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E. V. WALKER, B.Sc., A.R.S.M.

A Paper read before the London Centre on the 7th May, 1940.

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INTRODUCTION.

Metallurgy may be defined as the science, and to a certain extent the art, by which metals are extracted from the earth's crust and adapted for the use of engineers and craftsmen.

As an art Metallurgy has been practised for many thousands of years. It was, for example, the metallurgists of the time who enabled the Chinese to produce bronze ware of all kinds, even as early as 2,500 B.C., and the people of Damascus to forge and decorate the excellent swords, which the Crusaders brought back to this country in the 13th century.

Modern Metallurgy, however, covers a much wider field than that with which the Ancients were acquainted. It can be conveniently divided into a number of branches, viz., concentration and smelting of ores, refining of the smelted metal, the production of metals and alloys in a form suitable for the use of engineers, and last, but not least in importance, the study of the properties of metals and alloys, by which means the demands of the engineer can be met.

It is with the last two branches of Metallurgy that Communications Engineering is mainly concerned, but the metallurgist dealing with telephone, radio and telegraph equipment is occasionally confronted with problems which necessitate his being familiar with the methods of smelting and refining of metals.

In this paper it is proposed to confine the discussion to Engineering Metallurgy, as that branch of the science is called, which covers the shaping of metals and the study of their properties, because it is felt that this side of the subject will be of most general interest.

The majority of readers, no doubt, will not be well acquainted with the science of Metallurgy, so that a broad survey of the subject rather than a discussion of the finer points of the science has been aimed at.

The paper is, therefore, divided into the following parts:—

1. A consideration of some of the fundamental physical properties of metals and alloys.
2. A review of the methods of metallurgical investigation.
3. The uses of metallurgical work in the advancement of engineering practice.
4. Some specific examples of the application of metallurgical research to the solution of problems connected with Communications.

A consideration of some of the fundamental physical properties of metals and alloys.

Although it is over two hundred years since Réamur first showed that metals and alloys are definitely crystalline bodies, by which is meant that they consist of an agglomeration of crystals, there are, even to-day, many technical men who do not appear to be acquainted with this fact. The expression " the cable sheath failed due to crystallisation of the metal " is quite frequently heard, when what is meant is that the cable sheath failed due to repetitions of stress, commonly known as a fatigue failure.

That metals are crystalline can be demonstrated, if, say, a piece of copper, after a suitable preparatory treatment, which will be briefly described later, is examined under a microscope. It will be found to consist of a large number of polygonally-shaped grains bounded by fine lines, which are termed the " crystal boundaries."

Now metal crystals have a number of interesting properties, which are greatly responsible for the different degree of mechanical strength that can be obtained from a metal by hot and cold working or by heat-treatment.

In the first place, the crystal boundary is stronger than the crystal itself at normal temperatures. Thus, when a mechanical failure occurs in a metal, the line of fracture is usually transcrystalline and not inter-crystalline.

In the second place, when a metal is plastically deformed in the cold, slip begins to take place within the crystals, along certain crystallographic planes. The more the deformation, the more numerous do these planes of slip become ; and consequently in the later stages of the cold working operation, elongation of the crystals, in the direction of the application of stress, takes place. If the metal is suitably polished before cold working, slip can be seen under the microscope in the form of parallel lines running across the crystals. These lines, which are called " slip-bands," are steps on the surface of the metal produced by the elevation or depression of fragments of the crystals.

It has been shown that slip within a crystal is responsible for the hardening and strengthening of metals, which takes place when they are deformed in the cold.

A cold worked metal when examined under the microscope, after a suitable preparation of its surface, will show elongated crystals across which run fine markings, called etch-bands (Fig. 1). These are

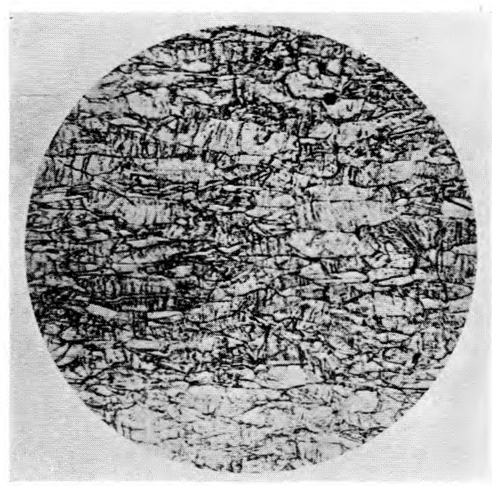

FIG. 1.

related to slip-bands in some way, not precisely known, but they are not actual slip-bands, since slip-bands are a surface effect, and are, therefore, removed when the metal is polished. Now, it is common knowledge that if a metal in the hardened condition is raised to a suitable temperature, it can be softened again. The mechanism of this change in mechanical properties is interesting, and it is this. Within the strained crystals there are a number of nuclei at which, on the application of sufficient heat, very small unstrained crystals begin to grow. On raising the temperature or prolonging the heating time, these crystals increase in size, some being absorbed by others, until they entirely replace those originally present. This change in crystal structure is called "recrystallisation."

