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President: JAMES DENNY, Esq.

Lecture on the Corrosion and Decay of Metals

BY MR. J. T. MILTON (MEMBER OF COUNCIL),

AT

THE FRANCO-BRITISH EXHIBITION,

On Saturday, September 5, 1908.

CHAIRMAN: MR. ALEX. BOYLE (VICE-PRESIDENT).

THE CHAIRMAN: I am sure we may congratulate ourselves upon having the second meeting of the Session of the Institute in this, the Congress Hall of the Franco-British Exhibition. I am glad to see that the attendance is more numerous than it was at our first meeting, when, unhappily, a good many of our members, who had come to the Exhibition with the intention of hearing Mr. Durtnall, were unable to find the Congress Hall. I hope that difficulty has not been experienced on this occasion. To-night we have the good fortune of being able to listen to a lecture by Mr. Milton on the "Corrosion and Decay of Metals." It needs no words to commend to a gathering of marine engineers one so well known in the engineering world as Mr. Milton. I am sure we may anticipate that a lecture by one so experienced, and dealing with a subject so important to all engineers as the corrosion of metals and their decay, will not only prove interesting and instructive, but extremely valuable. Mr. Milton has devoted a great deal of time and attention to the subject matter of his lecture. He will give us the results that he has found and the opinions he has formed after his long and extended obser-

vations, and the experiments he has made on corroded metals. The subject of the lecture is one, I may say, which very frequently forces itself on the attention of marine engineers, and on occasions demands immediate attention. The lecture will amply repay your closest attention on this occasion, and afterwards your most careful study.

THE subject of the lecture to-night is of such importance, both to the constructive engineer, and also to the engineer whose business it is to attend to the maintenance of the structures placed in his charge, that no apology is needed in bringing it before the Institute of Marine Engineers. To the constructor, because he has to provide an excess of material in his design to allow for an inevitable deterioration which he knows will take place; and thus at the outset, and right through the useful life of the structure he creates, it is handicapped by having to carry more weight than would be necessary if he could ensure that no weakening by decay or corrosion would occur. To the engineer in charge, because his every-day work includes the taking of precautions against the failure of each one of a large number of small details, the failure of any one of which, owing to the interdependence of so many parts of the mechanism, may produce serious consequences out of all proportion to the seeming importance of the detail in question.

By far the most important material used in engineering structures is iron in its various forms of cast iron, wrought iron, and mild steel, and unfortunately iron is one of the metals most liable to decay or corrosion. The corrosion of iron is almost but not invariably due to its affinity for oxygen, and the consequent formation of oxide or rust. Cases of decay of cast iron however occur, to which reference will be made, in which the formation of rust does not appear to be the sole cause of the trouble, but rather the formation of some soluble compound which is washed away or dissipated by the corrosive influence itself.

Although the formation of rust is of such a common occurrence there is not by any means a concurrence of opinion as to the precise way in which rusting takes place. The presence of water seems to be essential, but water by itself will not rust iron. When bright iron is immersed in pure water which has been freed from dissolved air it remains bright for an indefinite period, but, given the access of air or oxygen in solu-

tion in the water, rusting almost immediately sets in. It is stated that the action of oxygen and water is comparatively slow except there is also the presence of a small amount of free CO_3 , and that when this is present the rusting is much more rapid. It is on this account that in cases where oxygenated water has necessarily to be kept in contact with iron the presence of a little caustic lime in the water is found to be preservative. The lime (calcic oxide) has a strong affinity for CO_2 , forming calcic carbonate, and prevents the gas from remaining in the water.

In the cases of many metals which are readily oxidizable (lead is an example) it is found that when the outer surface of the metal has combined with oxygen, the thin film of oxide so formed prevents the access of further oxygen to the metal and so stops further corrosion. In the case of iron however this is not the case. It is unfortunately true that iron once rusted corrodes more quickly than clean iron when exposed either to moisture with access of air or oxygen, or when exposed to moist air. The reason for this is obscure; but it has been said that the oxide of iron formed (Fe_2O_3) will under certain conditions, either of temperature or moisture or both, occlude or separate out and absorb from the air an excess of oxygen, whilst in other conditions of temperature, etc., it gives up the oxygen so occluded. Evidently if this is the case, when the occluding conditions occur the coating of oxide can most readily obtain the oxygen from the side nearest the air, whilst when the reverse conditions occur it can equally readily divest itself from the excess of oxygen by yielding up some of it to the contiguous iron on one side as by giving it up to the air on the other side of the film. Whilst this is a possible reason, it may not be the only reason for the continuous oxidation of the iron covered by a film of oxide. It may be that the oxide itself is not an absolutely coherent solid mass such as the ordinary senses imagine metals to be, but it may really be of a porous structure, with openings or vacuities sufficiently large for molecules of oxygen to freely penetrate them and so obtain access to the iron underneath, or even sufficiently porous to contain sufficient moisture to support an electrolytic action, to which reference will presently be made. However the important fact remains that a coating of rust once formed on iron is no protection whatever against further oxidation, but the reverse, so in all cases where rust

has once formed it is best to remove it as soon as possible. Evidently the best way to prevent iron from oxidation is to prevent the corrosive influences from coming into contact with it, and for this purpose, whenever the use of the structure will permit it, the surface should be covered with something to keep air and moisture away from it. The most usual protection is paint, whilst cement, asphalt and galvanizing are also employed with more or less success.

The subject of paint is one very well worth study by engineers, but is too complex to be dealt with in the present lecture beyond making the statement that an ideal paint is one which can be easily spread on the iron, will not flake off, and will quickly dry into a hard coherent coating so continuous or free from porosity that it will not permit of the passage of moisture or of air through it. Such a paint has not yet been found, although many good paints when properly put on do protect in a very marked degree the metal under them from corrosive influences.

Portland cement is usually employed only for parts where water is always present, and experience with the inner surfaces of the bottoms of iron and steel ships shows that where it has been put on of sufficient thickness to ensure durability it effectually prevents corrosion both when applied originally to the bare iron and to iron previously coated with good paint. The thin coating of "cement wash" applied to parts which cannot be cemented in the ordinary way, however, cannot have the same good character given to it, as we see by the severe wasting which occurs to the floors and reverse frames, tank tops, etc., of vessels which have been treated in this way whilst building.

