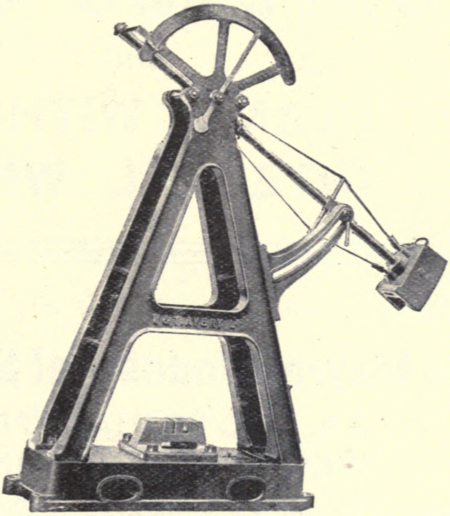
METALS IN AIRCRAFT CONSTRUCTION

WILFRED HANBY



METALS
IN AIRCRAFT CONSTRUCTION

METALS
In Aircraft Construction

BY

WILFRED HANBY

Member of the Institute of Metals; Associate Fellow of the Aeronautical Institute of Great Britain; Member of the Faraday Society; Associate of the Institution of Electrical Engineers; Member of the American Steel Treaters' Society, etc., etc.

WITH A FOREWORD
BY
L. BLIN DESBLEDS
Hon. Director of the Aeronautical Institute of Great Britain

(*FIFTY-SIX ILLUSTRATIONS*)

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FOREWORD

In November, 1918, when the Armistice was signed, which brought to an end the European War, it became evident that many young men would require intensive technical training in order to complete the engineering education they had commenced, and which, at the Nation's call they were, for the time being, forced to abandon. At this juncture the Aeronautical Institute of Great Britain undertook the establishment of courses in Aeronautical Engineering specially designed to meet the needs of a number of them. One of such courses—the fourth one—was held for the benefit of members of the New Zealand Expeditionary Force, and, in connection with this course, Mr. Wilfred Hanby, a recognized master of his subject, was good enough to give, in the summer of 1919, a series of lectures, on "Aircraft Metals," which form the basis of the present volume.

The chief purpose of the lectures was to describe, in broad outlines, the testing, the treatment and the application of the special alloy steels used in the construction of aircraft and their motors.

It may, perhaps, be thought that, for the construction of aircraft, there is little need to study metallurgy and its applications. It is true that, without any knowledge of metallurgical principles, one may design and build an apparently efficient and reliable-looking aeroplane; but, when the machine is put to the test, the questions always arise whether the right materials have been used in the right places, and whether the materials employed were of the best quality obtainable.

During the tests the crankshaft of the engine may take a permanent twist with the torque, or it may even suddenly fracture; a bolt may break off; a bearing may wear away too quickly; a RAF-wire or a turnbuckle may snap, when least expected. Why is it that these parts have failed in service? Simply because they either contained original defects, or because the materials of which they were composed were not in the proper physical state to withstand the conditions of service.

For such reasons a knowledge of the principles of metallurgy will stand the aircraft constructor in good stead. It will indicate to him what metal to use for a given part; the physical condition in which the metal should be in order to fulfil the particular service required of the part; and also how to secure the required condition before the part is put into actual service.

Although the design and construction of aircraft are now well past the experimental stage, and the machines of to-day are manufactured on sound mechanical principles, nevertheless, the success of commercial aviation will increasingly depend on reliability of construction; and provision must always be made for unforeseen emergencies by having a sufficient reserve of strength in the various members of the aircraft structure. It is highly desirable, therefore, that aeronautical engineers should have both a thorough knowledge of the treatment and strength of the various materials used for constructional purposes, and also a sound understanding of how best to apply those materials to specific parts.

It is realized that the present volume does not cover, either practically or scientifically, the entire field of special alloy steels but the book will be found to contain much information of great value to the aeronautical and motor engineer.

Mr. Hanby's clear exposition of the subject cannot fail to give to all those connected with the design, construction and manufacture of aircraft, a good understanding—or an enlarged one—of the best way to fulfil the demands of the various aircraft material specifications, and it will, at the same time, guide them to an appreciation of the capabilities of alloy steels and the wideness of their application.

L. BLIN DESBLEDS.

The Aeronautical Institute of Great Britain,
London.

AUTHOR'S PREFACE

THIS book is the outcome of a series of lectures given by the author in connection with one of the Aeronautical Engineering Courses of the Aeronautical Institute. It contains the substance of the lectures as delivered, supplemented by additional matter.

The Aeronautical Engineer—a term which, in the broader sense, includes the Motor Engineer—is called upon to deal with a large variety of complex metals; and it is only by correctly manipulating these metals, in the various processes of manufacture, that he can be sure of obtaining, in his finished products, the maximum possible efficiency.

This volume explains the main principles involved in the working up aircraft metals, and gives, finally, the physical properties and precise use of the individual steels, after correct treatment.

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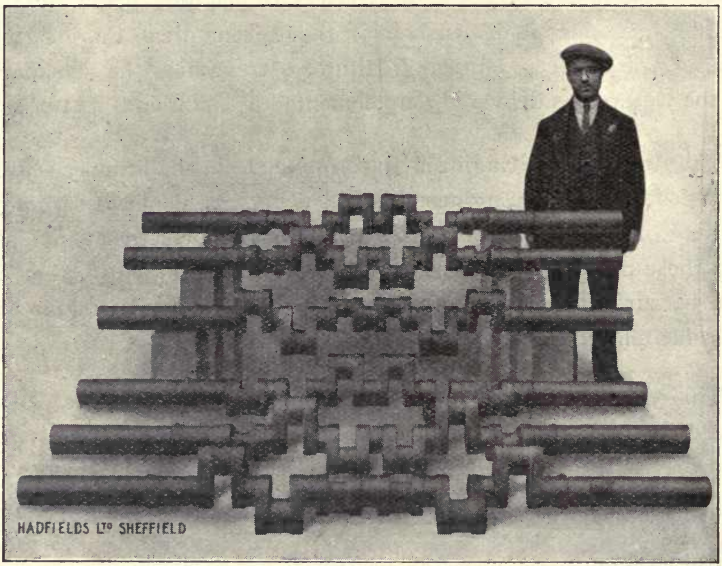

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METALS
In Aircraft Construction

CHAPTER I

INTRODUCTION.

