are used annually in the form of single-way, 2-, 4-, 6- and 9-way ducts, compared with only 60 bore-miles of all other types, including the small-bore service ducts.

The basic stages in the manufacture of earthenware, winning, preparing, extruding or moulding, drying and firing, are much the same as those that have been employed since the first pottery was made, but the techniques have changed considerably. In this article it is proposed to give a brief outline of the methods at present used in the manufacture of the Post Office designs of earthenware duct.

RAW MATERIAL

The raw material is clay, which occurs in varying form over a large area of the country. The original clay was produced by the natural weathering of granite rocks and is a mixture of several materials. The clay mineral is kaolonite, or chemically-hydrated aluminium silicate. It is this material that gives the clay its plasticity when mixed with relatively small proportions of water, and its important refractory properties. Quartz and mica in a finely-divided form are also present as the result of the weathering process. The former is relatively inert, but the mica is of some importance since it acts as a flux during the firing process. Clays of this general form occur as china clays in South West England and ball clays in Devon and Dorset; these are used mainly by the pottery industries. The vast majority of clays, however, are less pure, and, depending upon the age and conditions under which the deposit was laid down, contain varying amounts of other organic and inorganic earthy materials. It is these types of clay that are used by the earthenware manufacturer. The "adulterants" present may have desirable or undesirable effects on the firing and finished properties of the clay, depending upon their nature and the amount present. They are also responsible for the varying but characteristic colours of the finished earthenware.

During the firing process a series of relatively complex chemical changes occur. Broadly, these commence with a breakdown of the clay molecule at about 600°C and continue to the formation of glasses in the region of 1,100°C. The resulting material consists of complex crystals bonded together with a glassy substance, and it is upon the size and characteristics of these crystals that the strength and other properties of the finished article depend.

Before passing to the manufacturing processes, mention should be made of another characteristic of clay, —its high shrinkage on drying. This is clearly illustrated by the familiar summer ground cracks in a clay district. Shrinkage would perhaps cause no difficulty if the amount were consistent, but, due to the variable nature of the clays used in the manufacture of earthenware products, some problems do arise, especially as such variations may occur even within one manufacturer's clay pit. Some further shrinkage also occurs during firing. To reduce and control shrinkage and warping during both drying and firing a material known as grog is mixed with the raw clay before extrusion.

Grog, or red grog as it is sometimes called, is made by grinding broken duct to a fine powder. The burnt clay is unchanged by the second firing, thus its inclusion in the clay tends to restrict shrinkage. In some instances, the coarser residue from the screening of a ground raw clay is also used as a proportion of the grog. This is

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usually referred to as green grog and may contain small particles of gannister, or ironstone, etc. It has a lower shrinkage value than the finer clay and thus to some degree assists in the reduction of shrinkage and speed of drying. However, its inclusion tends to increase the porosity of the fired earthenware.

With certain clays it may also be necessary to add other materials to the grog to make good deficiencies that would otherwise result in an unsatisfactory end-product. Sand, for instance, may be added not only to control shrinkage and warping, but also to provide the silica necessary for partial vitrification of the clay. An excess of sand, however, can lead to brittleness. Lime is another additive necessary with some clays as a fluxing agent. Again, an excess of lime can be troublesome, and since the amount required is very small it is often added in the water used at the mixing stage rather than as a constituent of the grog. In general, however, earthenware clays are chosen for their natural firing properties.

PREPARATION OF THE CLAY

The clay is won from open pits, the top layer of soil having first been removed. Digging is usually carried out with mechanical shovels or excavators and the clay transported to the adjacent works by conveyors, light railway or lorry. At the works the clay is emptied into a hopper serving the grinding pan, which is usually of