Galvanizing is a process of covering the iron with a thin film of zinc, and is very efficient for a time in most cases in which it can be applied, and where only atmospheric influences have to be resisted; but after a time it (the zinc) becomes wasted and its preservative effect is lost, and then as the iron cannot be again galvanized the further preservation must be attempted by means of paint.

At first protection is afforded simply because the first coating of oxide which the zinc surface acquires protects the metal from further oxidation, but this in time wears off, more oxide forms, and at last the zinc coating, in spots, becomes completely worn through, leaving the iron surface exposed. The

preservative effect, however, has by no means been lost, and the iron in the exposed parts is still preserved by the zinc remaining on other parts through what is called galvanic action; and not until the zinc has practically disappeared from the whole surface does the now exposed iron begin to corrode.

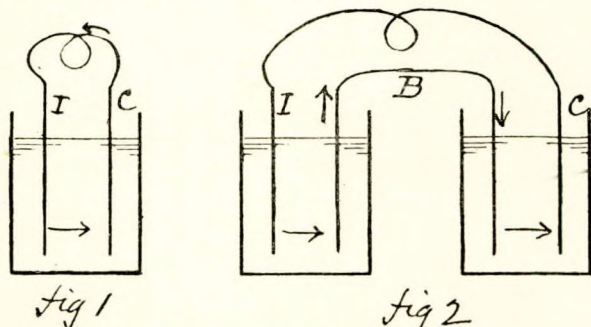
If two dissimilar metals are immersed in a corrosive liquid, or exposed to a corrosive atmosphere which will act on both of them, so long as they are not brought into electric contact, each is acted upon in precisely the same manner as if the other was not present; but if the two metals are brought into electric union, then the whole of the corrosive influence is transferred to one of the metals, the other being protected; at the same time an electric current is set up which proceeds from the most corrodible metal through the liquid to the other metal, and thence through the electric path or connexion back to the most corrodible metal. In the case of a plate of zinc and one of iron being both immersed, say in salt water and electrically connected the iron will not corrode, but the zinc will. In common language the iron is protected at the expense of the zinc. This is the principle upon which depends the preservation of boilers by means of zinc plates placed in them. In a worn piece of galvanized iron there is electrical communication between the iron and the remaining zinc, and so the iron is preserved at the expense of the zinc so long as any remains.

At the same time let it be noted that there is a galvanic current produced flowing through the electric connexion from the protected metal to the more corrodible metal. The energy of this current is proportional to the chemical action, which is represented by the corrosion.

Although we have taken iron and zinc as our illustration, the same results hold with any two dissimilar metals, one at least of which is acted on by the corrosive fluid, and we constantly meet with cases in which dissimilar metals placed in electric contact at one part, and subject to the same corrosive action at other parts, set up a galvanic action which results in the protection of one of the metals at the expense of the other. Even when two metals so much alike in chemical and physical properties as wrought iron and mild steel are used together, the slight differences between them lead to some galvanic action when they are exposed to suitable conditions,

and usually the wrought iron is then preserved at the expense of the mild steel.

Now let us take a glass vessel (see fig. 1) put in it a liquid of slight corrosive power,¹ and insert in it two plates, one of iron, the other of copper. So long as there is no electric contact both plates are acted upon in the manner peculiar to themselves and to the corrosive liquid; but connect the plates, say by a wire, and we have at once a current set up as indicated by the arrows, and at the same time the iron plate is more actively corroded than before, whilst the copper is preserved. If now instead of *I* and *C* being both immersed in the same liquid, which it will have been observed conducts the current from *I* to *C*, they were immersed in separate cells which have no electric conductivity between them (see fig. 2), then no current is set up and no protection



is afforded to *I* by *Z* even although they are connected by the wire. For the galvanic action to take place therefore it is essential that the current should flow from *I* into the liquid and from the liquid into *C*. This can be arranged by immersing a connection *B* in both cells and we then have the complete galvanic action produced. Note that the corrosion takes place where the current leaves *I* to go into the corrosive liquid. Now, instead of the right hand cell, let us suppose we have a source of electricity supplied altogether distinct from that obtained through the plate *C* (see fig. 3), so that we get

¹ In these experiments the liquid used was water with one part of nitric acid to 200 of water, a little common salt to increase its electric conductivity, and a small quantity of ferrocyanide of potassium. The latter gives an intense blue coloration when there is a trace of iron present.

a current entering I of the same intensity as before, and the same intensity of current consequently leaving I into the liquid, I will then be under precisely the same conditions as before in being exposed to a corrosive medium and in having a current passing through it, and it will be found that it corrodes exactly as before. We see then that one condition to ensure corrosion is that a metal shall be exposed to a corrosive influence, and that a current shall flow *out* of the metal into the corrosive liquid. This action is the cause of much trouble occasioned by the wasting of water and gas pipes, etc., in the earth by currents due to leakages from electric mains, and from the return paths of electric rails in tramways, etc. We must return to this question of electrolysis by and by when dealing with the deposition of scale on screw shafts but at the present it is enough for us to note that all that is required

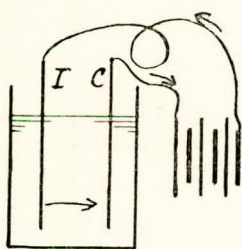


fig 3

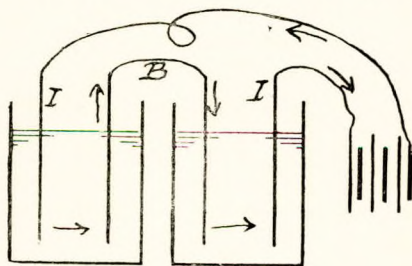


fig 4

to set up corrosion in a piece of metal is that a current, produced somehow, either by the corrosive influence itself or by some altogether extraneous means, does leave the metal where it is in contact with a corrosive element, and that then the amount of corrosion so produced is proportional to the amount of the current and to the time during which it acts. It is evident that if the same current is distributed over a large surface, so that its intensity per unit of area is small, the corrosive effect or loss of weight of the metal per unit of area will be less than if the same current is concentrated on a smaller area. Hence we see that if the surface of the metal is for any reason generally obstructive to the flow of the current, but at the same time certain parts of it are less so than others, so that these parts conduct more than their own share of the current, then these parts will receive more than the average of the

resulting corrosion, or in other words they will become "pitted." It is this which leads to severe pitting in places where paint or protective scale has been accidentally locally removed, and it points to the importance, where scaling has to be done, of having it thoroughly done, otherwise the freshly cleaned parts will receive the corrosive influence which ought to have been distributed over a larger area.