Another interesting property of metals concerns their solubility in each other. While most metals are mutually soluble in the molten state, this is not the case when they are solid. Some are soluble in this condition, but others are only partially so, or even completely insoluble. Upon the degree of solid solubility of one metal in another, some of the fundamental properties of alloys substantially depend.

It is customary to illustrate solid solubility and other related phenomena by means of the thermal equilibrium diagram. This diagram may be defined as a graphical representation of the phase or phases present in any alloy system, at any given temperature and concentration of the constituent metals, when at thermal equilibrium.

As an example of the value of these diagrams to the understanding of the behaviour of alloys, that for the lead-tin system may be considered. These two metals are partially soluble in each other in the solid state and Fig. **2** shows how this can be represented.

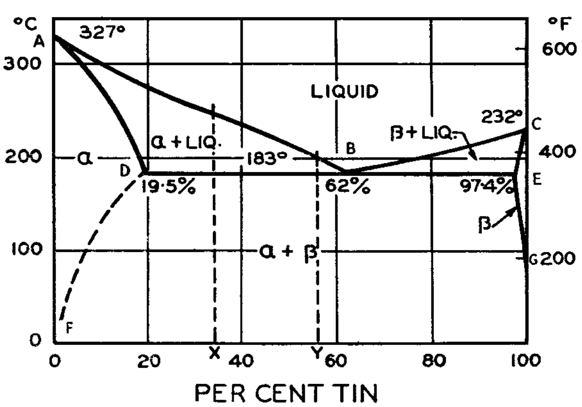

FIG. 2.

As with all thermal equilibrium diagrams, this one has been constructed by plotting against alloy composition (1) temperatures of commencement and completion of freezing and (2) temperatures at which changes in the solid state take place.

Thus lines AB, BC show how the commencement of freezing varies with the tin content. Lines AD, DE and EC indicate the temperature at which an alloy of any given composition is completely solid, and the lines FD, GE show how the solid solubility of tin in lead, and lead in tin increases with temperature.

The diagram indicates that solid solder is made up of two constituents, one consisting of crystals of lead in which is dissolved a little tin (α)—the other an intimate mechanical mixture of lead and tin with a little of each metal dissoved in the other. This mixture is called the eutectic ($\alpha + \beta$), where β is tin with a little lead dissolved in it. The eutectic part of the alloy melts at a constant temperature, while the alloy as a whole melts at temperatures varying according to the relative lead and tin contents. From this diagram, an explanation can be found as to why a plumbing solder, having a tin content of some 35%, is suitable for the purpose to which it is put; and why a bit of soldering alloy has that desirable property of setting as soon as heat has been sufficiently removed from it. At X is represented the composition of a plumber's solder. The diagram shows that between temperatures of 250 and 183°C such an alloy consists of crystals mainly of lead, floating in a liquid consisting of lead and tin dissolved in each other, and that there is a wide range of temperature between commencement and completion of solidification, *i.e.*, there is a plastic range. The result is that there exists a plastic mass between 250 and 183°C, which can be wiped around a joint.

At Y is represented the composition of a tinman's solder, and the diagram shows that the range of temperature between commencement and completion of solidification is small. Hence the quick setting properties of this type of solder.

This brief review of some of the properties of metal crystals would not be complete without some mention of the fact that physical changes can also take place while alloys are in the solid state. The hardening of steel is, for example, the result of such a phenomenon. The fact that steel with a suitable carbon content can be hardened by heat-treatment has, of course, been known for hundreds of years. The cause of this valuable property of steel, however, has been elucidated only within the last 60-70 years.

Many readers, it is expected, will not be familiar with the mechanism of the hardening of steel, so a few remarks on this subject should prove of interest.

Iron and carbon are the two main constituents of steel, and together are chiefly responsible for the good mechanical properties obtainable from this material.

Now iron has two very important properties:—

Firstly, it can exist in three allotropic forms, each of which is stable between certain ranges of temperature. It is usual to denote the allotropes of iron by the symbols α, γ and δ, α being the form stable at ordinary temperatures. Incidentally allotropy is defined as that property by virtue of which an element can exist in two or more forms the chemical properties of which are the same, but the physical properties of which are different. Each form is called an allotrope of the element.

Secondly, carbon which exists in steel as iron carbide, dissolves in γ iron, which is non-magnetic, but is practically insoluble in α iron. These two facts are fundamentally responsible for the process of hardening steel by heat-treatment.

Thus, if a piece of steel, with a suitable carbon content, is heated to a temperature at which the γ allotrope is stable, a solid solution of iron carbide in

γ iron is obtained. Next, suppose this piece of steel is allowed to cool slowly. When a temperature is reached at which γ iron changes back to the α form, the iron carbide comes out of solution again in the form of alternate layers of iron carbide and α iron, called Pearlite, embedded in a matrix of α iron.

