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The Characteristics of Copper under Various Conditions.

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READ

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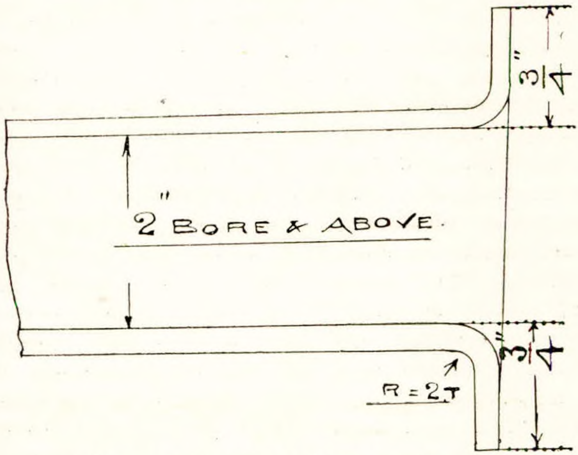
CHAIRMAN: MR. E. W. ROSS (HON. FINAN. SECRETARY.)

MUCH has been written within recent years upon copper and its peculiar characteristics, for the most part from the metallurgical and statistical side. Little appears to have been put forward from the practical tradesman's point of view, and this paper is an attempt to deal with the manipulating of this somewhat expensive metal at the hands of the copper-worker. Attention will be given more particularly to the working of copper for engineering purposes, both marine and land requirements, the domestic and other purposes to which the metal is put not concerning us for the moment.

The whole process of copper working is a closed door to many engineers not brought into contact with the coppersmith's shop, and it is more especially to such that my effort is addressed. Possibly the more widely experienced engineer will be able to gather some useful and interesting data from my remarks. Each process will be explained in detail, and in such a manner that the comparative stranger to the actual working of copper will, I hope, after reading this paper, be enabled at any stage in the process of pipe-making, to determine fairly accurately the quality of material and workmanship before him. In this manner I hope to restore, or gain the confidence, of the users of copper pipes. The notion that so-called trade secrets should be exclusive is altogether antiquated. Publicity leads to better understanding all round, and the Superintendent Engineer or the Overseer is always more satisfied when familiar with the process of manufacturing the commodity he is called upon to inspect. Were this more generally recognized, we coppersmiths would have less occasion to deplore the substitution of other metals. It is to be regretted that many otherwise good tradesmen work by "rule of thumb," which is of course no rule at all. This is peculiarly mystifying to the beginner, and accounts for the many diverse methods of working in different shops. The great majority of coppersmiths have little or no conception whatever of the reasons for adopting a certain method. Having seen it done before, they are quite satisfied and merely follow old customs. The scientific engineer will at once perceive the weakness of this method, and will no doubt recognize in the remarks I shall make that no development will be described unless the object aimed at, or reasons for its adoption are stated.

Deposited Copper.—Much reliance is placed in some quarters upon various mechanical tests for determining the quality of the copper, usually, I fear, misplaced. This craze for test pieces received a severe shock at the time of the Elmore panic. In this instance we had a metal capable of passing all the recognized mechanical tests twice over, yet this metal, after mere exposure to the weather for a year or so, without any attempt to put work upon it beyond that which the tube and sheet people had executed, literally fell to pieces upon efforts being made to work it. Without in any way submitting a chemical or scientific explanation for this phenomenon I would take the liberty of enlarging upon a theory of my own, which it may repay us to follow up, at any rate I offer it for what it may be worth. It is that the molecules or particles of copper, the cohesive force of which give the metal its peculiar ductile characteristic, being mechanically mixed, that is deposited crystal upon crystal in the electric bath, offers much less resistance to the action of atmospheric gases than does the metal mixed in the molten state. In the latter procedure, the poling of the copper by the insertion of a sapling, well stirred into the molten metal, introduces chemicals in the form of gases, which act as a protection against external atmospheric attack. When copper is heated to brazing heat, or an even less temperature for a long period, a transformation appears to take place in the copper, this peculiar protective chemical formation due to the poling, escapes, and the metal becomes brittle and useless for copper piping. Without going so far as to accept the somewhat extravagant hypothesis of the micro-organic theory in regard to metals, I am firmly convinced, by close observation, that there must be certain atmospheric gases which have a decidedly deleterious effect upon copper : call it a disease if you wish, but it is beyond dispute that degeneration takes place in copper under the action of gases. This is quite apart from common oxidizing or rusting. Moreover, in regard especially to deposited copper, this weakness can be demonstrated to be due not to the amount of work put upon the metal, but solely to the length of time the metal is exposed to the atmosphere. Whatever the weakness is, its development is abnormally rapid, as within the short period of a few months a piece of this Elmore copper, capable at first of withstanding extraordinary strains, becomes absolutely useless. This deposited copper could be gradually worked with repeated annealings (sometimes annealed over one hundred times) into a class of special work, such as expansion pieces of various designs, and it would finish with a surface absolutely clear of marks or defects, no other copper ever equalled it in this respect, yet if, when finished (at which stage it would be remarkably ductile), it were exposed to the atmosphere for from two to three years, or if under steam pressure with the corresponding heat for a few months, the result was disastrous, and the copper gave every appearance of breaking into small pieces. I have dealt at some length with the now somewhat ancient topic of Elmore copper for the simple reason that I believe the comparison of experience in this, compared with other metals, will give us the clue to some of the hitherto unexplainable difficulties. I am anxious that readers will bear in mind my digression and deductions, which will occasionally be referred to later.

Mechanical Tests.—Our study of deposited copper naturally leads us on to the subject of mechanical tests. I fear that the doubling over and bending of copper strips into various more or less fantastic shapes is of little final value. As a matter of fact, mechanical experiments, unless spread over a long period of time, are useless for authentic data purposes. The orthodox Board of Trade and Lloyd's test of doubling over an annealed strip of copper and thinning down the doubled edge with a hammer is unsatisfactory, as I have never, in over twenty years' experience, found a well-prepared test strip fail, yet I have certainly at times had some very poor copper through my hands, but this test fails to detect the weakness. If the craving for a mechanical test must be satisfied, I would sug-



FLANGING TEST FOR SEAMLESS TUBES.

gest that a test for detecting any latent weakness in seamless tubing be as follows :—

Carefully smooth file round the end of a piece of the tube to be tested, and after annealing, work over a flange with a hammer, the width of flange to be say $\frac{3}{4}$ inch for 2-inch bore tubes and above, and $\frac{1}{2}$-inch wide for below 2 inches, the radius at neck to be twice the thickness of the material. This should be clear of any signs of splitting or breaking. It is a fairly stiff test, and would undoubtedly show up any tendency the tubes may have for splitting longitudinally, and also be a fair test for transverse weakness.

My own personal experience, however, in regard to this mechanical test question has been unsatisfactory, good copper sometimes giving bad test results and poor fracture, at another time copper showing good results in the testing and first-rate fracture has in succeeding stages developed abnormal weaknesses, even after the most careful personal supervision in regard to temperature, etc. What I suggest is, that the buyer should take note of the most important details in regard to pipe manufacture, and from what is shown in this paper, judge for himself if he is being treated honestly, and in that way gain confidence in the capacity of the coppersmith to detect any faults and to replace same with good material. Where care has been taken to procure tubes and sheets from reputable makers, comparatively little trouble follows.

Corrosion.—The question of corrosion or wasting is one that comes more under the jurisdiction of the chemist or analyst, than the practical coppersmith. The coppersmith can but note results and theorize. I will give a few very striking instances of the effect of this wasting in copper piping. It will be worth the engineer noting the effect upon copper steam pipes of the patent covering sometimes used, composed of dung and other mysterious ingredients, the ammonia and other products from the covering acting upon the copper and causing pitting. The fact that the copper is pitted, and not acted upon uniformly may be explained in two ways ; first, the particular solvents may not be of equal strength and activity over all parts ; secondly, the metal may not be completely homogeneous : as a matter of fact, no metal is absolutely so. The extraördinary effect upon copper steam pipes on locomotives, when fixed in the way of the furnace gases is remarkable. A method adopted upon some old-fashioned outside cylinder locomotives of fixing the copper steam pipes in the smoke box at front end of the engine occurs to my mind. These pipes became sadly pitted and scored where the hot gases played upon them, and I have seen copper pipes $\frac{3}{16}$-inch thick under these conditions wasted completely through. Strange to say in the case of a seamed pipe under these conditions, the solder was not affected and stood out upon a wasted pipe sometimes like a piece of cord along the pipe. Heat undoubtedly aggravates the tendency to corrode when the particular chemicals and gases are present. I would suggest, if a durable and suitable paint can be procured, that all pipes be coated over, not necessarily to hide the coppersmith's bad work, but to exclude the atmospheric and other gases.