We will now take two cells and a battery, and we will arrange matters so that in one cell the current from the battery enters the iron plate to be corroded, flows through the liquid to the other pole, which we will make of carbon, which is an incorrodible material, thence to a similar carbon pole in the second cell, then through the liquid to another iron plate, and thence back to the battery. We shall find that in the first cell, as before, corrosion occurs on the plate where the current leaves the plate to enter the liquid, but in the second cell where the current *enters* the metal from the liquid no corrosion whatever occurs, even although there is precisely the same current passing through both cells.

In the next experiment we will make the current concentrate a more than usual proportion on one particular spot, and in this case we shall find the iron in a short time will be pitted right through.

Two instances only will be mentioned of sources of current affecting corrosion on board ship: First, electric machinery; second, the differences of temperature to which different parts of the structure are subjected. Electric leads are constructed on two systems, the single wire with hull return, and the double wire. In the single wire the current leaves one pole of the dynamo and is distributed as required by a system of branching mains. From the lights, etc., it is returned to the structure of the ship, and thence to the other pole of the dynamo. The conductivity of the steel hull of the ship is so enormous that it seems at first sight that absolutely no current could leave it between the points where it enters and the connexion to the dynamo pole; but where there are several ways open for a current to traverse, it is known that it will divide itself between all of them, the portion flowing through each path being inversely proportional to the resistance of that path, so that some current, however slight, must flow through every possible path between the electric light connexion and the dynamo pole; and if one such path lies along a way where the current

will leave a corrodible metal to enter a corrosive medium, some corrosion will take place there. With a leaky cable the leak similarly distributes itself over every possible path to the hull of the ship, and it may be that in some cases it finds a short path through some pipes or fittings which it corrodes, and which otherwise would be unaffected. In the double wire system a defect in one cable only will not leak electricity unless there is a means for the electricity to return to the other cable. If there are defects in both cables, then the leakage from one to the other divides itself between every possible course. In this way, with either system, we get what engineers, on board ship term "stray currents," very difficult to detect, but very serious in the long run, not so much on account of the loss of power of electric plant they represent, but because of their *sure* though *slow* action in effecting the corrosion of some part of the vessel.

It is, however, perhaps from the differences of temperature of different parts of the vessel that we have the most serious results ensue on board steam vessels. It is a well known experimental fact that given two pieces of the same kind of metal electrically connected, but at different temperatures, the warmest will always be electro positive to the other, and if they both are in the same corrosive medium a current will flow from one to the other. It is in the double bottoms under the boilers that this finds the greatest illustration. Here we have all the conditions for corrosion. The upper part is heated by the boilers, the lower plates are kept cold by the sea. They are in communication by the floors, etc., and are surrounded either by sea water when the tanks are full, or by moist air when they are, so-called, empty. A current is set up and corrosion occurs. The remedy appears, first, to as much as possible lessen the differences of temperature by preventing the heat of the boiler from reaching the ship structure, and second by ensuring that there is no corrosive medium either of sea water or moist air in these spaces. This can only be done by ensuring that the spaces are kept absolutely dry. Thirdly, by paying particular attention to keeping these parts thoroughly protected by paint inside, and by paint or other means outside. These points have much more attention given to them now than formerly, but they are so very important that they will bear repeating and emphasizing.

Another part of the vessel in which differences of

temperature must affect the structure and set up currents in way of refrigerating spaces. Here, however, the reverse conditions occur. The parts of the vessel hidden from view behind the insulation are kept cooler than normal, and so they tend to be preserved instead of corroded; moreover, they are kept dry instead of moist, and on these accounts they do not corrode or give undue trouble or anxiety. The same influence of differences of temperature can often be seen in boilers. For instance, the shell of a donkey boiler, if corroded at all, will be found to be corroded on the side nearest the main boiler chimney, and to be free from corrosion on the other side.

We have spoken of corrosion as due to the action of a corrosive liquid or medium on the metal either under normal conditions, or intensified by electric current so arranged that the current leaves the metal to enter the corroding medium. Now for a moment consider the reverse action. Turning to our original experiment, we saw that if both the plates were by themselves corrodible in the liquid, when electric contact was made the one which was least corrodible was protected by the arrangement, and we also saw that it was not necessary to have two dissimilar metals to make the one corrode; a current, however generated, was sufficient to effect the same purpose, provided it was made to leave the metal. Now let us reverse the direction of the current, and we shall find that, provided it is made to *enter* the metal from the liquid, corrosion is stopped. This experiment shows that electric currents may be made to protect as well as to corrode.

So far our remarks have all been made to apply to the case of a metal of homogeneous structure, that is to say one of which each and every point has the same physical properties. Let us see what will happen if the metal is not homogeneous. No metals are absolutely pure. How are the various impurities which exist in the metals actually distributed through the mass. When two or more elementary substances are mixed together we produce either one of three different kinds of arrangement of the individual particles. We may have first what is called a mechanical mixture, in which each individual particle of each substance has retained its own individuality and is merely mixed up with the other particles, and if we had patience enough we could again separate each from each. As an instance, consider a mass of iron and brass filings mixed together as intimately as possible. Each particle of iron

remains iron distinct from all the particles of brass, and the use of a magnet will be sufficient to again separate all the iron from the mixture.