Now the hardening of steel depends ultimately upon the fact that it is possible, by quenching, to obtain an unstable supersaturated solid solution of iron carbide in α iron. This constituent is very hard, and is called Martensite.

Martensite is too brittle a constituent to have in steel for some purposes, in which case tempering is resorted to. This has the effect of causing the unstable supersaturated solid solution of iron carbide in α iron to break down somewhat, and constituents called Troostite or Sorbite are formed, according to the severity of the tempering.

METHODS OF METALLURGICAL INVESTIGATION.

Having mentioned a few of the fundamental properties of metals, it will be appropriate here to pass on to consider the methods of metallurgical investigation.

The metallurgist has at his disposal five distinct methods of investigation, of which one or more may be applied for solving any particular problem. They can be classified as:—

1. Chemical analysis including spectrographic methods.
2. Metallography.
3. Mechanical testing.
4. X-ray methods.
5. Electron diffraction methods.

It is not proposed to deal in any detail with chemical and spectrographic analysis; nor with X-ray and electron diffraction methods. Suffice it to say that the methods of chemical analysis are in principle similar to those employed in determining the composition of any inorganic material; that in spectrographic analysis, the intensities of certain lines in a spectrum when compared with the corresponding lines in a standard spectrum give the composition of the alloy under examination; that by means of X-ray methods flaws can be detected in metals, and the internal structure, grain size and orientation of the crystals determined; that with the aid of the electron diffraction apparatus, the most recent acquisition the metallurgist has as a means of investigation, information about the surface of a metal can be obtained. For example, electron diffraction technique would appear to have possibilities in elucidating the nature of corrosion films on metals, and in investigations of the fundamentals involved in the wear of metallic materials.

Metallography.

This branch of the science of Metallurgy is chiefly concerned with the microscopic examination of the structure of metals, and its correlation with their mechanical properties and behaviour in service.

In this technique, a surface of the metal under examination is first prepared by filing, grinding on various grades of emery paper, and polishing on a rapidly rotating disc, over which is stretched a piece of velvet, and on which is placed some polishing medium, such as a suspension of aluminium oxide in water. As near an optically perfect surface as possible must be obtained, otherwise inferior results will ensue.

After polishing, the specimen may be examined under the microscope. At this stage flaws and inclusions in the metal can be seen. The crystal structure, however, is not revealed until the specimen is etched. This consists of dipping the metal in a solution of a suitable chemical reagent. The effect of etching depends upon the different degree of chemical attack on the various parts of the structure of metals and alloys. Thus some crystals are more readily attacked than others. Again, some constituents, on etching, take on various colours, so that it is possible with experience to identify them. The interpretation of the structure of aluminium alloys is a good example of this possibility. Some very beautiful patterns are often obtained in the structure of these materials.

By means of microscopic examination of crystal structure, therefore, it is often possible to ascertain the industrial history of a metal, and this is, of course, of the utmost importance, for it enables the metallurgist to say, among other possibilities, whether an alloy has been given correct heat-treatment and fabricated in the best way.

It will have been gathered from what has been said about the preparation of the surface of a metal, on which it is intended to conduct a microscopic examination, that metallurgical microscopes make use of reflected light for illumination purposes.

An arc, Point-o-lite, or a low wattage lamp are used as sources of light, either of the first two being necessary if photographs are to be taken. For special high-power work ultra-violet light is sometimes employed. The beam of light, after passing through condensing lenses, is made to impinge on to a thin glass plate, placed at 45° to the horizontal, or on to a right-angled prism, either device being situated in the tube of the microscope. They turn the beam of light through 90°, so that it passes through the objective and on to the highly polished surface of the metal specimen. Here it is reflected back *via* the microscope tube to the eye-piece.

Photographs of the crystal formation can be taken by attaching a suitable camera to the eye-piece; in fact the best instruments are designed with a camera in permanent position. Such an instrument is illustrated in Fig. **3**. Magnifications up to about 6000 diameters can be obtained.

Mechanical Testing.

A mechanical testing laboratory, employed on work of a metallurgical nature, is usually equipped with machines and instruments for carrying out tensile, hardness, fatigue and impact tests. A brief description of some of these machines and instruments installed at the Post Office Research Station at Dollis Hill will not be out of place.