1. The Work of the Metallurgist.—A working knowledge of the practical and scientific manipulation of aircraft metals must, obviously, be invaluable to the aircraft designer and constructor. Such appreciation of the work of the metallurgist is necessary to both, in order that they may be able to place their requirements clearly before him, and, also, that they may be in a position to handle, to the best possible advantage, the metal he produces. To help to bridge over the gap between the laboratory of the metallurgist and the workshop of the aircraft constructor is the object of this book.

The scientist in his laboratory is apt to develop the physical properties of steel from an almost purely theoretical point of view, often ignoring the practical difficulties which confront the industrialist in his workshop. On the other hand, many users of steel, because of their inability to utilize the scientific data already available, do not profit, to the full extent, from the researches of the scientist.

Although the steelmaker, working from well-known facts and a large accumulation of scientific data, can, with certainty, control the chemical composition of his material, the matter of heat treatment still remains obscure in many particulars. But enough is already known about the influence of temperature and the method of its application, both in the processes of manufacture and on the finished products, to show the importance of this aspect of the subject.

2. The Selecting and Handling of Metals.—However well prepared a steel may be, it still requires caution in handling. The practical engineer, indeed, is faced with many problems.

First he has to select the best economically available steel for his immediate purpose, and then he has to study how to use it. A steel which may, apparently, be ideal for certain purposes of manufacture, may have to be set aside as unsuitable, either owing to difficulties in working, high cost, or insecurity as regards supply. Its behaviour, under workshop manipulations, and, later, under variations of temperature and stresses in actual use, demands close consideration. There should, therefore, between air pilot, aircraft constructor and steel maker, be an intimate exchange of views and experience which would result in the increased reliability and safety of all types of aircraft.

3. Special Steels: Ternary and Quarternary Steels.—The subject of special steels is one of wide application. The term "special steel" is used to denote a steel which contains one or more special elements, such as nickel, chromium or vanadium in combination with carbon and iron. Special steels are divided into two groups, viz., those known as *ternary* steels, which contain but one special element alloyed with the iron and carbon; and those known as *quarternary* steels, which contain two special elements in addition to the iron and carbon.

Each of the special elements has a different effect upon the ultimate physical properties of the steel. The special elements which are added to give increased strength to structural steels are nickel, nickel-chromium and chromium-vanadium; and the steels containing these elements are those which are chiefly used in the manufacture of aircraft component parts. Considering that they possess widely different properties, it is an exceedingly difficult problem to estimate which class of steel is the most suitable for a given part.

4. Advantages of Special Steels.—On account of their greater toughness, special steels are more advantageous than ordinary carbon steels for constructional purposes; also, special steels are more readily adaptable to varying physical conditions. Ordinary carbon steels can be made stronger by increasing the percentage of the carbon content, or by heat treatment, but both these processes render them too brittle for use in aircraft construction.

The chief characteristic of special steels is the variety, and indeed contrariety, of their physical qualities, with their infinite adaptation to almost any specific requirement of construction. They can be made strong and tough at the same time. By maintaining the same strength combined with the additional toughness, parts can be made considerably lighter in section. This is of great importance in aircraft construction, where weight requires every consideration with regard to the speed, endurance and general structural stability of the machine.

5. The Production of High-Tensile Alloy Steels for Aircraft.—The development of aircraft steels is of increasing industrial importance. To realize thoroughly the practical possibilities of these steels under service conditions, it should be remembered that their characteristic properties are produced and controlled by precise and skilled handling during manufacture. The present age is one of specialization, and, so far as the steel trade is concerned, it is a well-known fact that the manufacture and treatment of high-tensile alloy steels for aircraft work now forms an important branch of the industry. Great progress has been made in the production of these steels, with the result that the aircraft designer is now able to produce machines possessing considerable strength with a minimum of weight.

6. Scientific Heat Treatment of Steels.—In recent years great progress has been made in metallurgical science. This has resulted in almost revolutionary changes taking place in the heat treatment of steel in the workshop. Formerly, before heat treatment was scientifically applied, the physical condition of a given steel was not taken into consideration, but its chemical composition was regarded as the criterion in selecting it for a given specified purpose. Recent advances, however, tend to show that although the chemical composition influences, fundamentally, the properties of all steels, yet it is the manner in which they have been physically treated that, ultimately, fit them for any special purpose. If a steel is chemically pure it is generally supposed to be fitted for the prescribed requirements; but, no matter how pure a steel may be chemically, unless it receives proper treatment in the subsequent working, it will be unable to stand the requirements of practice. There are instances on record where a chemically pure steel, employed for the same purpose, and used in the same manner, as a steel containing a large percentage of impurities, has, owing to improper treatment, failed under working conditions to give as good results as the latter.

Chemical impurities, such as sulphur, phosphorus and nitrogen, unless present to an abnormal extent, have very little effect upon the physical properties of steel, provided that these impurities are distributed uniformly enough to maintain chemical homogeneity. The presence of impurities is only injurious when they segregate into *"ghost lines."* These *"ghost lines"* usually contain a large proportion of carbon, phosphorus and manganese sulphide, thereby producing a mechanical separation, causing the steel to be weak and brittle.

Although in some cases failure is due to steel of unsuitable chemical composition, in most cases it is traceable to improper treatment. A slight difference in the chemical composition is hardly noticeable, but a slight difference in the heat treatment will soon be detected, particularly in the hardening and tempering processes.

Needless to say, the value of correct heat treatment is fully recognized in the aircraft industry. The new steels which have been introduced to meet the exacting demands of this section of steel users, can, under different treatments, be made to possess a wide range of mechanical properties. The same steel under different treatments, may exhibit extreme hardness with very little ductility, or an intermediate hardness combined with a fair amount of ductility, or extreme ductility together with softness. These varying conditions are entirely brought about by a judicious application of heat treatment.

CHAPTER II

TESTING THE STRENGTH OF MATERIALS

7. Special Importance of Strength of Materials to Aircraft Designers.—The subject of the strength and reliability of the materials used in aircraft construction has always been of considerable importance to the designer, and this importance will continue to increase with the development of commercial aviation. The employment of the best suited material in the manufacture of the various parts which constitute an aircraft not only leads to the increased reliability and longer life of the aircraft structure, but also tends actually to reduce the cost of aerial transportation.

