The Metallurgy of Fillet Wiped Soldered Joints*

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THE seriousness of the present tin scarcity has stimulated large consumers of this vital metal to develop drastic conservation measures in order to extend the available supplies to cover the emergency period. By devising new soldering methods and alloys the Bell System has contributed a substantial share in the tin conservation effort. Fortunately, the changes, as far as can now be determined, have not introduced weakness into the soldered joints. Some of the new procedures now used were already in the process of development at the onset of the emergency, while others were devised under its stress. In some instances, the newly developed solders were found to be more difficult to use than the alloys previously available, and would not have been introduced under normal conditions. One major change made that previously had been under consideration will result in large tin savings. Unless service difficulties are encountered, this modification gives promise to remain after the emergency has passed. The change involves a reduction in the amount of solder placed on a wiped joint between the cable sheath and the sleeve. Instead of the customary full size wiped joint a wipe of fillet proportions is formed. Through this change, a solder saving of over 60% per joint can be realized.

Plumbers and cable splicers have for many years joined lead pipes and cable sheath by a soldering process called "wiping." The name is an apt description of the operation. In wiping a joint the sections to be united are heated by pouring molten solder over their surfaces and manipulating the resulting semi-liquid mass by wiping with cloth pads to a well rounded symmetrical form such as is shown in Fig. 1. The operation requires considerable skill on the part of the splicer and close control of the solder composition. At first consideration, the problem of tightness in such joints seems simple but experience shows that even under the best conditions the fissures frequently found in the solder occasionally link to form a path that allows leakage to occur. In the case of telephone cables not maintained under gas pressure, such leaks permit the entrance of water to wet the paper covered conductors, thereby impairing the insulation value and causing service interruptions. By going to an extreme and wiping off all the solder in excess of a fillet, it has been found that many causes of porosity are eliminated. Figures 2 and 3 show cross sections of joints wiped the old and new

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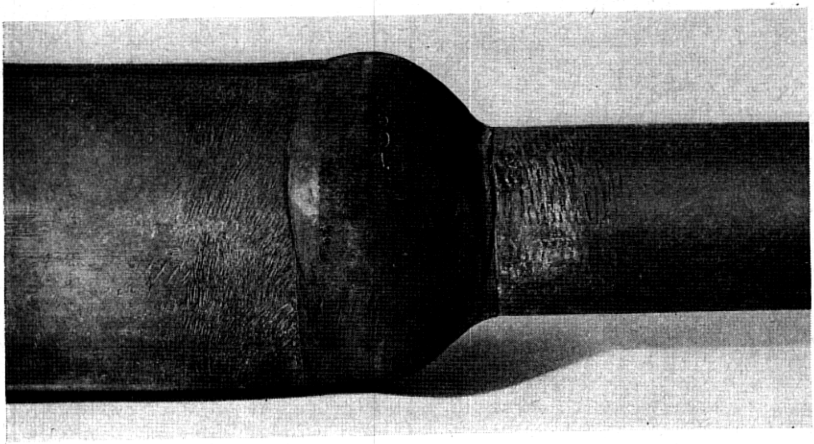

Fig. 1—A conventionally wiped joint between telephone cable and sleeve (third size).

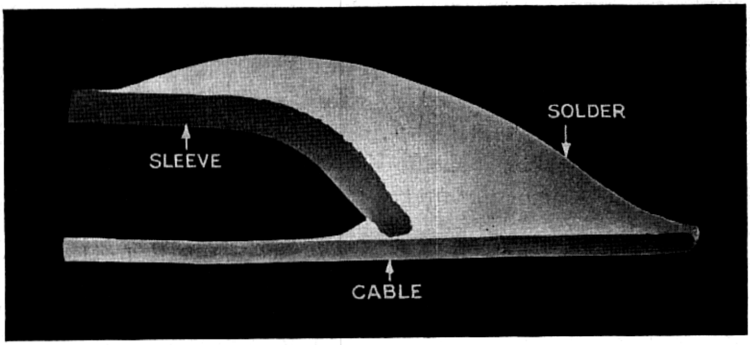

Fig. 2—A section taken from a joint wiped conventionally (magnification 1½ ×).