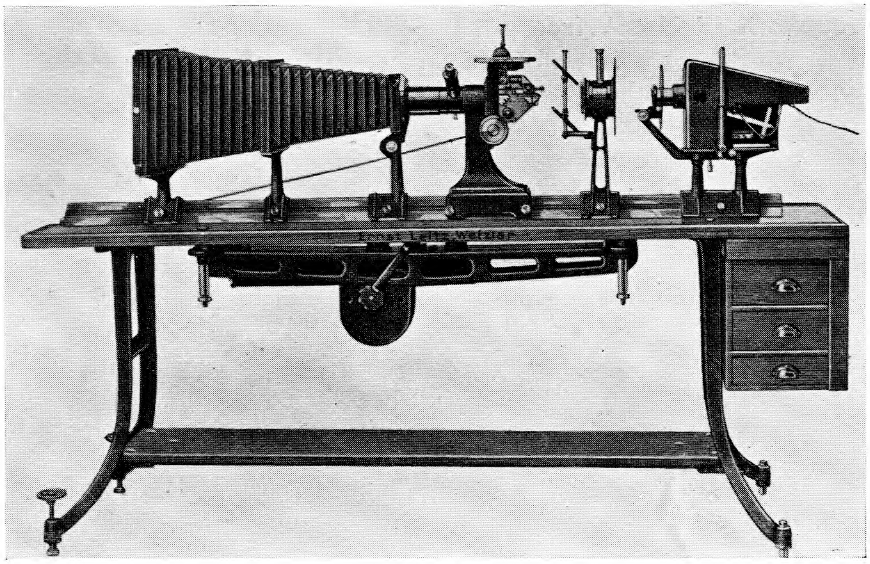

FIG. 3.

Tensile Testing Machines.

The machines available for tensile testing are of the usual type, and no detailed description of them is called for. Suffice it to say that there are three, and that they provide facilities for determining breaking loads from 3 or 4 lb. to 5 tons.

When the tensile strength of a metal is being determined, it is quite often necessary to find also its limit of proportionality, Young's Modulus of Elasticity and Ductility. The first two properties are determined by means of an extensometer which is attached to the test-piece (Fig. 4), while it is in the tensile testing machine. The third is evaluated by measuring the elongation of a test-piece after fracture. Extensometers magnify extensions of the test-specimen on application of increasing load by optical means or by a system of levers. Good extensometers are sufficiently sensitive to record changes in length of between 1/100,000th and 1/250,000th in. These instruments are of importance in Communications Engineering work, because they are necessary for the determination of the spring properties of materials.

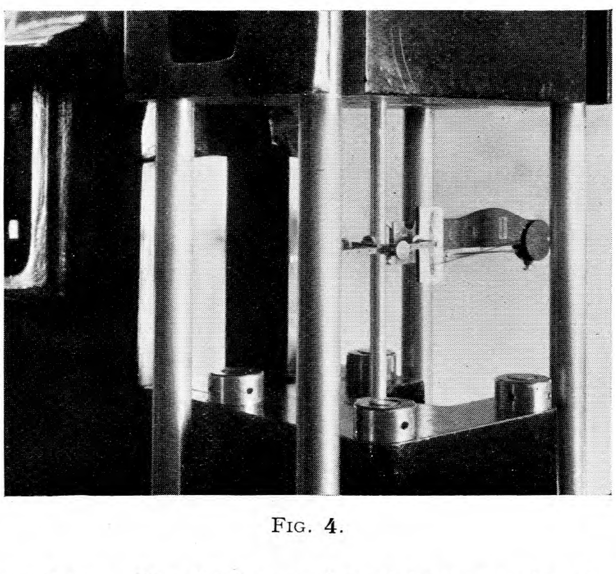

FIG. 4.

Hardness Testing Machines.

For hardness determinations, the Vickers hardness tester is admirably suited for the examination of materials met with in Telecommunications. This machine works on the principle of indenting a piece of metal with a square pyramid-shaped diamond under a given load. The diagonals of the impression produced in the metal are measured by means of a microscope attached to the machine, and by referring to tables, this figure can be converted into load supported per square millimetre, which is known as the Vickers pyramid numeral. A feature of this machine is that the load is applied slowly to the diamond indenter and sustained for about 30 seconds, the operation being automatic. Thus the way in which the load is applied is not subject to the judgment of the operator. Owing to its precision, the Vickers machine is a great asset in the hardness testing of thin strip, such as spring materials.

Fatigue Testing Machines.

There are three important aspects in fatigue testing of metals used in Communications Engineering. One is the determination of the fatigue strength of hard-drawn wire for overhead telephone and telegraph lines. The second is the determination of the fatigue strength of lead and its alloys for use as cable sheaths. And the third, the determination of the fatigue strength of materials to be used as springs. Work on the first two problems has been carried out at Dollis Hill for four or five years and has culminated in some useful information being obtained.

Fatigue Testing of Overhead Line Wire.

The Haigh-Robertson machine, specially designed for the testing of wire, has proved to be very useful for this work. The machine, which is illustrated in Fig. **5**, operates on the principle of the Euler strut. A length of wire (A) is inserted in a chuck (B) attached to a high-speed motor (C), mounted on a swinging headstock (D). On the other end of the wire is placed a collar, in which is inserted a 5 mm. ball. This ball sits in a trio of 5 mm. balls in a race resting on a back plate, the assembly thus forming a thrust bearing (E). On commencing a test, this bearing is moved along the bed-plate, on which it is situated, towards the motor. This causes the wire to bow in a horizontal direction, the amount of bowing being indicated on a scale (F) attached to the swinging headstock. When the desired degree of curvature has been obtained on the wire, the position of the thrust bearing is fixed. Thus the wire is under the influence of bending stresses, the maximum bending moment occurring at its centre. Repetitions of the stress so produced are obtained by starting up the motor, which rotates the wire as a curved shaft. Thus the stress on the wire is of a repeated character and can be calculated from the Euler strut formula.