With regard to this latter aspect of the commercial importance of employing the best obtainable material, much could be said, but it will, here, suffice to recall the fact that the more suited a material is for a given part, the lighter that part can be made, and, by so much, will the dead weight of a machine be reduced. And, if it be remembered that in an aeroplane there are hundreds of small parts, it will be easy to realize what a considerable weight will be saved, in the aggregate, if on each part a reduction be secured by using the best material obtainable for the particular part. This reduction in the dead weight of an aeroplane structure is immediately attended by the capability of the machine to carry a greater useful weight.

Again, by the use of the best available materials, it is possible to diminish the thickness of a wing structure, or the dimensions of a fuselage, or the size of the constituent parts of an undercarriage, or the magnitude of any other portion of the machine which offers resistance to penetration through the air. Such a reduction would lead to an increased *fineness* of the machine with all the resultant gain in the power required to drive it, and in the ease with which the various manœuvres necessary for aerial navigation can be carried out.

8. Stresses Induced in Aircraft Parts.—All the materials used in the construction of aircraft should be capable of withstanding certain definite loads. These loads, which are the external forces applied to the machine during flight, are termed *stresses*. Stress, therefore, may be defined as a force, or a combination of forces, which a body may have to withstand under working conditions. The effect of a load, or stress, upon a piece of material is to change, or tend to change, the shape of the material. The change of shape is called *deformation,* and, as it will be seen later on, each kind of load has its appropriate deformation.

Most aircraft parts have to resist more than one kind of stress, that is to say, the parts are called upon to withstand working loads applied in different planes with reference to the central axis of the object. The engine crankshaft may be taken as a typical example of a part subjected to combined stresses. When the engine is at work, the material of the crankshaft has to undergo bending and twisting stresses while, at the same time, it has to withstand shock. The material of the crankshaft should, therefore, be able to resist these various stresses and should, besides, possess the requisite amount of hardness to withstand undue wear.

An exact knowledge of the practical working conditions of each particular part of the machine, in both normal and abnormal flight, is indispensable to the aircraft designer if he is to secure the best results possible from any type of aircraft. The magnitude of the stresses, and the manner in which they are applied, should be carefully considered in the designing of each part, and the material selected for use in the construction of the part should be thoroughly capable of resisting the particular kind of stress to which the part is subjected in practice.

9. Variation in the Properties of Materials, and the Importance of Testing.—The properties of the materials used by engineers vary through many causes. If we take a pound of almost any gas and measure its volume and the temperature and the pressure to which it is subjected, we can estimate with accuracy the behaviour of the gas if it is to be compressed, under certain conditions, to a new volume. If, however, we take a pound of steel, we cannot forecast with certainty the behaviour of the material under a load, if we know nothing more about the material than the fact that it is called steel. It is of some assistance to us if we know the chemical composition of the steel, but, even with such information, we cannot estimate with accuracy the load which will cause the material to fracture.

Experience has taught us that the only satisfactory method of estimating suitable loads in the designing of machines is to submit to tests samples of the actual material to be used, which tests reproduce, as nearly as it is possible, the conditions met with in actual practice. Thus if a part is to be worked under conditions of direct pull, the most satisfactory way of deciding the value of the material to be used, is to subject samples of it to a test reproducing these conditions. It is of great importance that the specimens selected for testing purposes should be thoroughly representative of the material under inspection, and that *they should undergo exactly the same heat treatment process as the parts which are eventually to be made from the material represented.*

10. The Various Tests applied to Aircraft Steels.—Owing to the necessity of obtaining comparable results, it is important that standard methods of testing the materials should be adopted, as the test values are affected considerably by a difference in the size or shape of the specimen, and the manner of testing. The tests applied to aircraft steels may be classified under the following headings :

(1) HARDNESS.
(2) TENSION.
(3) IMPACT.
(4) BENDING.
(5) FATIGUE.

It is absolutely essential that one or more of the foregoing tests should be applied to each consignment of material before commencing to manufacture the parts, but, once the suitability of the material has been established, it is not necessary to apply all the methods of testing to each batch of parts. Thoroughly reliable information can be obtained from the use of simple and inexpensive methods. To test the final properties of the finished parts it is only necessary to check a proportion of them by the Brinell hardness method.

The relation between the hardness and the other properties of steels does not vary if they are of the same composition, and receive the same treatment. Therefore, provided that a hardness number, identical with that obtained in the preliminary test specimen is obtained on the finished part, it can be safely assumed that the final properties of the part are identical to those of the test specimen.

11. Hardness Testing.—The relation of hardness to other physical properties calls for a careful and detailed study. Hardness and ductility are the most important properties of high-tensile steels. In these steels high hardness combined with high ductility together form an alloy of great strength, introducing into the material a further important physical condition characterized as *toughness*. To secure the maximum efficiency in the finished parts, it is essential that hardness and ductility should be combined together in proper ratio. The hardness of a solid substance may be defined as the resistance offered by a smooth surface of the substance to abrasion or deformation. Hardness measured by the file denotes in a simple, yet practical, way the power of the object to resist the wearing away of its surface under the cutting action of the file teeth. In many cases the practical man, for want of more scientific means, has to resort to the file in order to determine whether, or not, the object is of the requisite hardness. It must be admitted that, although in many instances the intelligent practitioner obtains wonderfully successful results from its use, the limitations of the file are obvious; too much depends on the nature of the file, and the method of application is always liable to variation.

12. The Brinell Ball Machine and Hardness Number.—Hardness, as measured by the various standard hardness testing instruments, is based on the resistance of the material to penetration and deformation. Of the instruments in use the Brinell ball machine is perhaps the most satisfactory for general purposes. It has a universal application; and, by engineers and steel makers, it is arbitrarily accepted as a standard instrument. Hardness tests carried out by the ball machine are known as *static hardness tests*. A Brinell ball machine is shown in Fig. 1. The tests consist in pressing a 10 m/m diameter hardened steel ball under a known pressure into the surface of the material, and measuring the area of the impression. The area of the indenture varies according to the resistance to deformation of the material being tested. The result of the test is expressed in hardness numerals which are calculated from the following formula :

$$\text{HARDNESS NUMBER} = \frac{\text{TOTAL PRESSURE.}}{\text{CURVED AREA OF IMPRESSION.}}$$

For practical working, machines are designed to give a standard pressure of 3,000 kilos. The diameter of the impression is measured by a micrometer microscope, and, by means of the diameter indicated, the hardness number may be read off at a glance from a scale supplied with the machine. It must be noted that the accuracy of the test depends entirely on the correct measurement of the diameter of the impression. In a works machine, the hardened ball, owing to its frequent use, is liable to bear a number of flattened surfaces on the periphery.