Purity of Metal.—There seems to exist a somewhat erroneous idea that copper to be really trustworthy and durable must possess a small amount of impurities. No one appears to have any conclusive idea as to the exact quantity of this foreign ingredient necessary. The matter is usually mentioned in a delightfully hazy manner, that the impurities must not be too much, nor must they be too little. I have not the slightest difficulty in understanding the smelter's position in regard to this impurity question. The smelter's greatest trouble is to produce an approximately pure copper, and he, for obvious reasons, is not enamoured with the idea of producing an absolutely pure metal. In fact, by the ordinary smelting process a pure copper cannot be produced. The problem of how engineers and many coppersmiths come to regard impurity in copper as a *sine qua non*, is not difficult to solve. It is the result of attempting to determine the virtues of copper by the same methods applied to steel and other metals, that is by tensile and elasticity tests, and the various mechanical tests mentioned previously. It does not follow in the case of copper, that the piece giving the highest tensile figure, or showing the greatest elasticity limit is the best for the purposes of pipe making. Copper pipes rarely give way, because the pulling stress between the points at which it is fixed is too great, but as a result of a series of vibratory movements gradually hardening the material: this I shall deal with in the section upon "*Overstraining*." Some copper with a fair share of impurities in it gives splendid test figures, but completely fails when put under any prolonged working, either by the coppersmith or in its final position under pressure and vibration. The best metal I have ever had through my hands, giving the best results both in its production and final utility, was copper electrically pure, but smelted up again and cast into billets and drawn or rolled. I cannot see any ultimate solution to the question of purity in copper, until the metallurgist and the practical worker are more in touch with each other. Meanwhile I pin my faith, for the reason given, to the pure copper.

Overstraining.—A most important point to be noted in the working of copper, either tube or sheet, and probably this applies equally to many other metals, is that although in the process of annealing after hardening by working the metal is returned to its original ductile condition, this has its limits.

What I wish to infer by that is, that copper can be overworked or strained beyond the point at which annealing will return it to its previous malleable state. This is exactly what happens to pipes when they are kept at work unduly without being annealed, not only are they liable to failure at any time whilst in that strained condition, but if annealed, they will have restored to them their original quality only in a limited degree. Engineers naturally are suspicious that it is not so much the preservation of the copper pipe the coppersmith is anxious about, as the placing of another item upon his order book and later upon his ledger account. To such I can only say, read carefully this paper and then draw your own conclusions. In regard to this overstraining by the copper-worker, I have had exceptional opportunities of observing this in the many highly-worked pieces of copper passing through my hands. When one has to laboriously hammer, by hand, pieces of copper for days sometimes, to find at the end that the copper has failed, it makes one concentrate their faculties for seeking out causes, and the failure is often due to overstraining in trying to work the copper excessively to facilitate progress. It is obviously difficult to give definite advice on this particular subject, to say that copper should not be worked too much, neither too little, is somewhat nebulous, experience must be the final arbiter. Questions of gauge in the material and shape of work enter so much into the problem that fixed rules cannot be given, but if the data given in this paper for bending pipes and working bends be not exceeded, all overstraining will be avoided. Overstraining in the working of copper shows itself by irregular cracks, which after being cut out with a gouge chisel reappear. When any of these cracks appear it is not only a sign of overstraining, but also a sign that the piece of copper showing the cracks should be treated by the brass founder in his melting-pot, in a word "scrapped." These longish irregular cracks that develop must not be confused with the patches of irregular marks that sometimes show, and which give one the impression that if knocked up from the inside the piece would fall out; this is due to an entirely different cause, and will be touched upon in the section upon annealing.

Annealing.—The process of annealing gives, I dare venture to say, by far the most concern to the outsider. Any defect in a pipe of whatever description is at once put down to faulty annealing, that is, overheating. I am able to write with some amount of authority upon this subject, having carried on experiments and noted results covering a long period of time. It is of little use to a genuine inquirer to have made to him the bald statement that a particular defect is due to burning or overheating, unless some authentic reasoning is produced to support the assertion. It is useless, as a rule, making complaints to the manufacturers of the tube or sheet in respect to any defects coming to light in the working of the copper : they have one stereotyped reply to all comers which is that the copper has been overheated. The statement is the same, even if the copper has never been near the fire since its receipt from the mills. This burning notion is a fairly safe line to take, unless the person dealing with the copper has had a long experience and been observant. In similar respects to the question of impurities in copper previously mentioned, this subject of the temperature at which copper loses its characteristics is equally vague and arbitrary. The difficulty arises through efforts being made to trace all defects back to overheating, hence confusion and contradiction. I shall try to classify the trouble.

The actual temperature to which the copper is heated is not nearly so important as the length of time it remains at the given heat. I am not giving the temperatures of the different coloured heats, for the simple reason that an instrument for its detection is not usually part of the equipment of a coppersmiths' shop, and the coppersmith must depend upon a much more rough-and-ready method for daily use. Now I should define burning as raising a piece of copper to such a heat (as a matter of fact white heat) that caused the copper to become roughened and covered more or less with globules or blisters. This condition could not be mistaken, though it might be better to take a piece of copper oneself and try it. Strange to say, if the piece of copper has been treated in this manner, presuming the operation to have been rapidly performed, and the copper only slightly roughened, it apparently has received little damage and will stand all the ordinary tests that would be applied to the piece not so heated. This conclusion is not arrived at by hasty methods, and it amounts to this, that heating copper to any temperature short of blistering the surface has little ill effect upon the copper, though all the same I do not advocate trying how near one can get without actually blistering the surface, because it is not necessary to raise copper to even brazing heat to properly anneal it. What is a real danger in the heating of copper is the prolonged heating. The term "gassing" and "reducing flame" are new names for an old trouble, with which intelligent coppersmiths have long been familiar; many may not have known the actual chemical process, but the evil was recognized. Copper tube or sheet can safely be raised to a bright red heat without danger, the burning heat is considerably higher, and unless with gross carelessness, is rarely ever reached, but the sheet or tube must be immediately removed upon attaining to the heat mentioned. Any discussion upon the rival merits of quenching in water or natural cooling, would be "much ado about nothing." Cooling off in water shows a distinct disadvantage in the case of a very intricate and prolonged piece of work requiring some dozens of anneals. This I have proved time and again in the same manner, and for the same reasons as in the case of overstrain. For ordinary work, however, requiring but one or two annealings, the difference is so trifling as to be negligible. Quenching offers the most inducements for economic reasons, as when the copper is allowed to cool out, the coppersmith has to cool out with it, it not being practicable to give them fresh work at each anneal, therefore, on these grounds, quenching for ordinary practice is preferable.

A few words now in regard to the process of annealing. Furnace annealing for copper pipes is excellent on paper and in theory. In practice it suggests many objections—namely, high first costs, a large capacious furnace being requisite for the many lengths and varied-shaped pipes, heavy cost in upkeep in fuel, difficulty, perhaps not very great, of regulating temperature and securing uniform temperature throughout, also the distortions of the bends under heat. This latter is a great drawback, as even in steel pipes of sizes up to 5-inch bore $\frac{3}{16}$-inch thick, this takes place. There are equally good and more economical methods quite safe to adopt. Bends up to 5-inch bore can safely and satisfactorily be annealed on a large coke fire, with blast, say, half on, and a covering of sheet iron over to retain heat. It is not at all a delicate operation: the heat being quite easily judged, and any tradesman of moderate ability can safely be trusted. The fool would scrap the work under any conditions. Pipes above 5-inch bore should be annealed by slinging them up with lower and horizontal within easy access of about a 2-inch blast pipe. Charge end of pipe nearest blast connexion with light pieces of wood, lighting same with hot cinders or gas blow-pipe, then blow blast through : the wood being repeatedly replenished. The effect to aim at is the emitting at opposite end of pipe of good supply of flame. Too much wood results in dense volumes of smoke, too little wood causes lack of flame, and discharge of merely sparks and burnt wood. A little experience would soon enable the operator to decide upon the happy medium. A few minutes sees the pipe become a uniform red heat throughout its whole length. A 12-inch bore or even larger bend, 12 feet or so long, can be heated by this means from end to end a good annealing heat in a quarter of an hour or so, at an expenditure of a few coppers in wood, as old scrap template wood could be used. This method removes the possibility of any part not being properly heated. It may interest some to know that copper will attain to a degree of hardness by mere exposure to the atmosphere, the degree depending upon the time of exposure. It is advisable to re-anneal any pipes that have lain about for over twelve months, especially if any bending or working is required to be done to them.