Next we may have a chemical combination; definite numbers of atoms of each component unite together and form a new substance with altogether different physical properties from those of either of the component parts. A chemical combination has the property that each part of it, however minute, contains precisely the same definite proportion of each constituent as every other part, whereas in a mechanical mixture we may have very considerable variations of the different constituents when we closely examine very minute parts of it.

Thirdly we have what is called a solution. As an example take a solution of salt in water. Here we have, when carefully examined, the same proportion of salt and water in each and every part, but the proportions, instead of being definite as they are in a chemical compound, may be anything ranging from the very smallest amount of the dissolved substance up to that particular amount which saturates the solution. (Under certain peculiar circumstances it is possible in some cases to have a supersaturated solution, but this is always a condition of unstable equilibrium.)

We not only may have liquid solutions, but the same equable distribution of the one substance within the other, if in the solid state, is also called a solution, but in this case it is generally called a "solid" solution. The three states of distribution of different elementary substances then are: (1) Chemical compounds distinguished by every part, however minute, by being composed of precisely the same definite atomic proportions, and consequently being homogeneous; (2) solutions in which each and every part also is composed of precisely the same proportions, and the substance is therefore still homogeneous; but these are not atomic proportions and may be varied indefinitely below the maximum or saturated condition of any one of the constituents; and (3) mechanical mixtures in which, when minutely viewed, the substance is not homogeneous, some small measurable portions being composed wholly of one constituent and others of other constituents.

When we come to closely examine metals we find in them all three forms of these arrangements. As an example of a chemical compound let us take a yellow brass composed of about two atomic parts of copper to one of zinc. If the copper

is first melted in one crucible and the zinc is then added, either by having been separately melted and poured into the copper, or even by being put as a solid into the molten copper, combination takes place with the evolution of a considerable amount of heat, and the resulting metal is altogether different from either of its constituents. It is perhaps not so ductile as the copper, but is immensely more so than the zinc. It has a different colour from either of them and is stronger than either. Whereas copper can be worked either hot or cold, this cannot be worked hot—in fact it is a different metal altogether. If instead of taking two parts of copper to one of zinc we take about equal atomic quantities, and treat them in the same way, we obtain another chemical compound. Like the other it is yellow, harder than copper, and possesses considerable ductility, and is altogether different in its physical qualities from either copper or zinc. It is a true chemical compound.

Now instead of taking either of the proportions named, suppose we take some intermediate proportion, say 60 per cent. copper and 40 per cent. zinc, which is the composition of the alloy so well known under the name of "Muntz Metal." We still, on mixing the molten metals, obtain chemical action with the evolution of heat, but what really takes place is that we get a mixture of the two chemical compounds Cu_2Zn and CuZn . There is not enough zinc in the mixture to make all CuZn , nor is there enough copper to make all Cu_2Zn , so when equilibrium is obtained there is a mixture of these two constituents in such a proportion that every atom of copper and every atom of zinc is combined in one or other of these proportions. While the resulting metal is fluid each of the components is mutually dissolved in the other and we have a homogeneous solution of CuZn in Cu_2Zn , or of Cu_2Zn in CuZn , whichever way we choose to view the matter. If now the mass can be cooled very suddenly we are able to retain the two constituents in their homogeneous solution, and we have a homogeneous solid solution as a result. If, however, the cooling is allowed to take place more slowly, then each of these metals separates out from the other, and the result is that we have a mechanical mixture of the two constituents. Here then we have in one alloy, "Muntz Metal," an exemplification of two different chemical compounds, each differing from the constituent metals, of solid solution of one of them in the other, and of a mechanical mixture of the two

chemical compounds, the condition of solid solution or mechanical mixture being solely in this case due to the conditions of cooling from a high to ordinary temperatures. Actually the separation of the two constituents takes place at a temperature lower than that of solidification, so that here we have a wonderful instance of the transference of solid metallic molecules through the solid occurring during the "segregation," as it is called of the different constituents. This is a subject which has not been fully investigated and is outside the scope of the present lecture, but some illustrations will be given to show what actually takes place, as the mechanical mixture or separation of these two metals has a distinct bearing on our subject.

The actual mixture of the two constituents is shown by the microscope. Both the compounds are of the same yellow colour. When the metal is cut it appears to the eye a homogeneous, and when it is carefully polished and microscopically examined it still presents the appearance of a yellow mirror-like surface with no markings whatever on it. Let it now be lightly etched with acid, and we find definite markings on it, certain portions of the surface become darkened whilst others remain bright. What has happened is that the acid has really commenced to dissolve the surface of the CuZn portions, leaving that of the Cu_2Zn untouched. How we recognize each constituent which we see is by taking several samples of alloy varying in composition from CuZn to Cu_2Zn ; treating them all in the same way, we find that the CuZn alloy is composed entirely of the dark etching constituent, the Cu_2Zn entirely of the other, while in those alloys of intermediate composition there is always a mixture of the two substances, and the proportion of them varies just as the composition would lead one to expect.

Now returning to the question of corrosion. The etching by the acid which reveals the structure is simply a case of corrosion. Here we have two distinct metals, each by itself corrodible by the acid. They are in excellent electrical contact and are both immersed in a corrosive medium. Galvanic action ensues, the one least corrodible is preserved through the contact with its neighbour, which however is more vigorously attacked and eaten away by the acid. So far the matter is simple, and this explains what used to be considered to be so very mysterious, the decay of Muntz metal

and somewhat similar alloys when exposed to the action of sea water. Some examples of this decay are here shown.

There were exhibited portions of a Muntz metal condenser tube plate and of a Muntz metal diaphragm plate, some specimens of decayed yellow metal bolts taken from wooden ships, some brass bolts taken from a circulating pump chamber, and a metallic air pump valve. The latter was apparently sound, but it could be easily broken up by the hands.