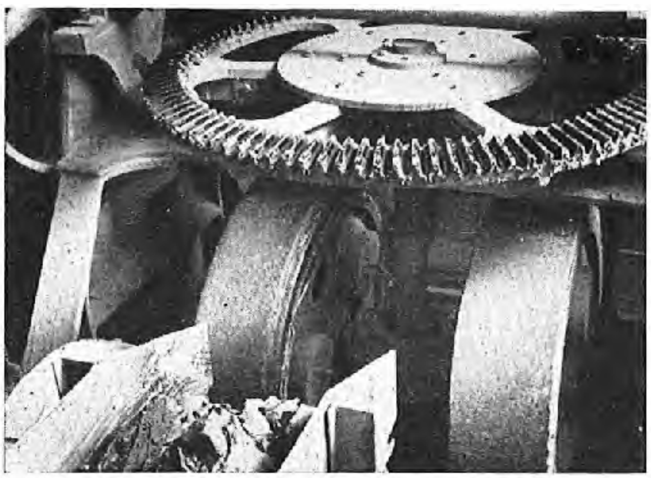

FIG. 2—CLAY GRINDING

the type illustrated (Fig. 2). This consists of two heavy rotating wheels that roll and grind the clay into a fine granular form, allowing it to fall through the perforated bottom of the grinding pan. The resulting powder is relatively dry and loose, but if firmly compressed it can be moulded in much the same way as the original clay.

The ground clay is often screened in rotating cylindrical sieves (usually a No. 10 sieve or smaller) to remove the coarser material so that, in general, only sufficiently-fine material is allowed to go on, the coarser material being returned to the grinding pan for further grinding. Sieves of this type have a tendency to clog, and modern screens use a sieve that is electrically heated and magnetically vibrated. The heating partially dries any material tending to adhere to the sieve so that it is more readily shaken free, thus avoiding clogging. The sieved material is stored in hoppers ready for use.

The clay as excavated is very stiff and does not vary greatly in water content even in wet weather; thus the process, so far, is designed to work the clay without drying or the addition of water.

From the hopper the ground clay passes to the mixing and extruding machines (Fig. 3). Here about 10 per

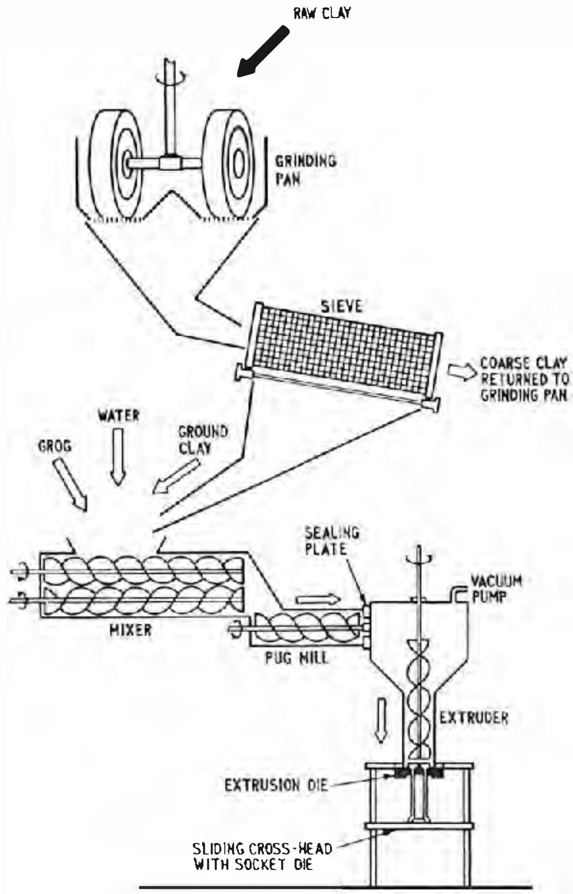

FIG. 3—DIAGRAM OF MIXING AND EXTRUDING MACHINES

cent of grog (including sand, etc.) is added together with just sufficient water to permit the clay to be kneaded into a plastic state by the contra-rotating double screws of the mixer. The proportion of grog used varies with the type of clay and earthenware to be produced, e.g. a 9-way duct will generally require more than a single-way duct. The double-shaft mixer feeds directly into a pug-mill. The pug-mill consists of a large coarse-pitch screw rotating inside a cylinder and works in much the same way as the domestic mincer or a sausage machine. The clay is thus compressed and forced directly through a sealing plate into the sealed hopper at the head of the extruder. The inside of the extruder is maintained at a fairly low pressure by vacuum pumps in order to extract air from the clay; the presence of air may cause the burnt clay to be porous and weak. The sealing plate is a perforated metal plate or it may be in the form of a narrow annulus. With either type, the clay is forced through the openings so that the vacuum in the extruder hopper is maintained by the body of compressed clay in the feeding pug-mill.