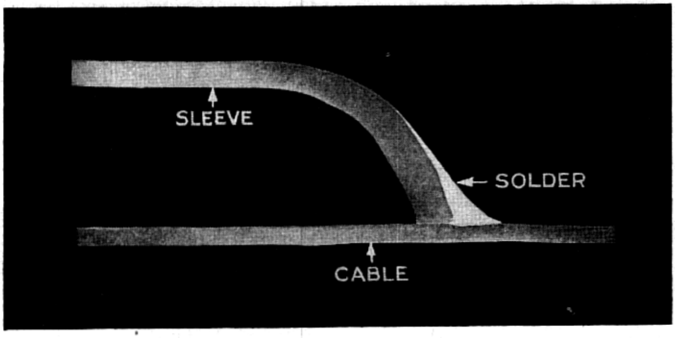

Fig. 3—A section taken from a joint wiped using the fillet technique (magnification 1½ ×).

ways. The saving in solder and consequently in strategic tin is evident. The field splicing forces find that joints are easier to make by the new method and are less apt to be porous.

Several interesting metallurgical considerations which are responsible for the success of the fillet wipe will now be discussed briefly. Much has been written about the wiping process of soldering cable joints and the many requirements of a good wiping solder have been frequently listed. The success of the procedure here described is dependent upon a few fundamental characteristics of lead-tin alloys in the process of freezing which have sound metallurgical explanations.

For an understanding of the defects possible in a soldered joint wiped in the usual manner, the simple solidification phenomena of metals may be considered. As is well known, molten metal in a crucible when allowed to cool with free circulation of air will begin freezing near the walls of the vessel and with a few exceptions, will end with a concave surface due to solidification shrinkage. Restricting the discussion to a simple lead-tin wiping solder, solidification progresses as follows: a lead-tin solid solution commences to freeze and forms a rather porous cylinder touching the crucible walls and extending to a height corresponding to the volume of the melt at that time; on further cooling, dendrites of lead-tin solid solution grow inward toward the center of the crucible and at the same time many tiny new crystals form throughout the liquid. There are thus taking place simultaneously, shrinkage of metal as it becomes solid, shrinkage of previously frozen solid as it cools, and shrinkage of the remaining liquid as the temperature drops. The originally solidified outer cylinder, adhering to the crucible walls remains essentially at its original height. The level of the semi-liquid portion nearer the center of the crucible continuously falls until the precipitated crystallites formed in the body of the melt make a loosely piled mass extending from the upper surface to the bottom of the crucible. Further shrinkage of the liquid then leaves these primary crystallites at approximately this level while the liquid recedes, leaving fissures between them. This can be beautifully observed by means of a binocular microscope focussed on the surface of a soldifying crucible of wiping solder or, on the top surface of a solidifying wiped joint.

Further insight into the mechanism of wiping solder solidification may be gained by another simple illustration. If two solder strips are cast by pouring small quantities of molten solder, one on a cold iron surface, and the other on a cloth-covered board and both are then bent cold to produce specimens as shown in Fig. 4, the chill cast sample will exhibit fewer cracks resulting from shrinkage than the slowly cooled one. In the slowly cooled sample primary crystallites form throughout the solidifying mass and pack at a level above that which the final volume of completely solid solder warrants. The sample cast on the cold plate starts to freeze at its surface in contact with the iron plate and, because of the rapid extraction of heat by the cold iron, it continues to freeze in a rapidly advancing smooth front until the last liquid at the top is solid. Because of the steep temperature gradient there is little opportunity for nucleation and dendrite formation in the upper liquid. The surface of this melt is therefore smooth and free from the fissures that are caused by the shrinkage of the eutectic away from the dendrites in the slowly cooled sample. Recession of the liquid in the slowly cooled sample leaves a multitude of shrinkage channels which, if they occurred at the critical portion of a wiped joint, would cause leaks.