It was noticed that in each case where a decayed piece of metal has been broken the surface appeared to be dull and non-metallic; where, however, the piece was filed it had a yellow metallic appearance, giving practically no indication of its actual character, although a careful comparison with a piece of sound metal similarly filed will show a distinct difference in brightness. How is this to be accounted for? If we take as an illustration a wall built with red bricks and white mortar, and supposing the bricks are stronger than the mortar, then if the wall is broken down by force the ruptured surfaces will show principally the white colour of the mortar. If, however, the wall is sawn through or carefully cut right through the bricks without dragging any of them out bodily, the fracture will show mainly the red colour of the brick. It is similar in the case of the decayed Muntz metal. In the sound metal the two constituents are mixed up mechanically. One of them then becomes decayed, and then it is represented by the mortar of the illustration, the other remains practically sound and is represented by the bricks. On fracture by blow the rotten portion gives way, and we observe its colour as dull brown, but on filing the metal some of the sound portions are filed through and we get the bright metallic appearance.

It may reasonably be asked why is it that in some cases the metal which decays or corrodes seems to do so in a different manner from that shown in the specimens exhibited, and disappears entirely without preserving its outward form? The explanation is probably to be found in the variation of the *intensity* of the corrosive influence. Where there are no extraneous electric currents to assist in the corrosion, but only the action of pure sea water, then the decay is slow and affects only the one constituent. It probably consists of a slow oxidation of the zinc, leaving the copper in an extremely finely divided metallic state. The zinc oxide formed must in part get

dissolved away, because the total volume of the decayed metal and oxide is only equal to that of its original bulk, but in part it surrounds the minute pieces of copper left and partially insulates them. If, however, there is in addition to the chemical action of the water, an added electric current, the action may be sufficiently strong to oxidize not only the zinc but also the copper, of the most corrodible constituent and the effect of the current then falls on the other constituent, and it also begins to oxidize and decay with the result of the formation of a pit hole or the loss of original shape. If the added electric current is strong it may actually from the first overcome the protective influence of the CuZn on the Cu_2Zn , and then corrosion of both constituents will take place simultaneously.

The case of Muntz metal has been taken because of the simplicity of its structure and the striking effect of the corrosion or decay to which it is sometimes subject, and it is therefore an example of what may be expected when a heterogeneous metal is subjected to corrosive influences.

The effect of impurities in metals may be inferred to be the following. If the impurity is of a nature to be dissolved uniformly into the metal so that the impure metal is homogeneous, local currents will not be set up at all, and the impure metal will be only subject to corrosion pure and simple, and will either tend to be preserved or to be more rapidly decayed according to the effect the impurity has. For instance, take a brass which has not a duplex structure, say that used in ordinary condenser tubes, 70-30 as it is called. If there is a little tin in it, either as an impurity or intentionally added, the tin diffuses uniformly through the metal and has the effect of retarding or diminishing corrosion. If, however, the impurity be a small proportion of lead, it also will be diffused or dissolved uniformly through the brass, but its presence will render the brass more corrodible.

When we come to more complex alloys, we in general get a still more complex structure than in ordinary Muntz metal. Most, if not all, of the so-called special bronzes used for propellers, etc., owe their strength to the iron they contain. They are mainly copper-zinc alloys of the Muntz metal type, with a small proportion of iron, tin, and sometimes of other metals. The tin appears to go into solution with one or other of the constituents, and cannot be separately ob-

served. The iron probably combines with some of the zinc, and the compound dissolves in the metal so long as its proportion does not exceed that at which the metal becomes saturated, which I believe is with about 1 per cent. iron. When, however, the iron exceeds this 1 per cent. there can always be seen in a prepared polished section of annealed metal numerous small points harder than and of different colour to the rest, and these contain the excess of iron combined most probably with zinc. When etched these points are the first to be attacked and dissolved. These bronzes do not always behave in the same manner. In iron or steel vessels they generally last well. In several composite vessels with coppered bottoms the bronze propellers made for the different vessels by different makers all dezincified on the surface. In the first case noticed this was attributed to the vessel lying for a long time in impure river water. The propeller was filed bright and the ship was then employed in deep sea water, and it was found that the same thing occurred in the new conditions. In subsequent vessels the same action took place. Now in iron or steel vessels this kind of action has scarcely ever been noticed. It was, therefore, reasonable to infer that it was due to the exceptional circumstances of the vessel being coppered. In fact the bronze propeller and the copper sheathing immersed in sea water formed a galvanic battery.

Leaving the bronzes now, let us turn to cast iron, which is well known to suffer severely from decay in certain conditions, although in other conditions it remains good for apparently an indefinite time. Cast iron is perhaps the most complex in structure of all the metals used in every-day work, as also it is the most varied in chemical composition. Every known brand of pig seems to have a different composition depending on the ores from which it is smelted, while even from the same blast furnace working with the same coke, ore and flux, different grades of pig are produced. In all cast iron we have besides iron a considerable proportion—sometimes as much as 3.5 per cent.—of carbon, some of which may be combined with iron, forming carbide of iron, whilst the remainder exists as graphite; we always have also present in various proportions silicon, sulphur, phosphorous, and manganese, all of which are recognized as ordinary constituents, and often we have other elements such as copper, arsenic, etc., as well, which are looked upon as impurities. Each of

these elements, according to its amount, influences the physical properties of the cast iron.

When the iron is molten the whole of the elements, however they may be combined amongst themselves, must be in a liquid form uniformly diffused through the mass, and the molten cast iron is homogeneous, or mainly so. On cooling, the first to solidify and to separate out is some of the carbon, which separates out in plates or partly spherical shells of graphite. If the cooling is very slow these graphite plates separate out in larger sizes than where the cooling is more rapid, and the iron is more grey and soft. Next, other parts separate out. The silicon combines with iron and manganese, forming silicides. The remainder of the carbon combines also with iron and manganese, forming carbides. The sulphur combines with some iron, forming a brittle slag-like substance FeS, (iron sulphide,) which separates out in small particles throughout the mass, and finally the portion which solidifies last is a compound of iron and phosphorous. When cast iron is carefully prepared for examination by polishing, the graphite plates can be clearly seen, even with small magnification, as can also the small particles of iron or manganese sulphide, but the rest of the materials remain bright. By etching, however, and by heat tinting, the different constituents can be seen and recognized, and it is found that the phosphide of iron is always at the greatest distance from the graphite flakes, occupying, it may be said, the centre of the spaces between the flakes. In this complex metal we have the very conditions for galvanic action to be set up directly a corrosive medium envelops the cast iron. The minute graphite plates are not readily oxidizable, they immediately become the minute poles of a multitude of miniature galvanic batteries. The phosphide of iron also appears to be very resistant of oxidation, so that the parts of this constituent also probably serve as poles of other minute batteries. At any rate we have every condition for a rapid oxidation of the surface.