In an alternative arrangement the pug-mill does not feed the extruder directly but the compressed clay is cut off into suitable pieces before being passed through a de-aerating machine and then to the extruder. Again, with some clays, de-aerating offers no advantages and the process may be omitted.

EXTRUSION

The extruder operates in the same way as the pug-mill. Normally, however, the screw is arranged vertically so that the clay is compressed and extruded through the die near the bottom of the machine (Fig. 4). Since extrusion is not a continuous process it is necessary to arrange for easy stopping and starting of the screw, and this is usually achieved by the inclusion of a clutch mechanism in the drive to the screw.

FIG. 4—EXTRUSION OF DUCT

The die fitted to the extruder can be changed to suit the type of earthenware required. It consists essentially of a metal plate, usually a casting, with an opening cut through it having the shape of the article to be extruded. The plugs forming the bores of the duct are held by a steel web affixed to the body of the die. Thus the clay flows around the web before emerging through the opening in the die. The die includes on its underside a mould for the exterior of the socket of the finished duct. A vertically sliding platform or cross-head carries the mould for the interior of the socket. The exterior socket mould is loosely fixed to the underside of the die so that, except when the cross-head is locked in the upper position, there is a narrow space between the die and the mould.

At the start of the extrusion process the platform is held hard up to the underside of the die. Clay is extruded through the die into the socket mould, which, when filled, allows some of the clay to escape through the bottom joint of the socket mould as a thin "flash". This flash may be used to operate a switch controlling the cross-head locking mechanism. When this occurs, the platform is released and moves downwards so that the barrel of the duct is extruded from the die. When the desired length has been extruded the screw feed is stopped and a wire passes between the socket exterior mould and the die, thus cutting the duct to length. The duct is then removed from the platform and the process repeated.

Single-way ducts are normally lifted off the inner socket mould, but, due to the weight of the larger multi-way ducts, a number of inner-socket moulds are used, each mould then being removed from the machine with the duct and a new mould fitted to the platform before the extrusion process continues.

The extruded duct is normally dark grey in colour, with a smooth, almost polished, surface. It contains about 14 per cent of water, but is quite firm and can be handled without distortion providing reasonable care is taken. The duct is trimmed and finished either by hand or machine, or both. The socket flash is removed and the interior of the socket scored to provide a key for the Stanford lining. A similar key may also be provided at the spigot end. The inside edges of the bore at both ends are radiused. The finished ducts are then stacked on pallets and passed to the drying rooms or sheds.

DRYING

In the drying rooms gentle heat is used to remove the moisture from the duct. This is an essential preliminary to the firing since, at the temperatures involved in firing, water contained in the material would be rapidly turned into steam and would splinter or crack the duct, making it quite useless. Drying time varies greatly with the size of the duct. For example, a single-way duct requires one day whereas a 9-way duct will require about 14 days.

It is important during the drying process to avoid distortion due to uneven drying, and the process is thus relatively slow and carried out under uniform air-flow conditions. The drying sheds have slatted or perforated floors that permit the circulation of warm dry air up through the ducts. The ducts are stacked closely together, and in a large shed each batch may be protected on all four sides by temporary screens. Even so it is necessary to turn the outer ducts of the batch at regular intervals, or uneven drying might result, causing bending and distortion of the ducts.

A more modern method uses a bank of drying chambers or ovens with a system of damper-controlled interconnecting flues. With this method the chambers are filled with stacked ducts and closed. Dampers are then opened so that the warm damp air from the remaining chambers passes into the newly-charged chamber. The warm dry air passes initially into the chambers containing nearly dried ducts and from this into chambers with successively wetter ducts until the last chamber containing the new charge is reached, when the cooler moist air is discharged to the atmosphere. Thus, as the charge in each chamber is dried and ready for removal, the flue dampers are closed to seal the chamber from the incoming dry-air stream which is diverted into the preceding chamber where the ducts are nearing the end of their drying period. The inlets and outlets for the air stream are therefore circulated progressively around the bank of chambers.