Unless the ball is frequently replaced, the impression in the samples will not be a perfect circle, thus causing liability of error in the subsequent measurement.

Table I (p. 22) shows the Brinell diameters of impression with corresponding hardness numbers, and also the approximate maximum tensile strength.

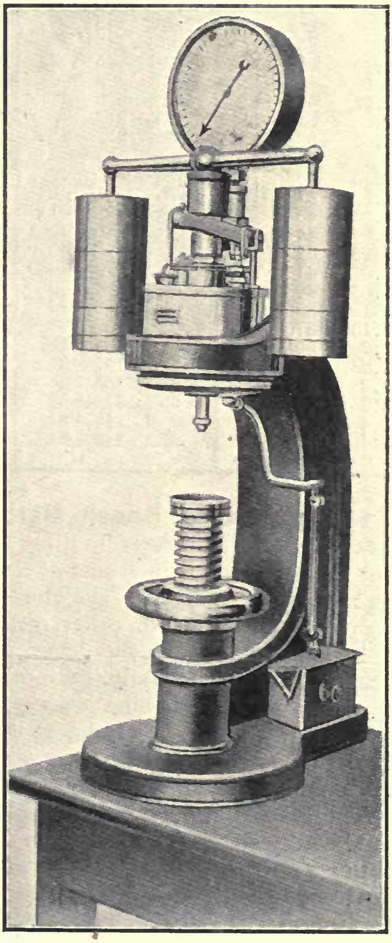

FIG. 1.
BRINELL BALL HARDNESS
TESTING MACHINE.

TABLE I OF BRINELL DIAMETERS OF IMPRESSION,

With corresponding Hardness Numbers and approximate Maximum Tensile Strength, using a 10 m/m ball.

3,000 Kg. Load.			3,000 Kg. Load.			3,000 Kg. Load.			1,000 Kg. Load.		
Dia. m/m.	Brin. No.	Tons Sq.in.	Dia. m/m.	Brin. No.	Tons Sq. in.	Dia. m/m.	Brin. No.	Tons Sq. in.	Dia. m/m.	Brin. No.	Tons Sq.in.
2.0	945	208	3.5	302	64.8	5.0	143	33.0	2.00	315	68
2.05	899	197	3.55	293	63	5.05	140	32.4	2.05	299	64
2.1	856	188	3.6	285	62	5.1	137	32	2.10	285	62
2.15	817	179	3.65	277	60	5.15	134	31	2.15	272	59
2.2	780	171	3.7	269	58	5.2	131	30	2.20	260	56
2.25	745	163	3.75	262	56	5.25	128	30	2.25	248	53
2.3	712	155	3.8	255	55	5.3	126	29	2.30	238	51
2.35	682	150	3.85	248	53	5.35	123	29	2.35	226	49
2.4	653	144	3.9	241	52	5.4	121	28	2.40	218	46
2.45	627	138	3.95	235	51	5.45	118	27	2.45	209	45
2.5	601	130	4.0	229	49	5.5	116	27	2.50	200	43
2.55	578	124	4.05	223	48	5.55	114	26	2.55	192	41
2.6	555	119	4.1	217	46	5.6	111	26	2.60	185	40
2.65	534	114	4.15	212	45	5.65	109	25	2.65	178	40
2.7	514	110	4.2	207	44	5.7	107	25	2.70	172	40
2.75	495	106	4.25	201	43	5.75	105	24	2.75	165	38
2.8	477	103	4.3	197	42	5.8	103	24	2.80	159	37
2.85	461	99	4.35	192	41	5.85	101	24	2.85	153	35
2.9	444	95	4.4	187	40	5.9	99	23	2.90	148	34
2.95	429	93	4.45	183	40	5.95	97	22	2.95	143	33
3.0	415	90	4.5	179	40	6.0	95	22	3.00	139	32
3.05	401	86	4.55	174	40	6.05	94	22	3.10	129	30
3.1	388	83	4.6	170	39	6.1	92	21	3.20	121	28
3.15	375	81	4.63	167	38	6.15	90	21	3.30	113	26
3.2	363	78	4.7	163	38	6.2	89	20	3.40	107	25
3.25	352	75	4.75	159	37	6.25	87	20	3.50	100	23
3.3	341	73	4.8	156	36	6.3	86	20	3.60	95	22
3.35	331	71	4.85	152	35	6.35	84	19	3.70	89	20
3.4	321	69	4.9	149	34	6.4	82	19	3.80	85	20
3.45	311	67	4.95	146	34	6.45	81	19	3.90	80	18

13. The Avery Brinell Hardness Testing Machine.—The Avery Brinell Hardness Testing Machine shown in Fig. 2 carries out the standard Brinell test of applying a load of 3,000 kilos to a 10 m/m steel ball, and allowing same to make an impression in a specimen of steel or other metal.

It is designed on the lever principle, so as to maintain its accuracy for an indefinite period. With this system it is possible to calibrate the machine with 3,000 kilos of dead weight. In operation, the action of the weights rising prevents any greater load than 3,000 kilos being applied to the specimen; hence, to a reasonable extent, the machine is "fool-proof."

The load is applied through phosphor bronze worm wheel and mild steel worm, the thrust being taken by a ball bearing. Quick action of the vertical straining screw is provided by disengaging it from its keyway by means of a thumbscrew at the top of the frame. The handwheel for rotating the straining screw can be moved up or down so as to give full view of small specimens under test. Weights equivalent to 500 and 3,000 kilo load are supplied.

A high-class microscope and a Table of Hardness Numbers are included with each machine.

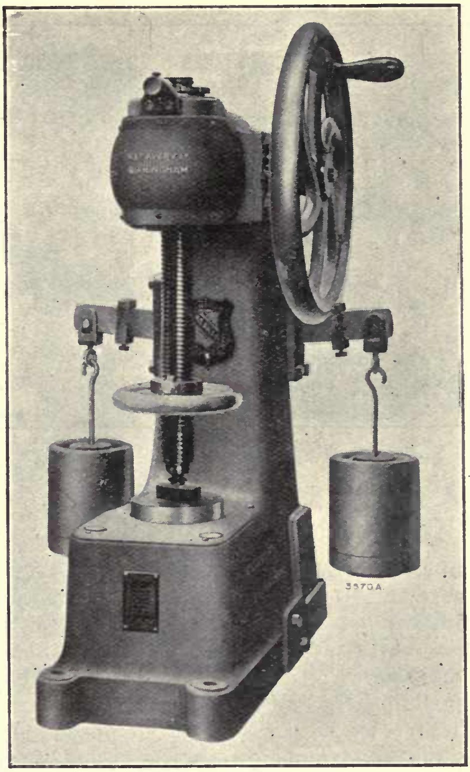

FIG. 2.