Now let us see how the decay of cast iron proceeds. It is only too common to find iron castings which have been subject to the influence of sea water so softened that they can be cut with a knife, and in this condition they are generally said to have been converted into plumbago. By carefully preparing a section of a wasted casting at the junction of the sound and unsound portions, it can be seen that the decay first at-

tacks the iron at its junction with the graphite plates; it then advances along the plates, and then gradually proceeds through the metallic portion surrounding the plates, leaving the phosphide compound till the last. Moreover, it is found that these phosphide portions have not only been left to the last because they have been the last attacked, but they are left intact in parts which have evidently been decayed for a long time, so that it is clear that they themselves offer great resistance to corrosion.

So far we are considering corrosion of cast iron by itself, but it will be seen that, given in addition a galvanic current in the right direction from an outside source, we need not be surprised at the rapid rate at which corrosion will occur. Now, again, let us consider another point. If the corrosion is simply oxidation, then iron oxide, being practically insoluble in water, will itself form a thick coating of rust on the cast iron, which although it will probably transmit oxygen through itself, as mentioned in the earlier part of the lecture, and lead to further oxidation, will not in any way account for the plumbago-like condition in which decayed cast iron is sometimes found. To account for this it is evident that plain oxidation is insufficient and that there must be, in some way, other corrosive influences which permit of a solution or partial solution of the products of decay and the consequent removal of some of the iron.

An analysis of some of the plumbago-like substance formed by the decay of cast iron is given here.

Iron	43.0
Graphite	7.8
Silicon	4.66
Phosphorous	3.68
Sulphur50
Manganese51

From this it is clear that whilst all or nearly all of the carbon, silicon and phosphorous have been retained, fully one half of the metallic iron has been removed, whilst the remainder of the iron is partly reduced to the form of oxide. Such a result will probably be accounted for by the formation of chloride of iron through the action of galvanic currents and sea water.

Now for a few minutes let us return to wrought iron and mild steel.

Speaking very roughly or roundly, we say that whereas

cast iron consists of iron with a large proportion of carbon, steel consists of iron with a considerably less proportion of carbon, while wrought iron is iron containing no carbon, that is, it is spoken of as being pure iron. It is the general experience that, given the same exposure to corrosive influences, high-class wrought iron, such as Lowmoor, Bowling, etc., rusts more quickly than the more common iron used for ship and bridge plates, and that mild steel corrodes more quickly still. Now let us see if the structure of the steel in any way explains this.

In cast iron much of the carbon exists in the form of graphite, but in the case of steel all the carbon exists in a combined state, either as Fe_3C , or Mn_3C . The carbide itself becomes very intimately mixed up with a definite proportion of iron; the mixture of iron and carbide is called "Pearlite," and this mixture is such that the percentage of carbon in it is .9. In steels containing less than .9 per cent. of carbon—and these steels comprise all structural steel—it is found that the carbon all exists in definite areas of "pearlite," leaving the remaining parts of iron free from carbon. This pure iron is called "Ferrite." In steel containing .9 per cent. carbon, such as chisel steel, we get the whole structure comprised of pearlite. In steel containing .45 per cent. carbon half of it will be pearlite, and half ferrite. In steel containing say .22 per cent. carbon, such as some boiler-plate steel, we get about a quarter of the whole area pearlite, and the rest ferrite, and generally the amount of pearlite is proportional to the amount of carbon in the steel. In steel containing a greater proportion of carbon than .9 per cent., such as some tool steels, the structure consists of pearlite and carbide, which is then called "Cementite."

Now let us take two polished specimens of steel, one containing less than .9 per cent. carbon, and the other more. One will consist of ferrite and pearlite, the other of cementite and pearlite. Etch both of the specimens in dilute acid, and in both cases the portion first acted on is the pearlite. After considerable action has taken place in the pearlite then the ferrite in the low carbon steel is commenced to be attacked, but the cementite in the high carbon steel escapes action. The explanation here is galvanic action. The carbide of iron is electro negative to the ferrite, and so in the pearlite where the two constituents are in close juxtaposition, the carbide is not acted on, but the ferrite, is rapidly dissolved.

This leaves the surface rough, and it therefore shows up dark coloured under the microscope. After a time the acid has eaten most of the exposed ferrite out of the pearlite, leaving only its carbide to be acted upon, then the action commences on the adjoining crystals of ferrite, and they commence to dissolve in the case of the soft steel, but in the case of the high carbon steel, where there is no free ferrite, the action is still confined to the pearlite. Now instead of the acid used for rapid etching let us assume ordinary oxidation to be taking place. In the chisel steel we have the substance practically all pearlite. It oxidizes quickly at first by reason of the iron in the pearlite, but the pieces of carbide hold the rust so formed, and the action is rendered slower. In the mild steel we have the innumerable small galvanic batteries formed by the pearlite and ferrite in juxtaposition, and consequently the metal oxidizes rapidly by galvanic action, and the action will be quickest when the proportion between the pearlite and ferrite is that which gives the greatest intensity of local current. Consequently mild steel corrodes more quickly than the harder steel used for tools.

Next we come to the Lowmoor irons, known as "steely" irons. We have a metal containing only a small quantity of carbon, and we find in it small patches of pearlite, just enough to set up some galvanic effect, and consequently in their case we get less rapid corrosion than in mild steel, but still more action than there is in the commoner irons which contain scarcely any carbon, and which are known to rust less rapidly than the better class irons and structural steels.