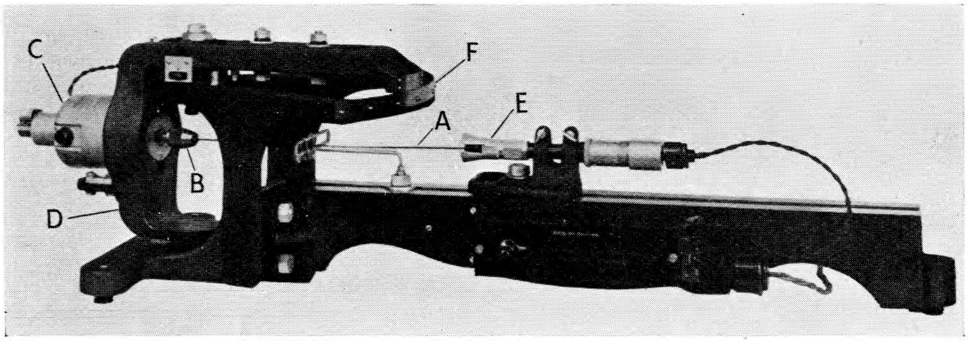

FIG. **5**.

Repeated stresses are always of a considerably lower magnitude than those required to cause a metal to break under a single application of stress, such as in the tensile test.

It is the object of fatigue testing to determine the maximum repeated stress to which a metal can be subjected without causing a fracture to occur after a given number of cycles of that stress. The figure taken is usually something greater than ten million reversals. This stress is called the fatigue strength or endurance limit. Therefore, in fatigue testing different magnitudes of repeated stress have to be imposed on the material until this value of stress is found.

Fatigue Testing of Lead and its Alloys for Cable Sheaths.

At the Post Office Research Station fatigue tests on lead and its alloys are carried out on strips 5 in. long, 0.5 in. wide and 0.06 in. thick (Fig. **6**). The test-

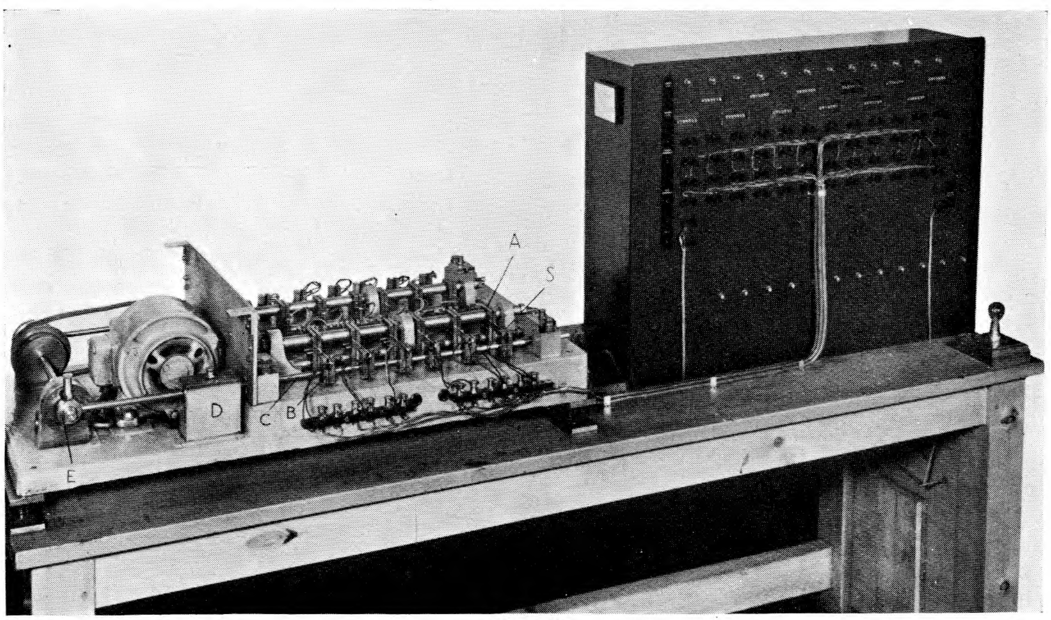

FIG. **6**.

pieces are gripped at one end (A) and vibrated as cantilevers by a bar (C) oscillating at right angles to the length of the test-pieces. Movement is conveyed from the oscillating bar to the test-pieces by means of clamps (B) mounted on the former which lightly grip the latter. Thus a stress is imposed on the strips which varies from + A to − A lb./in^2. The oscillating bar derives its motion from a variable eccentric (E) driven by a motor. The machine is capable of dealing with twelve test-pieces at one time, six of which can be submitted to one value of stress and six to another.