THE AVERY BRINELL HARDNESS TESTING MACHINE.

14. The Shore Scleroscope.—Another form of hardness test sometimes adopted is the one carried out by means of the Shore Scleroscope. This does not replace the Brinell machine, but it is very often used as a supplement to it. The apparatus, which is shown in use in Fig. 3, consists of a vertical graduated glass tube, which contains a small diamond-pointed drop hammer. By means of a suction bulb a vacuum is produced in the glass tube, and the hammer is drawn up to the top, where it is held in position by hooks. By applying pressure to the bulb, air is caused to act on the valve operating the suspension hooks, and thus the drop hammer is released. The height of the fall is ten inches. The sample to be tested is solidly mounted under the hammer, which on being released strikes the surface of the test-piece and quickly rebounds up the graduated tube. The position of the top part of the hammer should be noted on the scale when it comes to rest, and before it again commences to descend.

It is rather a difficult matter at first to get reliable readings, but after some experience fairly consistent results can be obtained. The surface of the test-piece should be properly prepared in order to secure reliable results. It is absolutely imperative that the decarbonized surface should be removed before testing, otherwise the reading will be much too low. Extremely hard surfaces must be free from tool marks, and should be perfectly smooth, but must not be highly polished. It is not essential, however, to so carefully prepare medium-hard and soft surfaces. Generally speaking, finishing off the surface with a second cut file is sufficient.

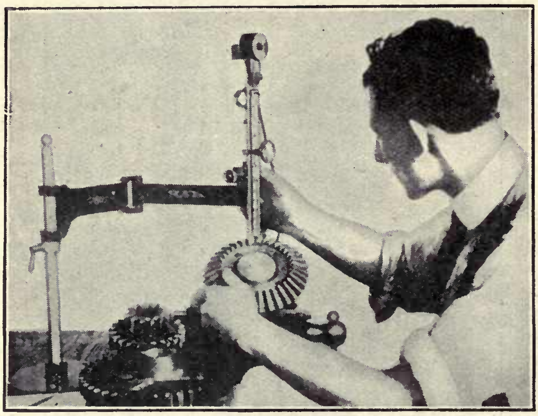

FIG. 3.

SCLEROSCOPE IN USE, TESTING GEARS.

The surface of the sample on the point of contact with the hammer is considerably strained, and the hammer should not, therefore, be allowed to drop more than once on the same place, as the reading will be then too high. It must not be assumed that the strained point has any detrimental after effect on the efficiency of the object, for the affected part is so minute that it has very little, if any, influence on the strength of the object tested.

15. Tensile Tests.—The tensile test shows the following items of information: (1) the *elastic limit,* (2) the *yield point,* (3) the *maximum stress,* (4) the *extensibility,* (5) the *reduction of area.*

In practical works testing, the elastic limit and yield point are expressed as one item. Here, however, they will be considered separately because, to some extent, they are two distinct points of the testing operation. Fig. 4 shows a general view of the Buckton 50-ton Vertical Testing Machine.

When the load is applied to the specimen the piece increases in length proportionally to the force applied, until a point is reached at which the increase in length ceases to be proportional to the loading. At this point, if the load is removed, the specimen will return to its original dimensions; the specimen is in no wise

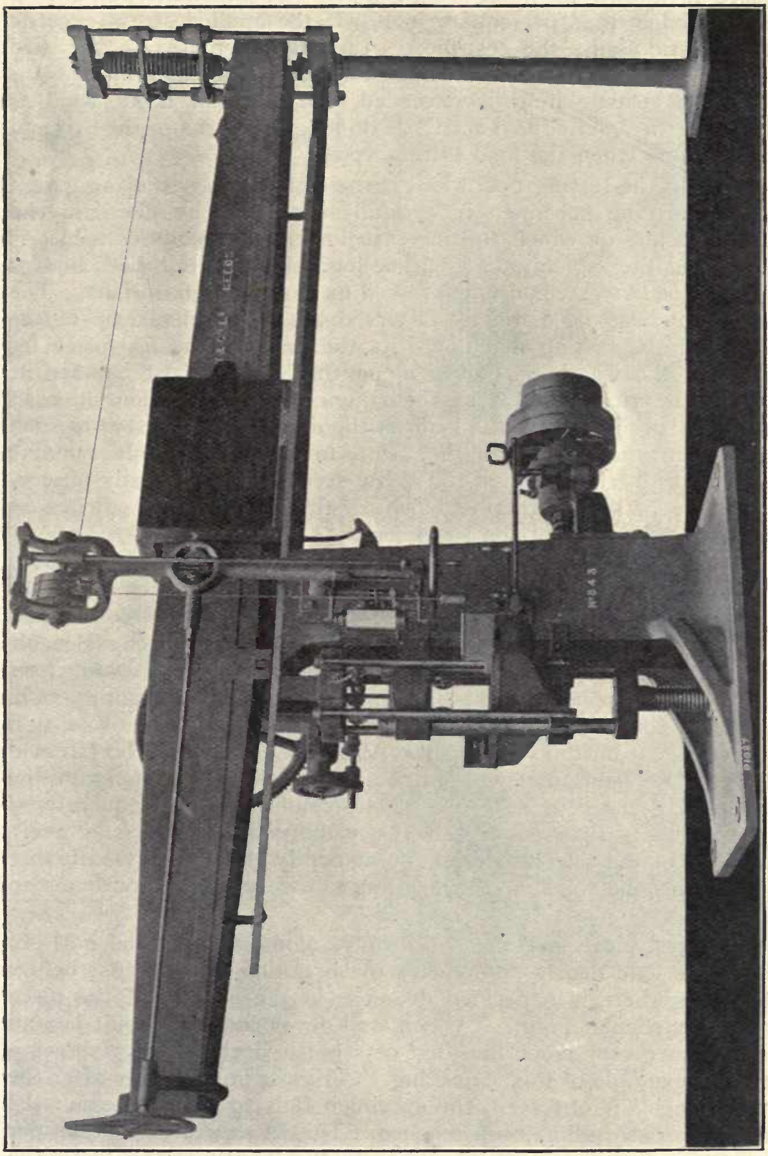

FIG. 4.—BUCKTON 50-TON VERTICAL TESTING MACHINE.

permanently deformed. Up to this point stress and deformation are in constant ratio. Repeated stresses up to this point can be applied, but each time the load is removed the test specimen will return to its former size. The maximum amount of force that can be applied without permanently altering the shape of the test-piece is known as the "*elastic limit*" of the material, and is expressed in tons per square inch. If the applied stress exceeds the elastic limit, the test-piece gradually decreases in the size of its cross-section, and at the same time increases in length. Once the elastic limit is exceeded, the material takes what is known as a "*permanent set.*" It no longer returns to the original dimensions when the load is removed.