There are, of course, other reasons which affect corrosion. For instance manganese is a very oxidizable metal, and it is only what would be expected that steel comparatively high in manganese should corrode more rapidly than that in which it does not so much predominate. Sulphur also, when it is in steel, seems to exist mainly in small isolated particles of sulphide of manganese situated in the ferrite, but Mr. Stead has found that some of the sulphur becomes dissolved in solid solution in some of the ferrite, and that it is then by no means uniformly distributed through the metal. The parts where it is segregated are called "ghosts" by microscopists, and they corrode or etch much more quickly than the rest of the metal, probably again by galvanic action. Sulphur, then, as well as manganese is objectionable from the point of view of

corrosion. The effect that phosphorous and silicon play in regard to corrosion is not known with certainty.

What has been said about local or stray currents existing in a ship may not appear to be quite clear. It may be easily appreciated that in a case where there is powerful electric machinery, leakages from the electric mains may set up local currents; but even then the matter seems obscure and requires a deal of, shall I say, faith, to believe that these leakages are the cause of corrosions at a distance from them, and technical skill of a high order is required to trace out the connexion; but when we come to a cargo steamer without electrical appliances, it does not seem unreasonable to say "How can these things be?" but that such currents do exist even in such cargo steamers I will now proceed to show.

We have seen that when a current is made to flow from a surface into a corrosive medium, corrosion is set up. Now let us consider what happens in electro plating, and in the electro deposition of metals. Here we have a current made to flow from the anode through a liquid to the cathode. The liquid is a solution of a salt of the metal required to be deposited on the cathode. The anode is made of the same kind of metal as it is desired to deposit. When the current flows, the salt of the metal is split up. Its metal is deposited on the cathode and its acid is formed on the anode, where, meeting the metal, it unites with it, reforming an equal amount of the salt to that which was split up. If, however, the anode were made of an incorrodible substance, the splitting up of the salt in solution would still take place with the corresponding deposition of metal on the cathode, and this would continue until all the salt was used up. If now we find that electro deposition of a metal takes place, we are sure that there must have been an electric current to effect this.

Now for the instances referred to.

My attention was drawn two or three years ago to the case of a cargo steamer which was then four years old, with no electric light fittings, and with a cast-iron propeller. The screw shaft was fitted with a continuous gun-metal liner, and it had not been previously drawn since it was fitted. It was very difficult to get out, and it was found to be covered at the parts between the stern tube bearings with a hard brownish scale of a greater thickness than the reduction of radius of liner which had been made between the bearing sur-

faces. Some of this scale was submitted to me and I examined it microscopically, and found it full of bright metallic spots apparently of copper. I had the scale analysed, and it was found that no less than 14 per cent. of it was pure metallic copper, the remainder being mainly *carbonate*, not *sulphate*, of lime. There was a little iron in it, probably as iron oxide, but no zinc or tin. Where did the copper come from? The stern tube was of cast iron. The only possible source of the copper was the gun-metal liner of the shaft or the gun-metal of the stern bush. The liner, however, was found to be perfectly sound under the scale, and perfectly sound and bright where working in the lignum-vitæ bearings, and the metal of the bushes was not in any way wasted. Minute examination of the scale showed that the copper and the calcareous parts of the scale had been deposited concurrently. At first multitudes of very minute crystals of copper had been deposited on the gun-metal liner, whilst the spaces between them had been filled up with scale; further depositions of copper had taken place on some of these first crystals, and more scale had been deposited, some of the crystals becoming buried up in the scale. Then those still unburied got more copper deposited on them; then some of them got buried up in scale so that in time the exposed copper crystals became much fewer in number than at starting, and the whole scale began to take on a nodular appearance. Some samples of such scale are here exhibited. The explanation of the presence of the copper appears to be that the rotation of the shaft rubs off exceedingly minute particles of the gun-metal from the bearing surfaces, these particles become dissolved in the water in the stern tube, probably as chlorides of copper, zinc and tin. The solution becomes electrolyzed by a current which, wherever it comes from, leaves the water and enters the gun-metal liner between the bearings, depositing the copper in so doing, but leaving the zinc and tin chlorides unacted on, in accordance with the well-known law that with weak currents only the most negative metal is deposited. This is not by any means an isolated case, for in several cases since I have had similar scale brought to me from continuous liners, and in every case I have found a considerable amount of metallic copper in the scale. In each of these other cases the propellers have been manganese bronze, and there has been electric machinery in the ships; but in the first case the pro-

cell was iron, and there was no electric light, and yet there was an undoubted case of electric current, for this alone could account for the electrolytic deposition of the copper.

The next case I will refer to shows the obscurity of the problem, as it appears that at some time or other, in this particular case, the current became reversed.

In a circulating pump the bucket was gun-metal, the rod was naval brass. For some reason water got in between the cone of the rod and the bucket, and the naval brass (which is a copper, zinc, tin alloy of the Muntz metal type), became dezincified on the surface in the way we have described when discussing Muntz metal, the zinc and tin vanished and the copper was at first left in the usual spongy form. The rocking of the bucket on the rod, however, hammered up the spongy copper into films, more decay took place, more sponginess occurred, to be again consolidated by the rocking of the bucket into films, and so we obtained the laminae exhibited; but at some time or other something else occurred. Some of the copper must have got dissolved, and the current becoming reversed, the copper was re-deposited on one of the laminated pieces of spongy copper in a beautifully crystalline form.

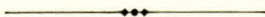
THE CHAIRMAN: You will all agree with me that we are very much indebted to Mr. Milton for the very interesting lecture he has given us. He has spoken so exhaustively on the subject he has so successfully undertaken, and the vast amount of ground he has covered, fully bears out the view I expressed in my preliminary remarks, that his lecture would not only be interesting but likewise instructive and extremely valuable. We shall have a good opportunity of appreciating the full value of the lecture itself. It is not proposed to have any discussion to-night. It would be better, before this takes place, that the members should be supplied with a report of the lecture. After that many of them will have something to say on many of the points raised. They may be able to say whether they look upon all the details from the points of view the lecturer has given, or from what we call persistence of change in nature—for it is all that. It has been arranged by the Council that the discussion of this paper will take place on October 26.