In actual practice results obtained from this machine are not expressed in terms of stress, but as a displacement of the free end of the test-piece. This is done because it is not possible to calculate the stress induced in the cantilever, owing to the fact that the fatigue strength of lead and lead alloys when determined in terms of stress on machines which apply a known load is much above the elastic limit of these materials ; and as is well known beam formulæ are not accurate when this is the case.

The number of vibrations necessary to cause the fracture of any one test-piece in the machine is counted by means of modified P.O. meters, operated through a contact on the motor shaft gearing, driving the eccentrics and two uniselectors. This circuit is combined with a device for automatically indicating when fracture takes place. This device depends upon the testing of each test-piece in turn by a current of 2 amp. from a 50 volt D.C. supply. When the test-piece commences to crack, its electrical resistance increases rapidly. The potential difference between one end of the test specimen and the other when the testing current is applied is likewise increased as the cracking develops and, at a predetermined point, operates a sensitive Weston relay. The consequent operation of a succeeding relay train throws out of circuit the meter associated with the test specimen.

THE USES OF METALLURGICAL WORK IN THE ADVANCEMENT OF ENGINEERING PRACTICE.

The science of Metallurgy can be of service to any engineering organization in the following three general directions:—

1. For diagnosing the cause of failures of metals in service.
2. In the examination of new alloys with a view to improving products and performance, and advising on the choice of a material for a specific job. In this category there falls also making recommendations in the drafting of specifications for purchasing purposes.
3. In the control of works processes.

As far as the activities of the Post Office Engineering Department are concerned by far the greatest amount of work done, of course, comes within the scope of the first two categories.

Diagnosing the cause of failure of metals in service.

As an example of the methods employed in the diagnosis of the cause of failure of metals in service, the case of a fractured copper overhead line wire may be considered. The first step to be taken is to examine the fracture under a low power microscope or with the naked eye. This will determine whether the wire has failed under tensile or fatigue stresses, the latter being caused by vibration of the line under the influence of wind velocities. If the fracture shows no reduction of area of cross section, and lapping and twisting tests have proved that the wire is not brittle, then the failure can be said to be due to fatigue. In addition to there being no reduction in area of cross section, a fatigue failure usually exhibits characteristic markings in the form of concentric rings encircling a spot at which the failure first commenced. This is illustrated in Fig. 7.

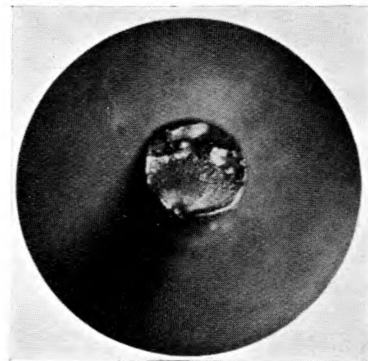

Fig. 7.

Having decided that the fracture is, shall it be said, due to fatigue, the next step is to discover what has caused the failure. Now, provided the fatigue strength of a metal is adequate for the service to which it is put, a fatigue fracture is usually brought about by some condition which has set up concentrations of stress. For example, inclusions in the surface or body of a metal, corrosion pitting or surface damage are all liable to produce such a condition. These points, therefore, have to be carefully looked into, before a decision can be reached as to what has brought about the fatigue failure of the wire under investigation.

Examination of new alloys; advising on the choice of a material for a specific job; making recommendations in the drafting of specifications.

The examination of new alloys, advising on the choice of suitable materials for a given use or recommending figures and tests for specification purposes, normally entail the determination of mechanical properties, chemical composition, crystal structure and resistance to corrosion. Just what course the investigations takes depends largely on the use to which the material is to be put.

For instance, any experimental work in connection with suggesting a reliable alloy for pressure die-casting selector frames, would naturally include tests for impact strength, since selector frames are submitted to impact stresses in service. Again, where it is proposed to use a low melting point alloy which has to melt and release a pin, but which is normally under tension, the effect of continuous loading is very important, and so " creep " tests have to be conducted.

The application of Metallurgy to the control of works processes.

The application of Metallurgy to the control of works processes is an extremely important side of the science. Specialized metallurgical knowledge is of great assistance, for instance, in carrying out in the most satisfactory manner, heat-treatment processes, hot and cold working or welding operations.

Some examples of the application of metallurgical research to the solution of problems connected with Communications Engineering.

The study of the properties of lead and its alloys has until the last fifteen years been very much neglected. Even at the present time, much remains to be done in this field.

The Post Office, in common with a number of other organizations, has been actively pursuing research on the properties of these materials, firstly with a view to deciding what alloy is the best to use for the sheathing of cables subjected to vibration, and secondly to discovering the effects of small amounts of metallic impurities on the properties of modern commercial high purity lead. The latter work commenced when trouble was experienced with the fatigue cracking of sheaths during transport of underground cables to the place of installation. It is believed that best quality commercial lead available to-day has not such good fatigue resisting properties as had that on the market some years ago; and it appears that this is due to its high purity. In addition, its ductility is not so good, owing to a large crystal size. If a suitable addition element could be found, which would increase the fatigue strength and ductility of present-day first grade lead, without at the same time worsening any of its other valuable properties, there is no doubt that an improved cable sheathing material would result.