Copper Pipes.—There are, generally speaking, two methods of making copper pipes—from seamless tube, and from sheets brazed up. For all purposes, where practicable, the seamless is the superior. The size of the pipe, radius of bends, thickness of metal, and cost, are usually the determining factors. The cost affects the matter in this way, all seamless copper tubes above a certain size in diameter, and lighter in thickness than what is termed "basis price," size and gauge, rapidly increase in price per lb. for each part of an inch larger in diameter or gauge lighter in thickness. It is, in the ultimate cost, more economical to make all pipes up to 6-inch bore 12 W.G. thick from seamless tubes, the ease and safety in bending the seamless tube more than compensating for the slightly larger outlay on a few of these tubes. The many shaped pipes the coppersmith is called upon to bend, make it bad practice to use seamed pipes where it is possible to avoid it, the seam often being a source of trouble, cracking and splitting when punished in the bending. When the size of the pipe, or the smallness of the radius, render it impossible to bend a tube satisfactorily, the pipes are built up from sheet, which method I shall deal with later. Any reference I make to tube or sheet only applies to them after delivery from the mills.

Seamless Pipes.—It may generally be taken as an axiom that copper which had withstood the test of being drawn into a tube, has but little the matter with its quality. Any defects that subsequently arise are usually discovered during the bending and hammering if not before, and they are purely mechanical, but not connected with the metal itself. These defects, when they do arise, consist of longitudinal flaws or marks, detected upon the interior or exterior of the tube, generally the cause is carelessness with the dies in drawing the tube, dirt and grit getting between the steel dies and the copper. A further mechanical defect sometimes found is what are termed laminations, which are the result of blow holes in the original billets becoming rolled and drawn in the subsequent working, showing in the finished tube externally as scale or loose skin of copper, and internally as blisters. The presence of these defects, except in cases where the marks are very superficial, must mean the condemning of the tube. Tubes should be delivered soft for economic reasons, and should be filled with resin and mixed with about 10 per cent. of pitch to prevent the resin crumbling. Lead should on no account be used. It is one of the worst of metals in its bad effect upon copper. It can never be absolutely cleared from the interior of pipes, even when the precaution is taken of whitening the inside of the pipe, and during subsequent heatings for annealing and other purposes the lead residue eats its way into the copper. To test the evil effects of lead upon copper, take a strip of the latter metal, and with a minute piece of lead upon it, heat over the fire to a good red heat, note the energetic action of the lead, and, after cooling, carefully examine the surface of the copper acted upon by the lead, remembering at the same time that the longer the copper is heated, the deeper the lead will penetrate. This is the action which takes place upon the bends and other inaccessible parts of the pipes when heated after having been treated with lead. All bends in ordinary practice can be shaped on the resin. Apart from the disadvantages mentioned, lead is excessively heavy and therefore expensive to handle. The actual bending of the tubes suggest some interesting problems, and has considerably to do with the ultimate success or otherwise of the pipe. It is not necessary to demonstrate the obvious fact that bending a copper tube lengthens the distance between two given points at the back of the bend, and reduces the distance in the throat of the bend. This naturally results in stretching the copper at the back and thickening or " puckering " the throat, the amount depending upon the radius. The thinning can, however, be seriously affected by wrong methods. The correct method of bending is to extend the area for thinning or stretching as much as possible, thus reducing it to a minimum in any given place. To do this, the blocks placed at the back of the pipe, across which the pipe forms a beam (the bending pressure being applied between) should be kept as widely apart as the radius of the bend required will admit, not less than four times the diameter of the pipe for the sharpest bend, and wider as the radius is increased. By this means it will be found that the tendency to reduce the thickness at the back of the bend is remarkably little, not exceeding one gauge in a fairly short radius. A radius of two and a half times the diameter of the pipe (to the centre) is about as short a bend as is possible to execute satisfactorily. This applies to any size pipe. It will be noticed that a copper pipe very rarely gives way across the bend when actually under working conditions : the tendency is for the pipe to split round the sides of the bends, due to the continual altering in shape from spherical to oval and back again when the bends are actuated upon by the expansion and contraction in the range of pipes. This tendency to split is enormously exaggerated in the case of a seamed pipe. Any weakness of the original tube in this direction will in all probability be discovered by the mechanical testing process, previously referred to, of turning over a flange. The fact will be readily grasped, that as the back of the bend stretches or lengthens, the throat of the bend shortens, and the material has a tendency to jump or thicken up, the lighter the material the less this thickening takes place, and we find that the copper works up into folds or puckers on the inside radius of the bend, the lighter the material of the pipe and the shorter the radius, the more it puckers. Now it is a great mistake to think that so long as these " puckers " can be beaten down with a hammer and leave all smooth, that no harm has been done. How often one finds after vigorously hammering down some specially large puckers that part of the bend where the puckers have been punished shows a series of irregular cracks, and has to be condemned. This is due to overstraining, an evil previously described. In this case again it is impossible to lay down hard and fast rules, but if the tradesman is aware of the possibilities of the evils, he can at least err on the right side, until from experience he learns the exact amount the copper will stand. In further reference to hammering of copper bends, any tendency towards slovenliness in this respect, although perhaps not in itself anything more serious than being unsightly, should cause grave suspicion of like carelessness in more important matters.

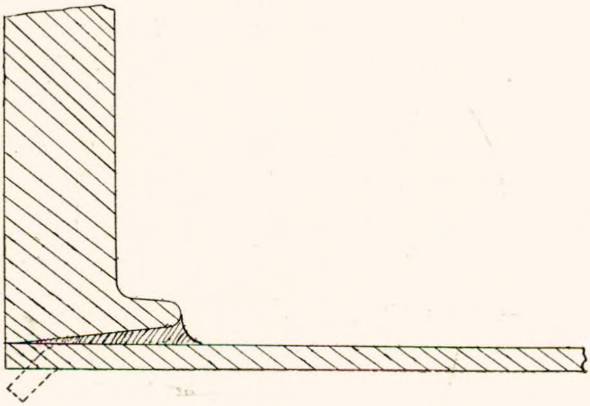
Flanging.—The flanging of copper pipes is an important process, but with reasonable care and supervision can be rendered simple and trustworthy. The flanges should be cast with a collar two thirds in height of flange thickness. They are usually faced and drilled before fixing on the pipe, and should be cast with a decided taper to within $\frac{1}{8}$-inch of flange face, say a taper of $\frac{1}{8}$-inch to ensure easy access of the solder between flange and pipe. It is of the utmost importance that inside of flange and outside of pipe ends be thoroughly filed clean, as dirt is the great enemy to a good braze. To fix flange, it is only necessary to caulk over the copper on the flange face to keep it in position, any knocking out of the copper pipe from inside at back of collar (sometimes done by incapable mechanics to keep flange in position) may be set down as another evidence of slovenly work and condemned. Under no conceivable circumstances is it necessary, yet one occasionally comes across some deplorable cases. The actual brazing on the flange is often rendered insecure by bad methods. It is a common practice to put the flange over the fire and blow up to a red heat, then cut off the blast and charge with solder, then blow up again until fluxing takes place ; and thus previous to the charging with solder the collar top and the space between pipe and flange has become covered with dust from the fire, and the flange and pipe covered with scale, rendering it difficult to make a good sound braze, sometimes powdered borax is sprinkled on, but it is unsatisfactory. The correct method is to carefully wash the brazing solder which should be coarse (No. 6) in clear water, then mix a handful of granulated borax with the wet solder and charge flange *before* putting on the fire, the moist borax runs into space between flange and pipe and keeps it chemically clean, and no trouble is experienced in making a good sound joint. Extra charging when flange is at brazing heat should be avoided, but if necessitated by flange collar not being sufficiently filled, the extra solder can be applied without the slightest need for stopping the blast, for the longer the pipe remains under heat, the greater the effect of damaging gases, and the more the molten solder penetrates into and reduces the thickness of the pipe. This latter effect is the cause of many pipes prematurely "necking" at the flange. Many coppersmiths complain that under the method I put forward, the solder becomes "drossy." This condition is not due to the method adopted, but to the solder not being sufficiently coarse. The brazing, or the assisting of the brazing of, flanges by gas blow-pipe, is sometimes recommended. The use of the blow-pipe for brazing may be classed as a necessary evil, that is to say, its use is only pardonable in extreme cases, for work inaccessible on the fire, or in an emergency, to save a flange giving trouble by the brazing solder running through. I condemn flange brazing by means of blow-pipes on several grounds :—

1st. The deleterious effect upon the solder of a fierce flame, causing what coppersmiths term "perishing." This is shown by the extraordinary amount of borax necessary to flux the solder, and the "drossy" condition of the solder after a few minutes' action upon it of the blow-pipe flame.

2nd. The fierce play of the blow-pipe flame upon that part of the copper immediately above the flange, resulting in excessive and more or less prolonged heating. This part of the pipe should be particularly guarded from any prolonged heat.

3rd. The cost of blow-pipe work is excessive, and if gas expenditure is charged against the shop expenses, it will tell its own tale in a few months.