The dried duct is quite hard, the plasticity of the clay having disappeared in the drying process. In fact, if subjected to a blow or heavy pressure the duct, in this state, would break rather than deform. The colour changes to a light grey, almost white, and for this reason the dried ware is often referred to as being "white hard".

FIRING

When the ducts are completely dry they are removed from the drying sheds or chambers and are ready for firing in the kiln. Perhaps the most commonly used kiln is the circular down-draught type. This is a brick structure circular in plan and having a domed roof, with firing hearths at intervals around the circumference (Fig. 5). The inside of the kiln is lined with refractory bricks and has an inner wall reaching to within a foot or so of the underside of the roof. The floor within this inner wall is perforated and gives access to an underground flue connected to the chimney. As a rule the chimney is arranged to serve a number of such kilns, which are built around it with the flues radiating like the spokes of a wheel from the base of the stack. It will be seen, therefore, that the hot gases from the fire hearths around the kiln are deflected upwards to the roof by the inner wall and then pass down through the earthenware, stacked on the floor of the kiln, into the flue and away through the chimney.

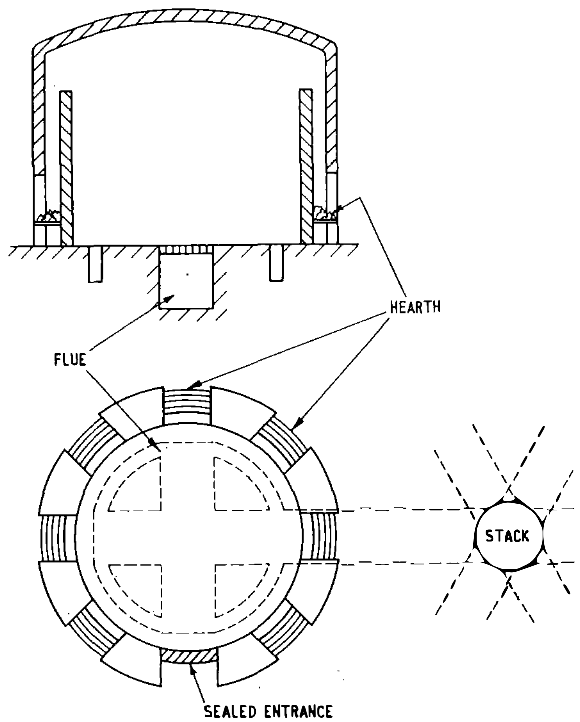

FIG. 5—DIAGRAM OF CIRCULAR DOWN-DRAUGHT KILN

The manner in which the earthenware is stacked is of considerable importance if the flow of hot gases through the kiln is to be evenly distributed and all the earthenware in the kiln burnt uniformly at the same temperature. Partly for this reason, it is often found that more than one type of duct is fired in the kiln at one time. Firing is one of the most expensive operations in the manufacture of ducts, and great care and skill are required to stack the maximum amount of earthenware in a kiln. The ducts should not touch, and the stack has to remain stable throughout firing. A collapsed stack would require a considerable amount of labour to clear and could ruin the kiln.

After stacking the white-hard ducts in the kiln the entrance is bricked up and sealed. The fires are lighted and the temperature raised to about 1,100°C, usually in a number of distinct stages or steps. Initially the temperature is raised to about 550°C as quickly as the clay will permit. This is known as the "water smoking" period, since all remaining water in the clay is driven off during this period. The temperature is then allowed to rise more slowly to about 850°C, whilst all carboniferous material and sulphur in the clay is oxidized or burnt out. Once this process is complete the temperature can be raised more quickly to about 1,000°C, followed by a slow rise to 1,100°C during the so-called "soaking period" whilst the vitrification process is completed. The earthenware is then cooled as quickly as is possible without fracturing. The time required for these different phases varies considerably with the types of clay and product. For single-way ducts the total firing period is about 5 days, whereas multiway ducts take somewhat longer since the heating and cooling stresses are more severe and, thus, firing must proceed more slowly.

Glazing is usually carried out at the commencement of the soaking period by throwing common salt on the fires. The resulting fumes passing through the hot earthenware attack the surface of the clay, fluxing it to form a glass surface on the duct. When sufficiently cool, the kiln is opened, and the burnt ducts, now having their well-known appearance, are removed.