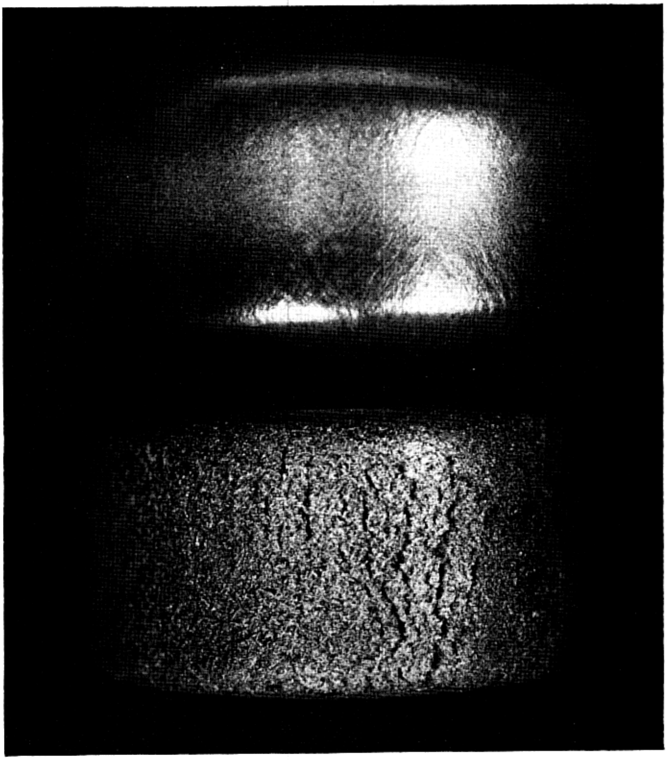

Fig. 4—Bent strips illustrating the effect of variations in cooling rate on the structure of wiping solders are here shown. The upper strip was chill cast and shows a sound ductile surface. The lower strip of the same solder was slowly cooled and upon bending exposes fissures between the crystallites at the surface (magnification 3 ×).

Another illustration may be useful in demonstrating the processes taking place in connection with joint wiping. Solder may be allowed to solidify in a crucible until its surface is quite firm to a probe. If, at this stage, the crucible is tilted sideways to a position shown in Fig. 5 a portion of the remaining eutectic may be poured out leaving spongy regions. This loss of eutectic is observed frequently during the formation of the old massive type joints which may lose several drops by drainage after the splicer has completed his shaping operations. It is also shown by the greater number of pores in the top half of a joint compared to the bottom and the somewhat grayer surface appearance of the top.

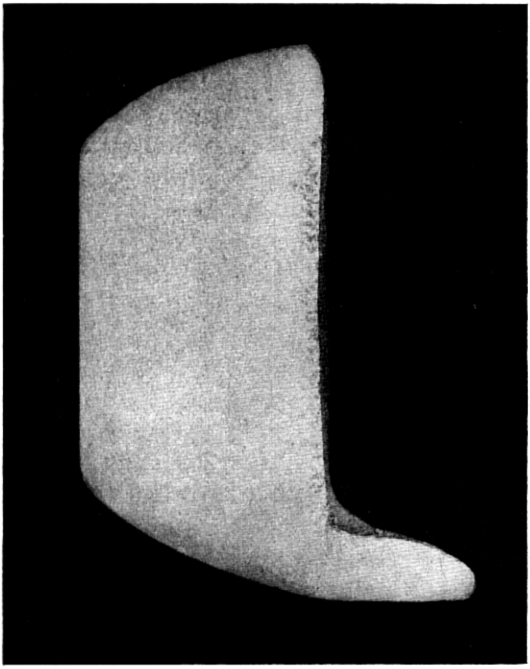

Fig. 5—An ingot of wiping solder which had been tilted while in the crucible before completely solidified. The lower lip represents eutectic drainage from the partially solidified mass (magnification $1\frac{1}{2}\times$).

Although a solidification range in which quantities of liquid and solid metal may exist at equilibrium is an essential feature of a wiping solder, another factor of major importance is the nucleation rate of the alloy. Wiping solders having high nucleation rates will develop quickly a myriad of points or nuclei throughout the melt from which further crystallization will proceed, while an alloy of low nucleation rate will develop relatively few of these points in the same time and consequently grow fewer and larger crystals. The former alloy will have a texture similar to fine clay while the latter will behave like coarse sand and water when subjected to wiping tests. In the fine clay-like texture there are more solid particles present than in the water-sand type of texture and therefore there is more surface available for the retention of the liquid in the former type of semi-solid mass. Drainage is thus greatly retarded with the result that porosity is materially lessened. The type of texture determines in a large measure the ease of shaping and potential porosity of a wiping solder.