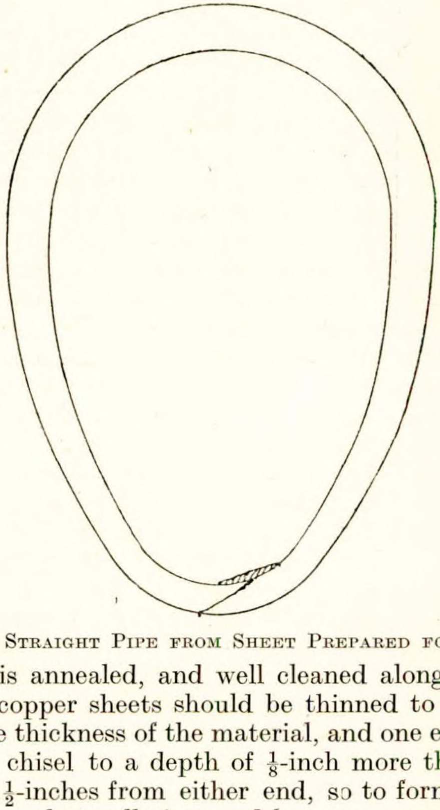
It would be imperative to make an outlay in blow-pipes for each fire used, as if not, delay would ensue from men waiting about for turns in the use of blow-pipes. There are no advantages in blow-pipe brazing excepting in the emergencies stated, or for use in emptying the resin out of large unwieldy pipes, and I should call a blow-pipe the incapable man's friend. The blow-pipe is no new thing and has been used for intricate work for twenty or thirty years. The pipe must be hoisted from the fire as smartly as possible after fluxing takes place. Smartness is the keynote to all successful brazing, as no time whatever must be lost during the process. This applies to all descriptions of brazing. The indications of a good flange braze are neatness and clearness round solder on the collar, and evidences of solder, when any part of the flange caulking is set back a little from the flange face with a blunt chisel within at most an eighth of an inch; this test would in no way damage the pipe. See sketch.



TEST FOR PRESENCE OF SOLDER.

There should be no filing round brazing at the collar, unless with a round file, as the tendency to file square corners is a frequent cause of premature necking.

Copper Pipes Brazed.—Pipes produced from sheet, offer the greatest possibility of failure, owing to defective work. The pipes can be made either as straight lengths, and afterwards bent, or shaped up in halves termed saddle and back, and brazed together. The size of pipe, radius of bends, and thickness of material again determine the process. The making up into lengths and bending on the resin is the less costly, and can be adopted for any sizes say from 6-inch bore up to 12-inch or even 14-inch bore, providing, of course, a press of sufficient power is available for the purpose, the larger sizes would require a hydraulic press of 60 to 80 tons capacity. The straight length is produced by taking a sheet equal in width to the circumference of diameter of pipe bore required plus $\frac{1}{4}$-inch; thus for a 10-inch bore pipe 10 W.G. thick, take the circumference of $10\frac{1}{4} = 32$ inches: for $\frac{1}{4}$-inch thick pipe take circumference of $10\frac{3}{8}$ inches. This sheet is thinned along each edge, wedge shape, by hammer or rolls. It is then afterwards bent up pear shape to offer a greater resistance to bending (see sketch below) and springing of the seam when only one side is being heated as during brazing, also by having the seam at the small end of the pear-shape section a small surface is presented for the solder to spread over, making a neater and better seam as per sketch.

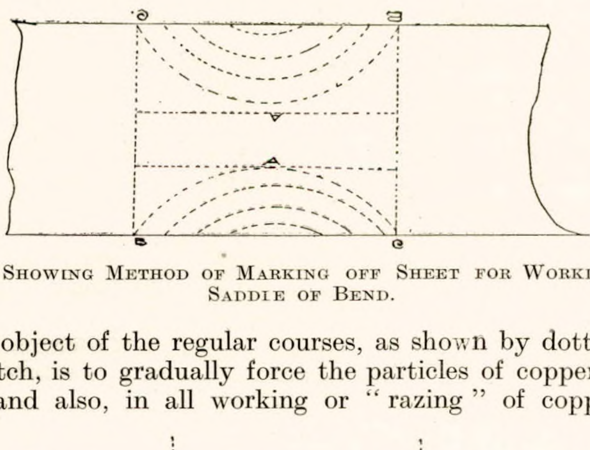


SECTION OF STRAIGHT PIPE FROM SHEET PREPARED FOR BRAZING.

The sheet is annealed, and well cleaned along the thinned edges. The copper sheets should be thinned to the width of four times the thickness of the material, and one edge cut down with a sharp chisel to a depth of $\frac{1}{8}$-inch more than the thinning, about $1\frac{1}{2}$-inches from either end, so to form the cramp. These figures apply to all pipes and for any purpose or pressure. The cramp is cut $\frac{1}{8}$-inch deeper than the thinned part to allow for any springing during brazing, as shown in the small specimens before you. The idea of the cramp being cut will pr.bably be fairly clear, as without the cramp it would be impossible to regulate the amount of lap. The edge of the side not cut into is placed between the cramp and the whole drawn together and bound with soft iron wire about $\frac{3}{16}$-inch thick.

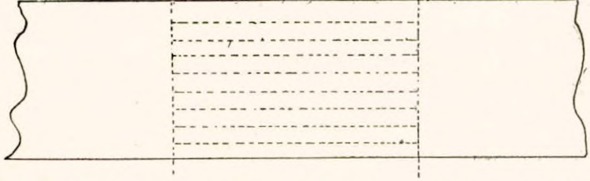
The pipe is placed on a mandril not exceeding 3 inches diameter, and hammered down close along the seam. The pipe is now slung up ready for brazing, and to ensure perfect cleanliness and facilitate the solder fluxing easily through the seam, a solution of boiling hot water in which borax has been dissolved should be poured along the seam. About a handful of borax in a pint of water will usually suffice. This will remove any greasiness or foreign matter from along the part to be brazed. The seam is loaded with coarse solder, and only experience will determine the quantity to use. The best plan is to have a length of small section angle iron or copper shaped similarly some ten feet or so in length, and charge this with solder uniformly the whole length, place the charged angle iron along the seam inside the pipe and turn it over and empty the solder on to the seam. It is advisable to blow up the fire before putting the pipes on. This may seem an unimportant matter, but it is the small things that many neglect, and which often make all the difference between a good and a moderate piece of work. The blowing up of the fire clears the dust and dirt out without blowing it on to the seam. The seam is drawn slowly across the fire to braze it and no time should be lost between the seam being cleaned and the brazing of it, otherwise the edges rapidly become oxidized and bad to braze cleanly. The rate of progress across the fire is determined by the fluxing of the solder. The outside edge of the seam which tends to spring open under the heat is put up close by means of the pressure from a flat-ended iron bar. If the seam has been properly cleaned and prepared no difficulty is experienced in steadily and regularly working across the fire. Sometimes, however, the careless operator has not sufficiently cleaned his seam, and he has a difficulty in getting parts of it to "take" as it is termed, his solder fails to flux properly and runs "greasy." If not prevented, the coppersmith, who may be incapable, will keep his pipe stationary on the fire, while he is trying to persuade the solder to unite to the copper. Now bearing in mind the comments made in the section upon annealing, of the disastrous effects of prolonged heating, it can readily be gathered how fatal it will be to the seam to allow it to remain for long over the fire. In cases of this kind, the parts giving trouble should be passed over, and progress continued with the remainder of the seam. After removing from fire and cooling off, the defective places should be thoroughly scraped and cleaned both inside and out, and steeped in a solution of vitriol to remove the burnt borax and other dirt, then returned to the fire and rebrazed. This may be a little trouble, but it is imperative. The necessity for cleanliness cannot be exaggerated, and slackness in this respect is responsible for the majority of failures in brazing. It will have been noted, no doubt, that solder in brazing unites to the copper, that is, it penetrates and becomes part of it, but the copper must be thoroughly clean for it to do so, if not, the solder merely flows over the copper, and to the inexperienced observer appears perfectly sound, whereas the slightest strain will part the two metals. Many in dressing off the exterior of the seam furrow the copper with a file, or make sharp corners: both are harmful and unsightly. A good seam can be determined by the closeness of the outside edge of copper, the absence of any groove, or hollow along the seam, the presence of a regular straw-coloured seam of solder along edge, and no evidence of thickened seam. Pipes made up in this way should not be hammered if for bending, but only malleted; hammering, if in any way extensive on the seam, reduces its bending strength.