This type of kiln has been standard for many years and is still much used, but alternative designs have been developed to reduce the firing and labour costs. One new form of kiln closely resembles in general principle the drying ovens previously described. The kilns are built together in a rectangular block containing 16 compartments. Each compartment or oven is provided with a firing hearth behind a curtain wall and in the body of the oven there is a perforated floor. A system of flues with dampers connects the underside of each hearth to the perforated floor of the adjacent oven. The hearths are fed with either coal or oil through small firing holes in the roof of the kiln. Only one oven is fired at a time. The air supply for this is pre-heated by drawing it in through the ovens containing burnt earthenware, from the coolest, where the ducts are nearly ready for removal, through successive ovens until it passes through the oven where firing last took place, and then into the oven being fired. The hot gases from this oven are then used to pre-heat the earthenware awaiting firing in succeeding ovens, and are finally exhausted to the chimney. It will be seen that with this type of kiln greater direct use is made of the available heat than with the traditional type previously described.

Another type of kiln is the tunnel kiln, which is also used in the pottery industry. This kiln is built in the form of an open-ended tunnel some 100 yd long. It may be heated with coal, but oil burners or gas jets set in the wall of the tunnel are more common, the exhaust gases passing out through a flue in the floor. The ducts are stacked on steel-framed trolleys or cars having a platform of refractory bricks, and these trolleys are moved on rails through the tunnel from one end to the other at the rate of approximately 12 ft/hr. The temperature gradients along the tunnel are arranged so that, during the progress of the trolleys, the earthenware experiences a firing pattern similar to that already described, the maximum temperature of 1,100°C being reached in a region a little beyond the centre of the tunnel, the earthenware emerging at the far end of the tunnel at a temperature near 200°C. This may seem rather hot, but by the time the trolley has completed its traverse to the unloading platform the earthenware is sufficiently cool to handle.

In the type of kiln just mentioned a salt glaze may be used, but there are difficulties due to the continuous nature of the kiln; thus, a ceramic glaze similar to that used in the pottery industry is often employed. The glaze, applied by a separate operation prior to firing, is a mixture, or slurry, in water, of finely ground borax, silica, lead and sodium salts, and other constituents. It is usually applied by spraying the bore only of the duct during the trimming process after extrusion. The constituents of the glaze are thus dried on to the duct during the subsequent process and during firing they melt and flux to give a glass-like coating to the surface of the clay. A glaze of this type has an advantage from the cabling viewpoint. With the salt glaze, results tend to be variable and a great deal depends upon the skill of the operator both when stacking the ducts in the kiln and during firing. Thus, with salt-glazed earthenware it is economically desirable to accept a small proportion of "dry" or partly-glazed bores which give higher cabling frictions, whereas a ceramic glaze permits better control and should always be perfect.

LINING AND FINISHING

It will be appreciated that the tolerances to which earthenware clays can be worked are rather greater than those common in most other manufacturing processes. Apart from shrinkage problems, the material is extremely abrasive, and as a result, if the extrusion dies are to have a reasonable life, a fairly wide variation in dimensions must be permitted. Tolerances of $\pm\frac{1}{8}$ in. and greater, depending upon the dimension to be considered, are not unusual. It will be apparent, therefore, that it is impracticable to manufacture earthenware ducts with a close-fitting joint. For sewage work the problem is overcome by cement mortar grouting the joints during laying. This is a tedious and costly operation and for Post Office work the same standard of watertightness is not usually required. Use is, therefore, made of the Stanford joint.

The duct is set vertically in a metal spigot mould and a socket mould is fitted. A compound made by boiling a mixture of tar, sulphur and sand or crushed burnt earthenware is then poured hot into the moulds. When cool the compound sets hard and adheres to the spigot and socket ends of the duct, sufficient key having been provided either by grooving the duct prior to firing or chipping away the glaze afterwards. It is a characteristic of the lining material that it moulds well with very little shrinkage. Thus with suitable devices to centre the duct in the lining moulds, much of the variation due to earthenware tolerance is eliminated and a well-fitting joint with optimum bore-centre alignment is obtained. Further, with the simple application of a soft jointing compound on site, it is, with good laying, practicable to obtain a silt-free, if not watertight, track.