Trouble arises from time to time with the failure of cadmium-copper wire in service, which takes the form of brittleness. Microscopic examination has proved that, while good quality wire contains no inclusions, brittle samples show their presence. As yet their nature has not been identified, but it is thought that they are either of cadmium or copper oxides. Further work is at present in progress on this problem, and it is hoped that it will lead to the discovery of the cause of this trouble.

Another instance of the value of Metallurgy to Communications Engineering occurred sometime back in connection with the cracking of selector frames. These frames were made about 25 years ago. A chemical analysis of the frames showed that a zinc-base alloy had been used in their manufacture, and that considerable quantities of lead and tin were present. It is now known that these metals are most undesirable in a zinc-base alloy, since they cause swelling and cracking. These phenomena are brought about by intercrystalline oxidation, especially in atmospheres where the humidity is on the high side. That intercrystalline oxidation was the cause of the cracking of the selector frames was confirmed by an accelerated " ageing " test in which the zinc alloy under examination is kept for ten days in a chamber full of steam at 95°C. When this test was applied to the selector frames, they were found to have cracked so badly that they were on the point of falling to pieces.

It should be emphasized that there are zinc-base alloys now available which are not liable to intercrystalline oxidation. Castings made from them are, therefore, entirely reliable from this point of view. In addition they are very strong under both tensile and impact stresses.

One of the recommendations of a Departmental Committee on Gas Explosions, Precautionary Measures, was to the effect that wherever possible plumbed cable joints should be made by the pot and ladle method. When attempts were made to carry out this recommendation with standard issue of Solder No. 5, the results were unsatisfactory in that the joints so wiped were porous. Some preliminary trials were conducted with various British Standard Specification and proprietary grades of solder, and the results obtained pointed to the possibility that certain of these were capable of making a better joint than Solder No. 5.

An investigation, therefore, was begun to see whether the failure to obtain sound joints with Solder No. 5 using the pot and ladle method was due to bad plumbing technique or to the use of an unsuitable metal. Practical plumbing trials were conducted with the co-operation of jointers and students at the Dollis Hill and Regional Training Schools. Solders with various proportions of tin and lead with and without antimony were made up. In order that the jointers should be unbiassed in their comments regarding the behaviour of the solders during plumbing, each sample was supplied to them under a code letter. After each joint was made, the usual pressure test was carried out and in some cases chemical analyses and examination of the crystal structure of the metal composing the joint were made. The result of these experiments was that it was found possible in a very large percentage of cases to plumb a pressure-tight joint with the pot and ladle method providing the composition of the solder was in the range 31-32% tin, 1.7-1.9% antimony, the remainder being lead except for the impurities generally permitted in solder. It was observed that the lower limit of antimony was very critical since an alloy containing 1.5% of this metal with about the same proportions of lead and tin was not capable of producing so high a percentage of sound joints.

CONCLUSION.

To conclude, in this paper an attempt has been made to give a broad survey of Metallurgy and its application to Communications Engineering. It has of necessity been very brief in parts, but it is hoped that it has stimulated the interest of readers in the subject and given some encouragement to telephone engineers to feel that, while at the moment they might consider they have not got the ideal material for a specific job, the science of Metallurgy will in due course improve matters.

NOTES ON DISCUSSION.

The view was expressed that modern developments and empirical methods are beginning to lead to a co-ordination of many puzzling phenomena, particularly in the field of iron and nickel alloys. An analogy was drawn between fatigue in the human state and the metallic state, and two questions were asked —(*a*) whether a solution to the fundamental problems of fatigue could not be found by the application of thermodynamics, and (*b*) why it was that crystal boundaries were stronger than the crystals themselves at normal temperatures.

A speaker said that recent political events in the battle for iron ore had made it increasingly clear that nations had not yet passed out of the iron age into the thermoplastic era. Somewhat unfamiliar metals now played an important part in communications. Apart from radio, copper would continue to be a necessity until some form of dielectric wave guide was perfected. The mileage of copper wire in use by the Post Office Engineering Department was stated to be of the order of 12,000,000 miles and over 50,000,000 contacts were used, the number employed in any single speech circuit increasing steadily. This dependance on metals called for expert metallurgists capable of taking the correct view of the problems which arise. The question was asked why some metals were magnetic and others not, and the view put forward that gyroscopically spinning electrons might have something to do with it. The speaker, in stating that there were 10 to 100 $\times$ 10^{12} atoms in a crystal and about 10,000 crystals in 1 c.c. of iron, mentioned that it was possible by modern methods to grow crystals having one inch sides, and that work on this was beginning to throw valuable light on the theory of magnetic materials. The necessity for careful control during production was stressed and it was stated that the Post Office Research Department was the first to investigate the use of spectrographic quantitative analysis for the control of addition elements to cable sheaths. Referring to the problem of the fatigue failure of cable sheaths it was stated that the Bell Telephone Co. had experimented with various lead alloys and in 1912 produced an alloy containing 1% antimony, which satisfactorily resisted the effects of vibration. This was a clear case of the way in which the metallurgist could be of assistance to communications engineering, for the discovery saved the Bell Telephone Co. much money. The question was asked (*c*) whether comparative tests had been made between Haigh-Robertson wire fatigue tests and cantilever beam fatigue tests on copper and if so how did the results compare.