During the testing operation, if the distance between the gauge points on the specimen is carefully measured by dividers, the actual point, at which the increase in length becomes visible, is known as the "*yield point.*" The load on the specimen is known as the *yield stress,* and is expressed in tons per square inch. The point can also be distinctly observed by the sudden drop of the beam of the testing machine. As the load on the test-piece increases, the weight is moved along the beam to just balance it. When the yield point is reached there is a sudden elongation of the test specimen, and the load on the machine is arrested to such an extent that it causes the beam to drop. It only remains stationary in this position for a few seconds, but is easily observable. It lasts until the movement of the pulling force catches up to the elastic flow of the specimen.

The load should be uniformly applied, without intermission, until the test-piece actually breaks; it should never be taken off and re-applied, but should always be maintained continuously.

The accurate determination of the yield point is of considerable importance. *The yield stress is the maximum safe working load for all parts working in tension.* Therefore the suitability of a material for any part that is to be worked in a state of tension is dependent on the yield point. Although a part may be stressed beyond the yield point without actually breaking, at this stage the material is more or less in a plastic condition. Consequently, if the working stresses exceed the yield point, there is a great liability of the part becoming permanently deformed. On further increasing the load on the test-piece, the specimen continues to stretch.

The test-piece stretches uniformly, along the parallel portion, until the load nearly approaches the breaking point. Just before breaking there is a decided decrease in the section of the piece at one particular point. When well developed, this point has an appearance very much like that of a bottle neck. Fig. 5 shows a typical example of this "necking." Almost immediately after the "necking" is observed, the specimen fails to lift the beam: the maximum stress has been reached. This is expressed in tons per square inch. The actual increase in the length of the test-piece is known as the *elongation* of the material, and is expressed as so much per cent on the original length of the parallel portion. *The percentage of the elongation denotes the ductility of the material.*

When expressing results, it is important that the distance measured between the gauge points on the parallel portion should always be stated, because, even for the same material, the percentage of elongation will be larger on a short specimen than it would be on one having wider gauge points. This is explained by the fact that there are two distinct elongations: one of which is uniform over the greater part of the parallel portion, and the other is confined to a short length in the region of the "necking." This latter part is only a comparatively small portion of the actual length under observation, and does not vary much in specimens of the same material, no matter what the overall distance between the gauge points may be. The amount of stretch in the region of the "necking" is much greater than that on the other part of the specimen. Assuming that we have two specimens of the same material, one having a one-inch acting length (as the distance between the gauge points is called) and the other a two-inch acting length, we should have the same amount of elongation in the region of the neck on each specimen. Therefore, as the actual stretch in this part is much greater than that on the remainder of the parallel portion, it follows that there would be a higher elongation per cent on the shorter specimen.

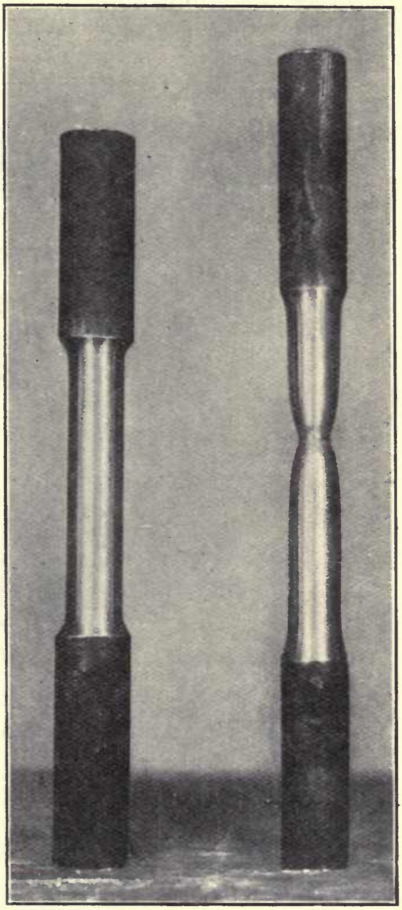

FIG. 5.

TENSILE TEST SPECIMENS, BEFORE AND AFTER TESTING.

Just as specimens having different acting lengths give different elongations, so specimens having the same acting length will give the same elongation only if they are of the same diameter. Thus a test-piece 0.5 inch diameter by 2 inches acting length would not give the same elongation as a test-piece 0.564 inch diameter by 2 inches acting length. It will be seen that it is highly important that the tensile specimen should be of standard dimensions, *i.e.*, the diameter and acting length should always be proportional to each other.

Fig. 6 shows a very useful and compact form of testing machine made by Avery, Birmingham. This machine is fitted with a variable speed motor, and has an autographic recorder. It can be adapted for testing specimens in tension, compression, bending, shearing, torsion and hardness.

16. Standard Form of Test-Piece.—The standard form of test-piece adopted for high-tensile steels is 0.564 inch diameter by 2 inches acting length. When, unavoidably, the material is too small to allow of this standard size of specimen being prepared, the smaller dimensions used should be in the same proportion. These may be calculated from the formula :

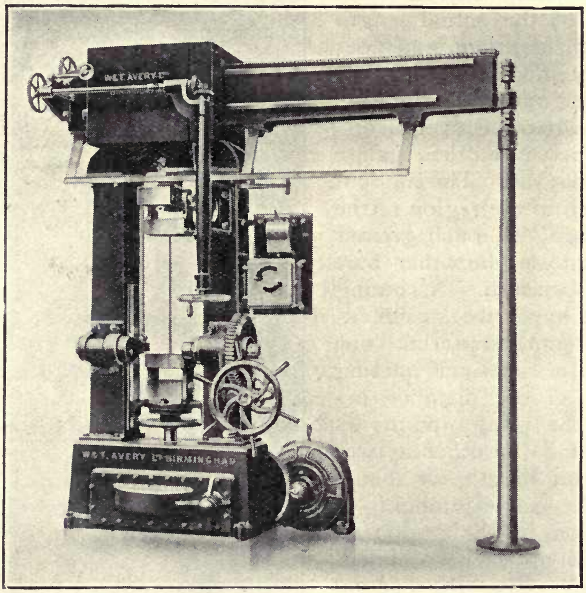

FIG. 6.
AVERY 30-TON TESTING MACHINE.

$$\frac{\text{Acting Length}}{\sqrt{\text{Area of Section}}} = 4$$

Figs. 7, 8, 9, 10 and 11 show the various forms of tensile test specimens in general use.