The actual form of the lining machine varies from the simple hand-operated type to a fully automatic multi-head machine. In the simplest case, with single-way ducts, the spigot die may be set on the floor and the socket die fitted by hand. Optimum alignment of the lining with the bore centre is the main consideration, since the linings provide a spherical mating surface. With multiway ducts, however, this type of ball-and-socket joint is not practicable and the mating surfaces are given a plain taper. It is, therefore, necessary to design the lining machine so that the spigot and socket linings are both parallel and concentric if the resulting track is neither to tilt nor twist. The socket die may be carried on a cross-head between two rigid vertical guide columns or, as in the automatic machine shown in Fig. 6, each socket lining is held by a headstock

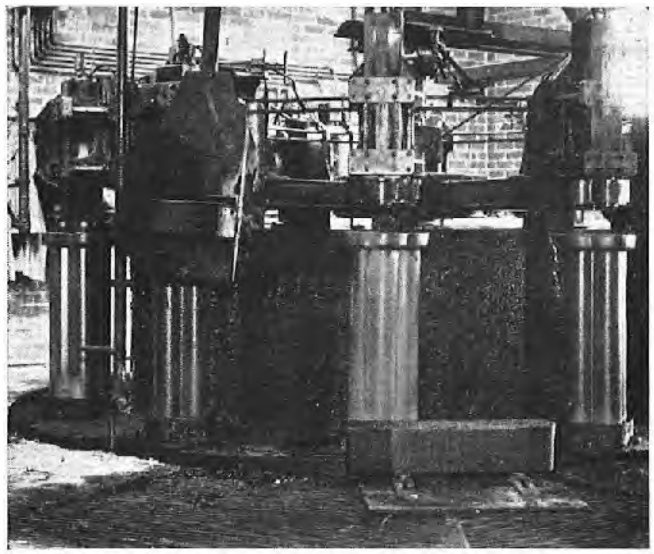

FIG. 6—AUTOMATIC LINING MACHINE

sliding on a large machined vertical bed similar to that of a lathe.

In this last type of lining machine, the whole machine rotates. The operator places a new duct on the spigot die as it passes him. As the machine rotates the socket dies are lowered automatically into the duct socket, and the lining composition applied. When this composition has set, the socket die is lifted ready for the finished duct to be removed; this occurs as the machine completes one revolution. The finished duct is removed to the stack yard for final inspection and to await despatch to site.

CONCLUSIONS

It will, perhaps, have been appreciated from the opening remarks and later discussion that progressive improvements in the design of earthenware ducts cannot readily be achieved. Furthermore, with the large quantity used, the price margin available for such improvements is relatively small if the annual bill for ductwork is not to be greatly increased. These factors, coupled with a reasonably satisfactory performance of the existing design, tend to lead to somewhat static conditions. It is therefore not surprising that prior to 1958 no rigid dimensional specification existed for Post Office multi-way ducts, and slight variations in dimensions and tolerances existed between different manufacturers' products This did not, in general, lead to difficulty since ducts for a particular work normally come from one manufacturer. However, instances could and did occasionally occur where difficulties were experienced in using ducts from two or more sources. It was decided therefore to tighten up Post Office requirements for all earthenware ducts. This apparently simple step, however, due partly to the nature of the item, presented considerable difficulties and the standardized duct was only achieved after much work and discussion with manufacturers.

However, development of ducts is not static, and other pipe materials, in particular plastics, are now presenting a potentially serious challenge to earthenware. Prices and techniques with these alternatives could, in the not too distant future, offer an underground-cable conduit system with advantages over earthenware and at comparable cost. A great deal of work remains to be done, however, before radical changes could be made.

Amongst the advantages offered by the new duct materials are improved rodding conditions and a completely watertight track. Earthenware on the other hand offers an assured life with a considerable background of experience. With this in mind therefore the Post Office, together with the earthenware manufacturers, is examining the prospects of alternative earthenware designs in an attempt to give this tried and proven material at least some of the advantages of the new types of duct. At this stage it would be foolhardy to attempt to predict future duct standards, but there is little doubt that earthenware duct will continue to have its place in the Post Office underground system.

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