Mention was made of the recently published works of the Physical Society dealing with single crystals, which may throw considerable light on many baffling metallurgical problems. A general resumé was given of the development of magnetic materials from the early days of soft iron to the latest dust cores for loading coils, and it was mentioned that metallurgy had played a very important part in the development of the thermionic valve. Reference was made to the activities of Sir W. Preece in developing copper for communications, and in referring to the modern methods of fire-refining copper it was stated that this material was equal, if not better in some respects, than electrolytically refined copper. An enquiry was made (*d*) why it was that the addition of antimony to solder improved the ease with which it could be wiped as a joint using the pot and ladle method.

An interesting account was given of ancient methods of tempering steel and it was stated that Brinell obtained some unusually high hardness figures when quenching 0.45% carbon steel in soap solution. The question was asked (*e*) whether the quenching solution had any effect on the hardness of the materials quenched and also (*f*) whether there did really exist an elastic limit, or was it merely a term used to cover the limit of experimental error.

An interesting account was also given of the effects of high purity on metals from an electrochemical point of view and examples cited of the vastly differing effects obtainable between chemicals in the very pure state and those with some impurities, especially when the question of isotopes was considered. The question was asked (*g*) whether a study of isotopes might not solve some metallurgical anomalies.

A contributor to the discussion regretted the brevity of the paper and hoped that it would not lead to a misunderstanding of important points. He thought that more might have been said on crystal slip in relation to work-hardening, as the theories which had been put forward to explain the effect were very interesting. The terminology of the paper, when dealing with recrystallisation, was not quite correct, and he suggested that Rosenhain's hypothesis, which he then outlined, might have been clearly stated. The lack of an iron-carbon diagram did not assist the clear understanding of that part of the paper dealing with the mechanism of heat treatment of steel. He enquired (*h*) whether the author could state if any likely additional element to lead for cable sheaths had been found and why the lower limit of 1.7% antimony in Solder No. 8 was critical.

Facts concerning the adoption of the pot and ladle method of making joints were given and it was stated that this method was first used on the original London-Birmingham cable and the suggestion (*j*) made that the difficulties encountered recently might have been due to the inexperience of the plumbers.

It was mentioned that when this method was introduced no one could be found to make satisfactory joints with Solder No. 5. The speaker suggested (*k*) that the possible reason for the sound joints on the original London-Birmingham cable was due to the presence of antimony in the solder used at the time.

The AUTHOR, in replying, thanked those who had taken part in the discussion and stated that the metallurgist was not yet in so favourable a position as the chemist in being able to predict the properties of new materials, but there was a gradual improvement in this direction. He stated that it was not possible to give any definite answer to the questions (*a*) and (*b*) whether fundamental problems of fatigue could not be solved by the application of thermodynamics, and why crystal boundaries were stronger than the crystals themselves at normal temperatures. In regard to question (*c*) concerning comparative tests between the Haigh-Robertson fatigue tests and cantilever beam fatigue tests on copper wire, he stated that as far as he was aware no such comparative tests had been made, but that between Haigh-Robertson type and tension-compression tests the latter gave lower results. He thought the remarks on magnetic materials interesting, and said that the new magnetic materials were undoubtedly one of the more important contributions of the metallurgist to communications. In replying to (*d*), he said the porosity of solder was probably due to the wiping away of the eutectic from the bottom of the wipe. No experimental work had been done to show why antimony in Solder No. 8 prevented porosity, but it was possibly bound up with the viscosity of the eutectic. In reply to (*e*) he said it was true that the quenching medium had some effect on the hardness of steel, and in answer to question (*f*) on elastic limit said it was very likely that the evaluation of this property depended very largely on the fineness of the measuring equipment. The question (*g*) raised concerning isotopes was, he thought, interesting. They had thought at the Post Office Research Station that the trouble experienced some time ago with the cracking of cable sheaths during transport might possibly be bound up with this question, but further work on the fatigue strength of lead had not confirmed this. The author pointed out in regard to (*h*) that too much material in a paper of this type might be confusing, especially to those unfamiliar with the subject. There were as yet no concrete theories explaining the relation between crystal slip and work-hardening, and as far as the description of recrystallisation given in the paper was concerned, he suggested addition would probably have made the matter clearer. Promising alloying elements for cable sheaths were in view, but it was early yet to make any statement. Referring to the points raised in (*j*) and (*k*), he stated that the reason put forward in (*k*) that antimony was probably present in the older types of solder was possibly correct, and that although the pot and ladle method was used by early jointers the method of application was not quite similar to that in use now as some type of smoothing with a spoon was done.

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