Having examined elementary forms of solidification, attention may now be focussed on the setting up of the wiped joint itself. In practice, the parts to be joined are cleaned and fluxed. Circumferential paper pasters are then applied to the sheath and sleeve to restrict the spread of the solder. The splicer then pours hot solder from a ladle over the prepared parts and catches the excess in a cloth held in contact with the bottom of the joint. The caught solder is repeatedly pushed back around the cable with a wiping motion to aid "tinning" or alloying and to distribute the heat. After a few such operations the prepared surfaces can be seen to be thoroughly wetted by the solder. At this stage a portion of the caught solder is mixed in the ladle with more hot solder and the mass which now has a clay-like consistency is poured on the joint and molded into place using cloth pads. When solidification has proceeded to a condition where the solder can support itself in position, manipulation is stopped. From this point on, loss of heat takes place by conduction away from the joint by the sheath and sleeve, by radiation, and by air convection currents at the surface of the solder. As a result of this combination of heat losses final solidification takes place in the interior of the solder mass near the important sheath-sleeve junction. The action that causes pipes to form in castings draws the eutectic from the critical area between the sheath and the end of the sleeve. If the solder has the proper characteristics there will be a shell of solder which does not have interconnecting shrinkage cavities, drainage cavities or fissures due to the wiping operation and the finished joints will be gas tight. If the solder is unduly coarse or has insufficient liquid eutectic at the time the mass is too rigid to manipulate further, the resulting joint may leak.

The new fillet wiping technique is similar to the old up to the step where the splicer molds the mass to shape. At this point the new technique consists in wiping the solder to a small fillet similar to that shown in Fig. 3. The resulting joint has much less solder and therefore much less total shrinkage and tendency to draw eutectic from the space between the sheath and sleeve. Also, at the temperature where wiping is discontinued there is insufficient volume of solder left by the fillet wiping technique to permit drainage drops to accumulate and fall from the bottom of the joint. Thermal conduction along the sheath and sleeve cause rapid solidification of the solder at the joint, eliminating the possibility of drainage. Experience has shown a consistently high percentage of sound joints when fillet wiping is rigidly practiced. During the development period of the fillet wiping technique examination of the few fillet type wiped joints that were found to leak showed quantities of solder present much in excess of that required. Under the microscope such joints showed the tell-tale sponginess where the eutectic had been drawn away from the junction in the course of final solidification.

Physical tests on joints made using the fillet wipe between sections of telephone cable and sleeving, have demonstrated that fillet joints similar in size to that shown in Fig. 2 made with 38% tin, 0.1% arsenic, balance lead wiping solder are stronger in tensile strength, creep and fatigue than the cable itself.

The application of the new technique has gone much further toward saving tin than any known permissible change in the composition of solder. Using the old technique, a reduction of only one per cent in the nominal tin content of a lead-tin wiping solder resulted in widespread occurrence of leaky joints, indicating that little tin could be saved by a simple change in solder specification. This observation was to be expected since many studies had been conducted over the years to reduce the tin content in wiping solders to the minimum consistent with the production of satisfactory joints. Tin has always been much more expensive than lead and for large users of solder a reduction of one per cent in the tin content might result in savings of many thousands of dollars annually.

While the use of the fillet wipe results in large savings in tin other avenues for conserving this strategic metal are available such as the substitution of ternary and quaternary alloys containing less tin than that required by the binary lead-tin wiping solders. A satisfactory alloy of this type was developed which contains 13% tin, 23% bismuth, 0.1% arsenic, balance lead. Though readily available a short time ago, bismuth now has become too restricted to be used extensively in solders. A wiping solder is now being introduced into service in which, through the inclusion of a small quantity of antimony, it has been possible to reduce the tin content. This material appears suitable for fillet wiping although it requires more skill to use than the 38% tin, 0.1% arsenic, balance lead wiping solder. Other compositions may be usable that contain less than normal tin, but on the whole, the savings accomplished by composition modifications will be small compared to those produced by the new wiping technique that has been described.

IN SUMMATION

By virtue of its small solder volume the fillet wipe reduces tin consumption and produces joints less liable to leakage than the conventional wiped joints. The reasons for the success of this type of joint are based on the sound metallurgical principles herein described. The use of the fillet wipe promises to survive the period of restricted tin consumption.