Whatever size of specimen is adopted it should be prepared with the greatest care and accuracy. In the case of a hard material, such as for instance a 100-ton steel, the angle between the parallel and the shoulder should be nicely radiused, otherwise difficulty will be experienced in the manner in which the specimen breaks. If the vertex of the angle is sharp, the specimen is nearly sure to break in the sharp corner.

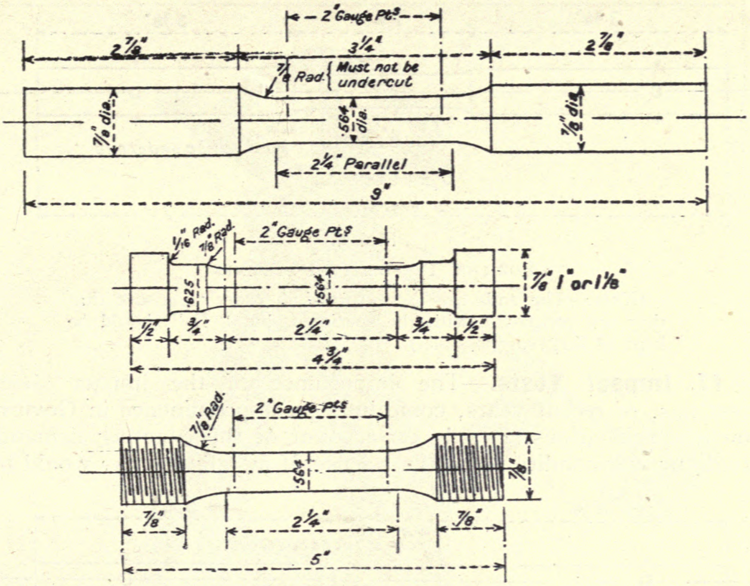

FIG. 7.

FORM OF TENSILE TEST SPECIMEN.

(*Note.*—When the ends are 1 inch or 1⅛ inch diameter, the shoulder shown .625 inch diameter may be increased in diameter if desired.)

The amount of contraction in the section of the test-piece at the point where the fracture takes place is expressed as a percentage of the area of the original section, and is specified in the test result as the *reduction of area.* Together with the elongation, the reduction of area indicates the ductility of the material. Moreover, it usually follows that if a material has a good reduction of area, it will also give a good impact result.

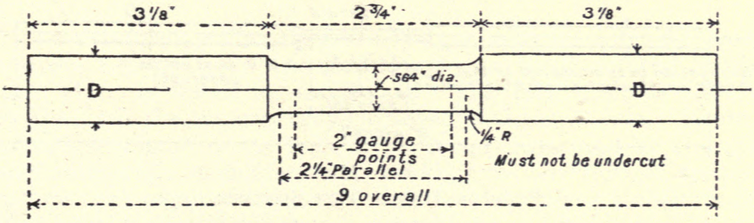

FIG. 8.

FORM OF TENSILE TEST SPECIMEN.

(*Note.*—The ends are to be turned to ensure that they are concentric with the specimen, but " D " should be kept as large as possible.)

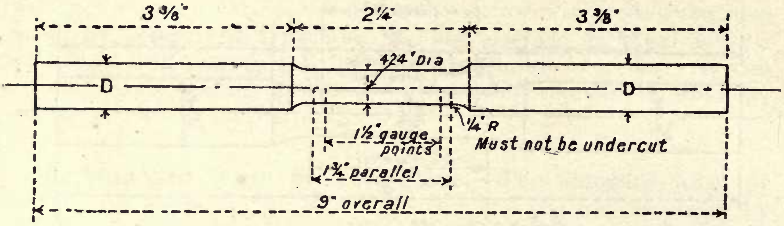

FIG. 9.

FORM OF TENSILE TEST SPECIMEN.

(*Note.*—The ends are to be turned in order to ensure that they are concentric with the specimen, but " D " should be kept as large as possible.)

17. Impact Tests.—The importance of the impact shock test has, of recent years, come into great prominence in Government specifications, largely on account of the exacting demands made by war conditions on the science of metallurgy. As would be expected, munitions of war necessitated extreme care in workmanship and the selecting of materials, in order to reduce to a minimum the risk of failure at a critical moment. The impact test reveals the property known in the engineering world as *" brittleness,"* denoting the capacity of a material to resist shock or, in other words, its toughness in withstanding suddenly applied loads.

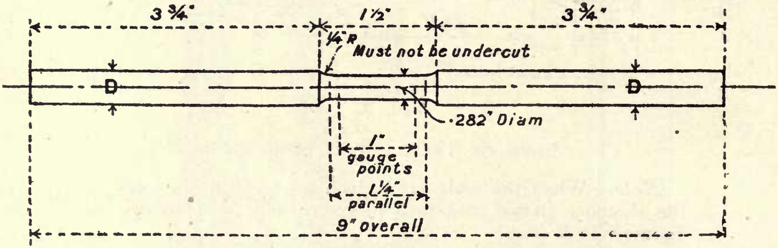

FIG. 10.

FORM OF TENSILE TEST SPECIMEN.

(*Note.*—The ends are to be turned in order to ensure that they are concentric with the specimen, but " D " should be kept as large as possible.)

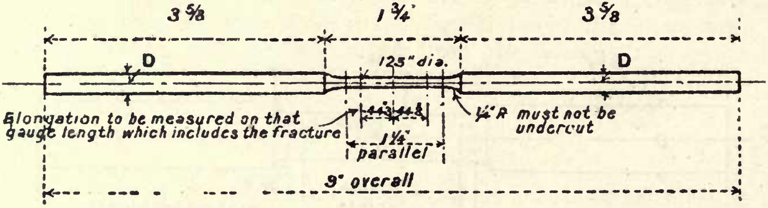

FIG. 11.