Copper Pipes Worked Up.—The built-up pipes, saddle and back, are by far the most interesting, both from the point of view of the mechanic and the observer. The same rule as to width of sheets applies in this case as in the straight length, only the sheet is cut in halves in width for saddle half and back half. In shaping the copper correctly, there are a few well-defined rules to bear in mind, applicable to all shapes, sizes, and radii, which, if carefully followed, will result in a first-class production, with the copper unimpaired, if not improved in ductility. It is hardly necessary to point out that without the requisite skill, which can only come by practice and general experience, all the reading and studying possible will not enable a good piece of work to be produced. I cannot, by reason of time limit, give every detail of the processes, a word-picture of such would be totally inadequate. The fact must be grasped that copper possesses the property of flowing, if correctly handled, that is, the thickness of the metal can to a large extent be retained, and the particles of copper worked to different positions. To give one example typical of this principle, lay down a full-size sketch of, say, a 10-inch bore right angle bend, say 15-inch radius to centre of bend. If the sketch be carefully measured round, the centre radius will be found to be 50 per cent. greater in length than the inside radius. Thus theoretically a piece of copper worked into shape should be much thinner round the centre radius part than, say, along the throat. Say if ·160 inch or 8 W.G. to begin with, should finish round centre radius ·104 or 12 W.G. If ·128 inch or 10 W.G. to begin, should finish round centre radius ·080 inch or 14 W.G. After, however, the copper has been made to flow by right methods, it can be worked over with a loss not exceeding one gauge in thickness, that is for any reasonable radius. The copper must be worked over in regular courses, not exceeding $1\frac{1}{2}$-inch pitch.



Sketch Showing Method of Marking off Sheet for Working over Saddle of Bend.

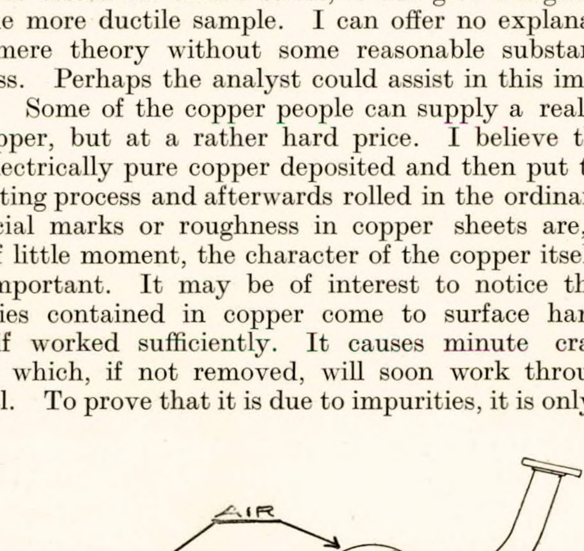
The object of the regular courses, as shown by dotted lines on sketch, is to gradually force the particles of copper to the edge, and also, in all working or "razing" of copper, the



Sketch Showing Method of Marking off Back of Bend.

regular coursing keeps the shape of the work to the radius desired. The sheet, being marked off as shown on the sketch, is held at an angle of not more than 10° to block or anvil, and commencing at point A work to B and back to C, then from point A to C and back to B, working alternately in courses of not exceeding $1\frac{1}{2}$ pitch. The copper to be only beaten down to the anvil, *not on any account to be given a solid blow* upon the anvil. When worked to edge, opposite side of sheet to be treated similarly, and then the whole annealed and hammering repeated for some five times for an ordinary radius—the finishing of shape can be done on an iron mandrel. The back, as will readily be seen, is contrary to the saddle, and shorter round centre radius than outside radius. The material will gather round centre radius and thicken: this must be beaten out.

The back sheet is hollowed out by marking as per sketch p. 163 and regularly hammered with wooden mallet on dotted lines, blows not repeated in one place or undue straining results, then annealed and hammering repeated until copper is up to the template. The sides of the back of a fairly sharp bend should be "razed" in on an iron "cod" with a full-faced hammer to assist the shaping. If the halves after shaping are placed upon a full-sized sketch, it will be found that the saddle is short of the centre mark, and the back in excess, that is, if correctly worked. These halves are thinned along edges as in the straight lengths and cramps cut in after annealing and carefully cleaning. The cramps must not be cut in the radius or bend of the pipe, but in the straight; if cut in bend the pipe is likely to split at the cramp during the altering in shape of the bend under actual working conditions. Cramps are better cut in the backs to facilitate dressing off of the seam after brazing. I have made no mention of any test for copper sheet; I must confess to having no faith in any mechanical testing. The great majority of bends in ordinary practice, if correct methods are adopted, put little strain upon the copper, and ordinary commercial copper is quite capable of meeting the requirements. Exceptional copper work requires special pure copper to stand the manipulating and carries with it also a special price. It is rarely that a firm of good repute supply bad copper sheet from their mills; when they do, all the bending tests applied will not, I fear, determine its quality. There does not appear to be that co-operation between the chemist or metallurgist and the actual worker of the copper without which it is impossible to arrive at any trustworthy data. The connexion in this direction is not nearly so complete as in the case of iron and steel. Many times the coppersmith has supplied to him copper sheet of abnormal hardness, that is sheeting which despite the most careful annealing never reaches the normal state of ductility. The man working the sheet is soon conscious of this fact, and exceptional care is required not to overstrain it. The difficulty in respect to this phenomenon is, that if the copper be tested for tensile stress, it will give a higher figure than the more ductile sample. I can offer no explanation of this; mere theory without some reasonable substantiation is useless. Perhaps the analyst could assist in this important matter. Some of the copper people can supply a really good soft copper, but at a rather hard price. I believe the best to be electrically pure copper deposited and then put through the melting process and afterwards rolled in the ordinary way. Superficial marks or roughness in copper sheets are, unless deep, of little moment, the character of the copper itself is the most important. It may be of interest to notice that any impurities contained in copper come to surface hammered upon, if worked sufficiently. It causes minute cracks to appear, which, if not removed, will soon work through the material. To prove that it is due to impurities, it is only neces-



sary to point out that these cracks are usually at first isolated, and when only on the immediate surface can be cut out by a gouge chisel and they will not again show themselves in subsequent working, also the small pieces cut out are, upon examination, found to be foreign substance, excessively hard and discoloured, similar to what is sometimes termed "dross."

Hydraulic Testing.—It is essential in pipes intended for pressure, and in seamed pipes, to test them with hydraulic pressure to detect leakages. In doing this care must be taken that the jointing for testing is kept outside the copper pipe on the flange face, otherwise it will not be a genuine test of the flange brazing.

To exclude the air from the pipes they must gradually rise the whole of the length ; it is not sufficient to have the exit the highest point, if any other part varies in height, the air will remain at that high point and cannot possibly be forced past the depression (see sketch, p. 165).

To test the presence of air in any part of the pipe, two methods can be adopted, and neither will give rise to any suspicion of doubt. If when the pressure is turned on, after the pipes are filled, the pointers of the pressure gauge immediately and steadily advance, no air is in the pipes ; if they refuse to move at once, or violently oscillate, that indicates the presence of air. If the highest or any other point in the range of pipes be given a sharp rap with a hammer, the pointer of the gauge will reciprocate and vibrate, that is, if no air is present. Air being present, it will fail to respond. Unfortunately, hydraulic testing is of little use in determining the strength of a pipe, only by a careful use of data, based upon long experience can the necessary scantling be fixed, and if the method herein described is adhered to, no misgivings in regard to workmanship need arise.

Design of Pipes.—In the designing of the copper pipes by the draughtsman, much can be done to assist the expansion and contraction effects. Space and general arrangement enters largely into the question of pipe design, and is undoubtedly restrictive. A few points may be mentioned to be borne in mind in fixing up the ranges of piping. As much straight as possible to be left at the flange ends of pipe ; if practicable not less than 4 or 5 inches, double that where permissible. All radii to be kept as large as space will allow, to avoid undue stiffness and to reduce friction of the steam and water. Most designers and draughtsmen to-day are quite capable, if permitted, of laying down a good workable pipe arrangement, and generally show themselves quite conversant with up-to-date practice.

Generally.—I am not altogether unconscious of the fact that many coppersmiths lay the blame for failures upon the draughtsman, or may be the copper manufacturer. This, however, is not peculiar only to coppersmiths, and seems to follow the line of least resistance in many cases. I scarcely know what to answer to the critics who condemn present day copper and workmanship and eulogise that produced in their youth. Probably, as in other matters, "distance lends enchantment to the view," at any rate no attempt is ever made to bring facts to prove the assumption. Most of us are familiar with the tendency of age to, by constant repetition, keep fresh the victories, and by careful neglect deface from memory the failures. Personally, I find much the same conditions in regard to the quality of copper to-day as, at any rate, twenty years ago, but better results are produced by more up-to-date and systematic methods available now. The substitution of steel for copper in cases of high steam pressure and other directions has developed rapidly since the production of the seamless steel tube—a distinct improvement certainly when correctly designed, and adequate provisions made for its characteristic action. A treatise upon the working of steel piping may be useful at some future date, but with all this substitution of steel, the doom of the copper pipe is not pronounced yet. Naturally I have a great faith in copper work, and resent strongly any insinuation that the coppersmith has deteriorated. We possess on the north-east coast, amongst our coppersmiths, tradesmen second to none in the world for either ability or despatch, and who can be depended upon under favourable conditions to produce first-class work. If engineers will closely examine the matter I have placed before them and memorize the main points, they can feel assured of being quite able to determine from stage to stage in the productions, the actual quality of the pipes supplied.