Mr. WILLIAM LAWRIE (Chairman of Council) : I have very great pleasure in proposing a vote of thanks to Mr. Milton for the very instructive lecture to which we have just listened. His knowledge of the subject is wide and comprehensive, and the members of the Institute feel very grateful to him for the very clear and thoughtful manner in which he has put the subject before us. To say that we appreciate Mr. Milton's kindness is to put the case in a somewhat feeble manner, and I am sure that when the chairman puts this vote of thanks to the meeting it will be demonstrated not only that we have profited from the lecture, but that we have enjoyed it. I have very much pleasure indeed in proposing this vote of thanks.

Mr. JOSEPH HALLET (Member) seconded the proposition, which was unanimously carried.

Mr. MILTON, in acknowledging, said : Before I say very much more, I should like to remark that I thought we were going to have a discussion, and that the discussion would have been commenced to-night. One of the members (Mr. Doherty) sent in a very interesting sample of corrosion, the subject with which we have been dealing to-night. I only wish he had been able to draw our attention to it. Had I thought he was not to have the opportunity I should have mentioned it in my lecture. The sample he has sent in is this pumping rod, which has decayed through, as one can see, or very nearly through, leaving the thing apparently sound. He has brought up the pieces that broke off from it, and he points out, as I did in the samples I put before you, that it still looks metallic, and yet in another part of the rod there are indications of actual decomposition of copper. This appears to have been a case where the decomposition was actually due to a change in the currents. I do not know the conditions which have produced the change in this case, but no doubt this will be brought out in the discussion. I am much obliged to you for having listened to me, and for passing this vote of thanks.

On the motion of Mr. Balfour, seconded by Mr. Doherty, a vote of thanks was accorded the Chairman for presiding.



* **Engineer-Captain R. W. Edwards, R.N.** The death of this officer so suddenly on October 3rd, while away in the North of Scotland cruise in the *Agamemnon* on duty as staff engineer with a division of the Home Fleet, gave a shock of grief to many engineers by whom he was well known as a good comrade and reliable friend, as well as to a large circle beyond, by whom he was admired and esteemed for his efforts to maintain and enlarge the possibilities of engineers in their own particular sphere of action. His remains were conveyed to Sheerness on board the battleship on which he died, and were interred with the honours due to his station and reputation, amid the regrets of all with whom he had been associated. Engineer-Captain Edwards served as a student in H.M.S. dockyard at Keyham, and joined



The Late Engineer-Captain R. W. Edwards, R.N.

the Royal Navy in 1874. He was promoted through the various grades to that of Fleet Engineer and during his long service of thirty-four years he maintained an excellent record. On several occasions he was within the fighting zone, and while the South African war was under way, he served in the *Powerful* as Fleet Engineer with credit and distinction in his own special department, and rendered considerable assistance in directing and advising where his engineering training and skill were required outside the engine room. He took a keen interest in the proceedings of the Institute of Marine Engineers, of which he was a member and a vice-president as representative of the engineers of the Royal Navy. By a singular coincidence as to the date, Engineer-Captain Edwards responded on behalf of the Royal Navy to the toast of "The Imperial Forces" at the annual dinner of

the Institute on October 3rd, 1906, when Lord Pirrie presided. Deep sympathy has been expressed towards Mrs. Edwards and family on account of the great loss which has befallen them so suddenly, and we unite in offering our respectful regrets. The Lords of the Admiralty have honoured his memory by conveying to his widow their great appreciation of his zealous and life-long service, and deploring also the loss the Naval service has suffered by his decease.

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1908-1909

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VOL. XX.

PRESIDENTIAL ADDRESS,

On Monday, October 5th, 1908.

LECTURE ON THRUST BEARINGS,

By MR. GEO. B. WOODRUFF,

On Monday, October 12th, 1908.

CHAIRMAN : MR. W. C. ROBERTS, R.N.R. (VICE-PRESIDENT).

PAPER NO. CL.

TIMBER USED IN MARINE INSTALLATIONS FOR THE CARRIAGE OF REFRIGERATED CARGOES

By MR. C. M. B. DYER (MEMBER),

On Monday, October 19th, 1908.

CHAIRMAN : MR. E. W. ROSS (HON. FINANCIAL SEC.).

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OBITUARY.

***John A. Rowe.**—The sad tidings of the death, at about sixty-six years of age, of Mr. J. A. Rowe, which took place at Finchley, London, N., on September 12th, has revived many memories, and among these occur the name of the late Mr. J. Macfarlane Gray, whom in January, 1897, he worthily succeeded in the office of Chief Examiner of Engineers, Board of Trade, and served in this capacity until failing health compelled his resignation, and the appointment of a successor—the late Mr. D. G. Watson, who died in 1905. The enforced retirement of Mr. Rowe was a source of great regret to those who were brought into personal intercourse with him. Born in Cornwall, in the neighbourhood of Falmouth, he received his training as an engineer and naval architect in the Government dockyard at Keyham. He then entered the Royal Navy, and served for fourteen years. In 1876, he was appointed Board of Trade Surveyor and was located on the north-east coast until his removal to the London district in 1889, where we were brought



JOHN A. ROWE.

into personal contact with and learned to esteem him for the excellence of his characteristics and his unflinching courtesy, with consistent attention to the duties of his office. Shortly after coming to London, Mr. Rowe was elected a member of the Institute of Marine Engineers, of which he was afterwards elected a vice-president. He gave a paper on 'Stability, and the motions of a vessel among waves,' Part I. being read in the Town Hall, Stratford, in October, 1891, and in the University College, Cardiff, the following month. Part II. was read in the Gresham College, Basinghall Street, London, in January, 1892. At the subsequent discussion, which took place in the Town Hall, Stratford, the meeting was presided over by Mr., now Sir, Wm. H. White, Prof. Greenhill and the late Mr. Macfarlane Gray taking part. Broken health removed him for the past few years from the intercourse of most of his old friends and associates, whose memories recall many pleasant associations, and we respectfully offer to Mrs. Rowe and family our deep sympathy and regrets for the loss they have sustained.