Chairman: I am sure you will agree that we have had a most interesting and comprehensive paper. I think most of the details of pipe-making and copperwork generally have been touched upon by the author, and I am only sorry he is not here, so that we might have asked him questions on the practical work from the coppersmith's point of view, which would have been interesting to us as engineers. One thing he has not touched upon which may perhaps be the subject of comment. He condemns the blow-pipe, but if any of the members present have had any experience of brazing by the oxy-acetylene, or electric processes, we shall be pleased to hear them.

Mr. P. C. Garnham: I am not very well acquainted with the brazing processes; it is the manufacture of the pipes and sheets only that I am conversant with. From the manufacturer's point of view I think this is a most interesting paper, especially as the author has put forward some ideas which certainly had not occurred to me in connexion with the manufacture of pipes. I am not altogether acquainted with the coppersmith's part of the work, but it is very interesting from the point of view he has raised, because over and over again we are having complaints from the coppersmiths as regards the qualities of the pipes, and as he has pointed out very clearly failures in copper are by no means entirely due to the faults of the manufacturer. I am sure it will be interesting to most of the works in Birmingham which have anything to do with the manufacture of copper pipes.

Mr. J. T. Milton: I very much regret that Mr. Handscomb has not been able to be present this evening to read the paper and to reply to any criticisms which may be passed upon it. Mr. Handscomb is a skilled coppersmith, foreman in one of our largest copper-shops, and everything he has to say in connexion with his every-day work must be listened to with a good deal of respect. There are two or three things in his paper with which I do not agree, and very much in it which is exceedingly valuable; if he were here he would probably be able to explain the apparent discrepancies, and thus remove some of the difficulties one has in accepting the paper as a whole. One gets the idea from the paper that the author seems to be under the impression that the coppersmith at present is under a cloud, and there are several parts of the paper which show the reason for whatever distrust there may be in coppersmith's work. He says, "We possess on the north-east coast, amongst our coppersmiths, tradesmen second to none in the world for either ability or despatch, and who can be depended upon, under favourable conditions, to produce first-class work." Apparently "favourable conditions" are necessary for the production of first-class work. In other places he says, "If the method herein described is adhered to, no misgivings in regard to workmanship need arise." "It is to be regretted that many otherwise good tradesmen work by 'rule of thumb.'" "The great majority of coppersmiths have little or no conception whatever of the reasons for adopting a certain method";

and in many cases he shows very clearly that to get good work from the coppersmiths, you must have exceedingly careful as well as exceedingly skilful men. That is the reason, I think, why people look with distrust on copper steam-pipes, and that is the reason why, now that steel and iron pipes are available, all the big ships and good ships have steel or iron rather than copper steam-pipes. But, as Mr. Handscomb says, there is a great deal of use for copper pipes other than steam-pipes, and the coppersmith's doom is not yet passed. I would like to make a few remaks on points upon which I think he is wrong. First, with regard to deposited copper. Of course, as most of you are aware, I gave a lecture on copper some time ago, and referred pretty fully to the Elmore or electro deposited copper, and I certainly did not give any one the impression that I thought it a good material for steam-pipes. But I fear Mr. Handscomb is not strictly correct in some of his statements, when, for instance, he says, "this metal, after mere exposure to the weather for a year or so, without any attempt to put work upon it beyond that which the tube and sheet people had executed, literally fell to pieces upon efforts being made to work it"; and "whatever the weakness is, its development is abnormally rapid, as within the short period of a few months a piece of this Elmore copper, capable at first of withstanding extraordinary strains, becomes absolutely useless." That kind of thing I have never yet come across, and I have had to do with a great deal of Elmore copper. I have a piece in my possession which was in use a long time ago—a great deal more than three years—and the copper has not been spoiled by keeping it, although it has been exposed to the atmosphere ever since. There is no doubt whatever that the Elmore copper has failed for steam-pipes, but to say that it falls to pieces under atmospheric conditions, is, to my mind, certainly incorrect.

Mr. Handscomb again, like a good many other coppersmiths, is not a chemist, and he misjudges the effect of poling and the action of gases on the copper. In the paragraph on deposited copper, he confuses things which do not apply to deposited copper, that is in connexion with the poling. He says, "In the latter procedure, the poling of the copper by the insertion of a sapling well stirred into the molten metal introduces chemicals in the form of gases, which act as a protection against external atmospheric attack." Well, every copper-maker, and every chemist, knows that the sapling, instead of introducing chemicals into the copper, extracts oxygen from it; there is no shadow of a doubt about that. Then he says, "When copper is heated to brazing heat, or an even less temperature for a long period, a transformation appears to take place in the copper, this peculiar protective chemical formation due to the poling escapes." That, as I stated in my lecture, and I think very clearly, is not what does take place. It is not the protective chemical formation due to poling that escapes, it is the oxygen that is still there which comes out in the reducing flame. The copper-maker here will be able to correct me if I am wrong. Mr. Handscomb decries mechanical tests. I am sorry an experienced man such as he is should do so; but if we are to judge copper at all we cannot judge it by faith only, we must have mechanical tests. It is rather curious the way he has put it—"I have never, in over twenty years' experience, found a well-prepared test strip fail, yet I have certainly at times had some very poor copper through my hands"; and a little further on he says, "My own personal experience, however, in regard to this mechanical test question, has been unsatisfactory, good copper sometimes giving bad test results and poor fracture." The two things do not agree. Again he says "at another time"—this I quite believe; in fact, if this were said by itself I should say we were in entire accord—"copper showing good results in the testing and first-rate fracture has in succeeding stages developed abnormal weaknesses, even after the most careful personal supervision in regard to temperature, etc." I take it that what that experience really shows is that good copper has sometimes been spoiled by the coppersmith, and then when tested has shown a bad result, and then at another time good copper giving a first-class test has been gassed and the final result has been unsatisfactory.

Now with regard to the question of corrosion he says: "The question of corrosion or wasting is one that comes more under the jurisdiction of the chemist or analyst than the practical coppersmith." I suppose it does, as the coppersmith has nothing whatever to do with it; but he thinks there is pitting on the outside of copper pipes through the coating being mixed up with a mysterious compound. It is not the pitting on the outside that gives trouble. Sometimes there is pitting inside steam pipes, but the pitting which gives engineers the most trouble is in the inside of pipes used for conveying sea water, and no coppersmith or maker has given any plausible explanation of the very erratic corrosions we sometimes find. "The extraordinary effect on locomotives" is a thing we have nothing to do with. The pipes he refers to are in the uptakes; we do not put copper pipes in our uptakes, and the extraordinary corrosion which takes place there is well recognized, under those conditions, as being due to the sulphur in the fuel. Sulphur has a high affinity for copper, and if you have copper heated to any extent, and put it in contact with sulphurous gases, you must expect corrosion to take place. Mr. Handscomb thinks the purity of metal is a good thing; he says, "There seems to exist a somewhat erroneous idea that copper to be really trustworthy and durable must possess a small amount of impurities. No one seems to have any conclusive idea as to the exact quantity of this foreign ingredient necessary. The matter is usually mentioned in a delightfully hazy manner." "The problem of how engineers and many coppersmiths come to regard impurity in copper as a *sine qua non* is not difficult to solve." He implies that it is because the impure copper gives better tests, which of course he says he despises. The fact that some impure copper is thought to be better than pure copper is a matter of life-long experience. Very many years ago nearly all the copper used for conditions where great ductility was required came from Cornwall, and all the Cornish copper was impure, containing a proportion of arsenic, and the experience of all locomotive engineers is that copper containing about ½ per cent. of arsenic is far more durable than pure copper. It is no hazy matter at all; the fact that arensic gives extreme ductility under trying circumstances is well known. But there are many other impurities, the properties of which are not so well known—bismuth, antimony, and certain other impurities, of which it is not known whether they are very bad or very good for the copper. Mr. Handscomb pins his faith to pure copper; well, locomotive engineers say, "let us have arsenic in it."

I have no doubt Mr. Handscomb is perfectly right in saying that although annealing does restore to a very large extent the quality of the copper, if strained or hardened in any way very frequent annealing must have an effect on the crystalline structure of the copper, so that repeated annealing may be deleterious to copper. But a few annealings are certainly not, and the author himself mentions some work requiring 100 annealings in the making of the pipes first and foremost. Mr. Handscomb again, as a coppersmith used to his work all his life, does not think that pipe annealing in a furnace is likely to be satisfactory, and gives some reasons why it should not be. The principal one, irrespective of cost, is the difficulty of preventing distortion of the bends under heat. Two or three days ago the discussion took place on a paper read at the North-East Coast Institution of Engineers and Shipbuilders by the manager of one of our large works on the Tyne. He made experiments with copper pipes in a furnace, taking thin pipes of large size, rather complicated in shape, properly supporting them in a furnace and making them uniformly hot, and he found no difficulty in doing it, and no distortion when the annealing was done with care. If the heat, on making a pipe red hot, is likely to distort it, I would rather take the risk by putting it in a furnace than by having it slung over an open fire. In the latter case it is sure to have an over-hanging tendency, straining the red-hot portion. You are far more likely to distort it by trying to anneal it over a fire than in a furnace, and do what you will, however careful the men may be, there is always the risk that some part of the pipe will be left unannealed. If coppersmiths would only go to the expense of putting up annealing furnaces, they would never close them down again ; I am quite sure they would make a thorough good job. There is a point here in connexion with which my own experience is not in the direction of that of Mr. Handscomb. He says, "It may interest some to know that copper will attain to a degree of hardness by mere exposure to the atmosphere, the degree depending upon the time of exposure. It is advisable to re-anneal any pipes that have lain about for over twelve months, especially if any bending or working is required to be done to them." I think Mr. Handscomb is perfectly right in saying it is advisable to re-anneal any pipes in the shop after lying about for over twelve months, simply because in that time you probably cannot trace them, and are unable to say which are hard and which are not, and if you want to use them it is always safe to anneal them. But I do not think it is necessary because they have been hardened by exposure for that length of time. Pipes that stand do not harden merely by being exposed to the weather ; I do not see how they can. He is rather obscure in another point also, where he says, "There are, generally speaking, two methods of making copper pipes—from seamless tubes and from sheets brazed up. For all purposes where practicable the seamless is the superior." And lower down he says, "It will be noticed that a copper pipe very rarely gives way across the bend when actually under working conditions; the tendency is for the pipe to split round the sides of the bends, due to the continual altering in shape from spherical to oval and back again when the bends are actuated upon by the expansion and contraction in the range of pipes. This tendency to split is enormously exaggerated in the case of a seamless pipe." I should like an explanation of that remark, because I think he is wrong altogether. I do not see where the question of using a seamless pipe comes in, except that it is generally the seamless pipe that is used. If a brazed pipe is used it may be so arranged that the seam is at the side, the part where it has a tendency to split, so if it has anything to do with the seam you put the seam in the worst place possible. If the seam is at another place, the pipe has then no seam where it is supposed to be principally affected and is therefore just like the seamless pipe. Now, as to this, there is another point of workmanship. He says, "How often one finds, after vigorously hammering down some specially large puckers, that part of the bend where the puckers have been punished shows a series of irregular cracks." That again is one of those points which shows that coppersmiths are not altogether reliable mechanics, because it stands to reason that, when bending, if you allow specially large puckers to form, it is an admission of bad workmanship. Before they become so large, the man ought to stop the bending, hammer the puckers out, run out the filling, then re-anneal, reload and go on with the bending.

On the whole there is a very great deal of useful information in the paper, but, as I said, there are some points, such as those I have mentioned, which it is just as well to point out so that there may be no misconception. Another point to be remarked is the frequent occurrence of passages of this description, "Pipes produced from sheet offer the greatest possibility of failure, owing to defective work." "Sometimes the careless operator has not sufficiently cleaned his seam, and he has a difficulty in getting parts of it to 'take' as it is termed, his solder fails to flux properly and runs 'greasy.' If not prevented, the coppersmith, who may be incapable, will keep his pipe stationary on the fire." "I have no faith in any mechanical test." And so he condemns the workman right through from beginning to end.

I do not think I have anything more to add; in the main, of course, one agrees with nearly everything in the paper. With regard to the Chairman's remarks, I have had no experience whatever of the oxy-acetylene process for copper work. At the discussion on my lecture we had some present who use it at London regularly. Perhaps some of the gentlemen present may be able to speak of it.

Mr. W. Britton: I certainly agree that this is a very able paper, and one from which one can learn a good deal. The oxy-acetylene process has been mentioned; I have not used it much with copper, but I have used it a little with steel. The other day I tried it with a copper pipe and flange; as a matter of fact, it was an attempt to fasten steel to copper by means of the oxy-acetylene blow-pipe, and I found it necessary to have a greater space between the flange and the copper than when done over the fire.

Mr. Garnham: With regard to corrosion, perhaps some members present are aware that there has been of recent years a tendency to adopt the brass pipe as being far more durable than the ordinary copper pipe, and more suitable for the condenser tubes referred to particularly by Mr. Milton.

Mr. Milton: I did not refer to condenser tubes at all. I referred to copper circulating water-pipes, a thing we have trouble with as well as the others. These copper circulating inlet pipes, full of sea water, are often found corroded in an abnormal way.

Mr. Wm. Earnshaw: I would like to congratulate Mr. Handscomb on his very excellent paper on Copper, and I think it is well that we should have these papers showing the constructional side of engineering as well as those dealing with the theoretical. After the very able and lucid lectures given by Mr. Milton, and the further paper which recently appeared in Engineering, read at the North-East Coast Institution of Engineers and Shipbuilders, one feels a diffidence in offering remarks upon this subject; yet, having had considerable experience of copper pipes and coppershop work, I venture to offer a few suggestions upon several important points raised in the paper. First of all, with regard to brazed copper pipes and flanges, with worked bends, etc. I think it may be conceded that, while there is as good sheet copper made to-day as ever there was, yet it is equally true that, as in the case of cast pig-iron, there is not that care in its production as in years gone by, the chief feature being the endeavour to put a raw material upon the market at the cheapest possible price. The molten copper does not receive that labour and care that was devoted to it in former years, quality being sacrificed in too many instances in the struggle to compete on the commercial market, and every copper worker knows by experience how variable is the quality of commercial sheet copper. In working up into bends, many men, foolishly attempting to save extra annealings, work the copper altogether too hard, and set up thereby stresses and strains that are the early precursors of an infinite number of exceedingly fine cracks of very short lengths. I have examined a number of worked pieces of copper with a powerful glass which showed these cracks quite clearly. Such worked copper must of necessity give evidence of rapid metal fatigue, besides ensuring the formation of an apparently inexplicable crack at some future date. In working copper-pipe halves into shape, steel hammers should not be used. The hammers should be of block tin, or block tin with a small percentage of copper added; these are rigid enough and allow the metal to be worked further into shape without giving rise to undue stress within the metal. In brazing, all pipes should be dovetailed along the entire length of the seam, as the joint is kept more surely together during the heat of brazing, and the closer the faces are kept together under heat, the better the joint. Faces should be smoothly scraped; the more smooth the face the firmer will the solder adhere—solder does not flux well to a filed face, however smooth the file. Every care should be taken that the fire is free from smoke, and more particularly that the coke fire has had the blast well on it so that it is free from sulphur, the sulphur having a very injurious effect both on the brazing and on the copper, producing in the copper a condition known as "red short," or quite brittle. The lap should be of liberal quantity. Copper is often perished through having too fierce an under fire. While the fire should be clear and bright, the joint will be a better one if the melting heat first comes off at the inside on the solder by the use of a good blow-pipe, and the solder drawn through by the application of the red-hot, welding heat end of a fine iron poker.

It is rarely that one sees flanges of material or strength suitable to the work they are called upon to do. Copper flanges should not have more than one-sixth of best Silesian zinc in alloy; they are often made of metal not much better than Muntz—6 of copper to 4 of zinc. Further, it is seldom that flanges are put on in the right way. The common way is to tap on a plain disc flange and rivet the end over a little. The best way is to turn a small half-round groove near the face end of the flange (inside the bore), and so that there shall be a fairly long pap at the pipe end. The groove is for the purpose of expanding the pipe, so that a twofold purpose is gained; first, the flange will not fall or shift its angle under the expansive heat of the fire; and secondly, the brazing solder will not pass the groove and allow of the very important part of brazing to be secured—that is, when the solder has fully run, the blast may be slowed down and the solder allowed to keep fluid for a minute or two, thus forming a skin metallic alloy with the copper pipe, and also with the flange. The pap, which should be extended until it is only twice the thickness of the copper pipe, allows a perfect expansion and contraction of the brazed joint at the place where the brazing solder is thickest, and so gets over the stress of the expansion and contraction of two very widely differing metals, copper and brazing solder.

There are, of course, many different ideas regarding annealing. The old handicraftsman of a bygone period thought he knew something of copper-working; I refer to the copper kettle men who used to throw the whole body of the kettle up out of the sheet. They used to bring the piece of copper to a red heat, copper red, and then plunge it into the lant tub—a tub kept in every old copper shop for the men to urinate in. Copper so treated was soft enough for them. I am of opinion, however, that if large steam-pipes are being annealed which do not require to be planished afterwards, they should not be quenched, as such treatment, while it undoubtedly makes the copper softer, yet also makes it more porous. Mr. Milton's remarks about the annealing of the pipes over the fire are perfectly true, and very often pipes so treated, unless great care is exercised, get burned—it must be remembered that over a good fire there is only an instant between the point of adequate annealing and that of burning. I do not think the furnace idea is practicable ; it certainly would be costly owing to the awkward shapes and lengths of most fairly large pipes. If, however, a circular gas pipe with bunsen burner jets is applied to the pipe, the pipe being hung up in the shop vertically and the ring being applied from the bottom, a full red heat can be carried along the length of the pipe equably and without altering the set of the pipe. I have used this simple device most successfully and more quickly than the operation could be done over the open hearth. Also there is the certainty that the pipe will not be overheated even if an inexperienced person is doing the work.

With regard to the question as to whether pipes should be planished or left annealed, the advocates of both processes are right. It all depends on the quality of your cloth. If in these days of high-steam pressures makers will persist in putting in light pipes, then it is a necessity that everything must be done to make such pipes able to stand the work expected, and in such cases there is no question that the pipes should be planished. I used the term "planished" in its proper sense, not spotting here and there, but careful closing up of the pores of the metal, giving an equal stiffening of the metal without making the pipe brittle. But it has to be admitted that planishing is becoming one of the lost arts, and I therefore lean to the position taken up by Mr. Milton, that safety and economy lie in seeing that the pipes are of ample thickness, and that they be left as soft as possible. As the modern high pressures naturally set up fatigue of the metal much more rapidly than under the old order of 60 to 80 lb. pressure, so there ought to be a still greater increase in the thickness of the modern pipe. I have had great pleasure in listening to this paper, and must thank Mr. Handscomb very heartily.

Chairman : If there are no other remarks I will bring the discussion to a close. If any of the members would like to make written communications on the paper, Mr. Adamson will be pleased to send them to Mr. Handscomb for him to reply to, along with a report of the remarks that have been made to-night.

The meeting closed with a hearty vote of thanks to Mr. Handscomb, also to the Chairman.

MR. HANDSCOMB'S REPLY TO DISCUSSION.

My thanks are due to those members and friends who have taken so kindly an interest in my efforts to put into readable form the peculiarities of copper in its working, and the general manufacture of pipes, etc. More especially are my thanks due to those gentlemen whose interest has materialized into question and discussion.

Personally I am the gainer, in many ways, from the statements made during the discussion, and am amply repaid, if our gain of knowledge is mutual.

Mr. Milton, in his exceedingly interesting remarks, has touched upon some very important points, and says that "apparently favourable conditions are necessary for the production of first-class work." I should imagine the manufacture of few commodities would fall outside this category.

I quite appreciate the distinct advantage of iron and steel over copper for large steam pipes.

In regard to "Elmore's" copper failing from mere exposure to weather, I have any number of cases that could be quoted to demonstrate this statement; one will suffice. I had occasion some years ago to remove a horizontal rack used for storing copper tubes, and some $5\frac{1}{2}$ bore seamless tubes 10 in. thick had lain in the rack exposed to the weather for some three or four years, and upon attempts being made to haul these tubes out by means of a pair of iron tongs, the pieces came out that were caught hold of by the tongs, and the copper would actually not support its own weight. Upon investigation, by means of the numbers stamped on, these were found to be Elmore production. Now for my proof of the extraordinary rapid deterioration of Elmore copper under steam. Some fifteen years ago I purchased (being in business in Birmingham at the time), a fairly large amount of copper sheet from Elmore's to work up into seamless bellows joints; the action of this copper, during the working, was remarkably good, the percentage of failures being nil, and the finished articles absolutely free from flaws or marks. Many of these bellows joints were put upon the market, with every prospect of success. Within twelve months, complaints began to be received, and I should say that within two years not one of them was in sound condition. They were fixed in all manner of places, and under every conceivable condition; in many instances undeniable proof was given that no expansion or contraction had taken place. Yet, in every case, the condition of the copper was such that it could only be described as literally falling to pieces.

My clients and myself had only too painful proof of the unsuitability of Elmore copper for any class of work exposed to heat or weather. The mechanical tests that Elmore copper could be put to, and successfully stand, were altogether exceptional, and have completely dissipated any lingering belief in mechanical tests.

I bow to Mr. Milton's superior knowledge of the metallurgical side of copper, and accept his statement unreservedly in respect to chemical action due to poling. It does not affect my contention, however, that the essential gases requisite to the "life" of the copper escape under prolonged heating.

In regard to mechanical tests, if Mr. Milton, or any one else, after the statements under this heading that I have given, still prefers to worship at the shrine of mechanical tests, then I have no more to say. If any pleasure can be derived from it, well and good, but I really should like to know how many pieces of copper are condemned from test failures.

My apparent discrepancies in this respect are only apparent; my statement of "good copper sometimes giving bad test results and poor fracture" was intended to reply relatively, that is, no pieces failed the test, but some stood much more than the orthodox requirements.

Mr. Milton's statement that my case proves the good copper under test to have been spoiled by the coppersmith is an arbitrary conclusion to arrive at. Practically the whole of my remarks under this heading were definitely given to repudiate such a conclusion. It appears to me to hold out much greater security of the pitfalls being avoided, when the existence of the danger is recognized; hence my wholesale condemnation of the wrong methods sometimes adopted in working sheets and tubes.

Mr. Milton seems to think that I am wrong in my allegiance to the pure copper; my case was not argument, but a statement of facts. Mr. Milton gives his case away when he brings in the locomotive engineer. Tubes for locomotives undergo a totally different treatment to the ordinary copper pipe, they do not require to be ductile so much as to offer resistance to furnace gases; hence I can quite believe the impurities to be a desiratum.

Mr. Milton makes the following statement in regard to annealing: "That although annealing does restore to a very large extent the quality of the copper, if strained or hardened in any way very frequent annealings must have an effect on the crystalline structure of the copper, so that repeated annealings may be deleterious to copper." As I endeavoured to point out, it is the "*over-straining*" that does the mischief, not the frequent annealings.

In the reference to annealing furnaces, a remark is made that in a given instance mentioned in a paper read on the north-east coast, experiments were made with thin pipes of large size, and no distortion took place. If the sketches given of the pipes experimented upon are referred to again, it will be found that the shapes were so plain and simple that distortion was impossible, unless dissolution should have taken place.

But the exigences of marine work will not permit of such accommodating copper pipes being made, and I will defy any man to put a *steel* pipe of complicated shapes, much less a copper pipe, into a furnace and heat to annealing temperature without distortion, unless, of course, some elaborate and intricate packing up was insisted upon; this, with the consequent labour expense, would spell insolvency.

Any experienced coppersmith will bear out my contention that copper hardens appreciably under exposure; try a piece of tube recently annealed with the rough and ready test of the hammer, and then try a piece that has lain about, maybe for years, since annealing.

It is necessary for me to point out a misprint in the original proof, and this clears up the difficulty Mr. Milton has in understanding my meaning: the line, "This tendency to split is enormously exaggerated in the case of seamless tubes"—for seamless it should read seamed; this completely alters the context. Although the error is so glaring, I should have expected suspicion to have arisen as to a misprint. On looking it up, I find the original typed copy contained the error, and escaped my notice.

Mr. Milton thinks my remarks in reference to the allowing excessive puckers to form, shows the coppersmith not to be a reliable mechanic. I have a shrewd suspicion that the coppersmith is like other people, he does silly things until he is taught better, and this paper is an attempt to impart that knowledge.

I am sorry Mr. Milton thinks I condemn the workmen; if I do so, I condemn myself. I have tried to condemn the errors that have arisen in the hope that with the right methods before them, these errors will become less frequent. The man who cannot make a mistake usually does nothing.

I must tender my thanks to Mr. Milton for his criticism and interest taken in the lecture.

Mr. Earnshaw gives some very valuable information in his remarks, and has evidently not only had extensive experience but been exceptionally observant.

I have had no experience with working copper by means of block tin hammers. I should have felt dubious of bringing tin so much into contact with copper requiring subsequent heatings.

I am afraid the material the hammer is composed of is of less importance than the amount the copper is forced into shape unduly.

Mr. Earnshaw says :—" In brazing, all pipes should be dovetailed along the entire length of the seam, as, etc., etc." This is only practicable when the length of pipe is finished straight. Should the pipe require subsequent bending, these same dovetails or cramps will give way during the process of bending.

Mr. Earnshaw's remarks upon flanges and their fixing and brazing, seem to suggest an over-elaboration in details. I see no detriment in his ideas, but I fail to see a benefit to correspond to the extra cost of his methods.

Mr. Earnshaw gives some exceedingly interesting data in reference to old handicraftsmen's methods, and also details a rather serviceable device for annealing pipes by means of a circular gas arrangement.

I still, however, prefer my own method of burning sticks and blast, both for cheapness and effectiveness.

Personally, I believe planishing would rapidly become a regained art if the exigences of commercial competition allowed of the payment of such high-class work.

I must, in conclusion, tender to the members, associates and others connected with the Institute my sincere thanks for the opportunity afforded me of putting my views upon copper work before a body of skilled scientists, who have kindly listened and added their comments.