FORM OF TENSILE TEST SPECIMEN.

(*Note.*—The ends are to be turned in order to ensure that they are concentric with the specimen, but " D " should be kept as large as possible.)

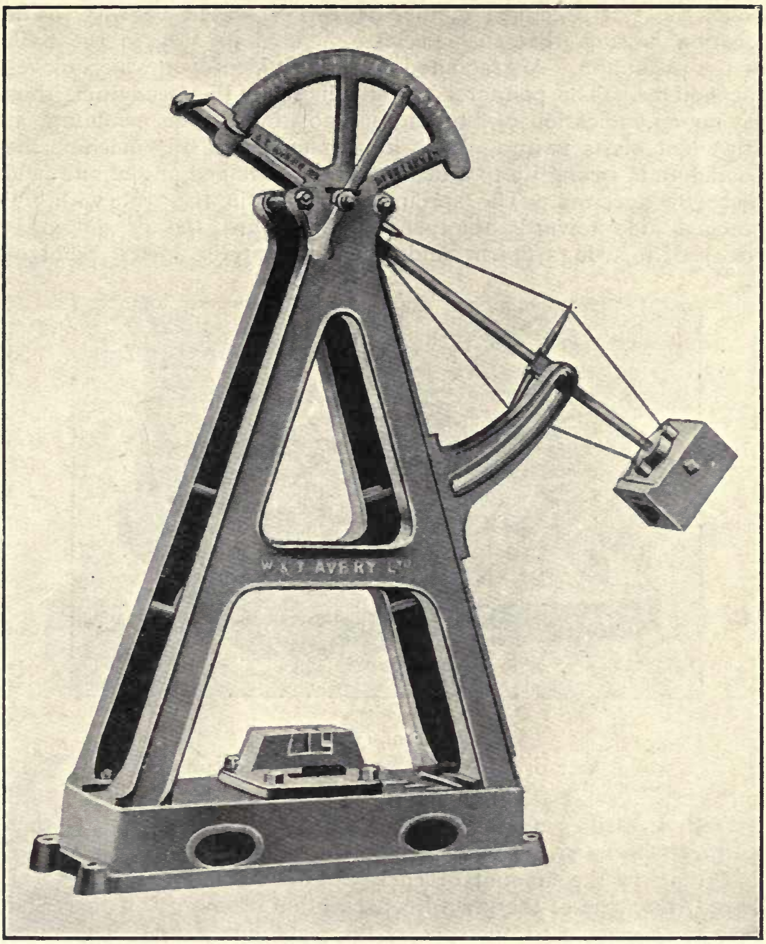

FIG. 12.

IZOD IMPACT TESTER.

The two forms of impact test most generally used are the Izod and the Charpy. Both methods employ a small notched specimen which is tested to destruction. The Izod machine shown in Fig. 12 is the one generally employed in Great Britain. Representative samples of the bulk of the metal parts used by aircraft and automobile manufacturers, working to Government specifications, are required to comply with pre-determined standards of Izod value before the parts are assembled.

18. The Izod Machine.—The Izod machine consists of a heavy pendulum swinging in a vertical plane about the point of suspension. The pendulum swings on ball bearings, and develops an energy of 120 ft.-lb. The vice fixed on the bed of the machine holds the test specimen in the manner shown in Fig. 13. The location is such that the specimen is held directly in the path of the pendulum. A graduated arc is provided over which moves the pointer. The pointer is rigidly fixed to the pendulum, thus giving an indication of the angular position of the pendulum at any point of its swing. In making a test with this machine the pendulum is swung up to a definite pre-determined angle, and held there by a clamp. The specimen is fixed in the vice with the notched side towards the pendulum. When the pendulum is released, it swings down; and when it is at the lowest point of its fall, it strikes against the specimen and breaks it. It then continues on its swing with its momentum more or less diminished according to the amount of energy required to break the specimen. By virtue of the law of conservation of energy, if there had been no specimen to obstruct it, the pendulum would, neglecting slight frictional effects, have risen on the other side to a height equal to that from which it was let fall. The specimen in being broken absorbs a certain portion of the pendulum's energy, and this is measured by the continued and diminished swing of the pendulum moving the pointer over the graduated scale. The greater the resistance offered by the specimen, the less the pendulum will continue in its swing, and so the pointer will be carried over the graduated quadrant a shorter distance.

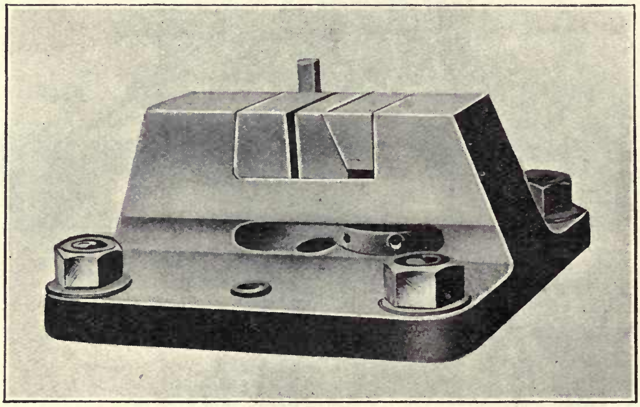

FIG. 13.
VICE OF IMPACT TESTER, SHOWING SPECIMEN IN POSITION FOR TESTING.

Fig. 14 shows the form of test specimen which is machined to standard dimensions. It is provided with a notch. The presence of the notch concentrates the stress at one point relative to the point of contact with the pendulum; otherwise extremely soft or ductile materials would bend over. Specimens are usually made three on one bar, the bar being raised in the vice after each one has been broken. It is essential, in erecting this machine, to bolt it down on to a concrete base. If this is not done, the test results will be affected, and will not be strictly comparable with tests made on other Izod machines in use.

19. Value of Impact Test.—The reasons which have brought about the use of the impact test, and its usefulness in connection with the construction of aircraft, will now be considered briefly. The impact test is applied because it is the test which gives most information as to whether the heat treatment, which has been given to the steel during the manufacturing processes, is satisfactory or not. If the material under consideration has been heat treated to the best advantage, the Izod value will be relatively high. If, on the other hand, the heat treatment given has been inferior, then the Izod value will be relatively low.

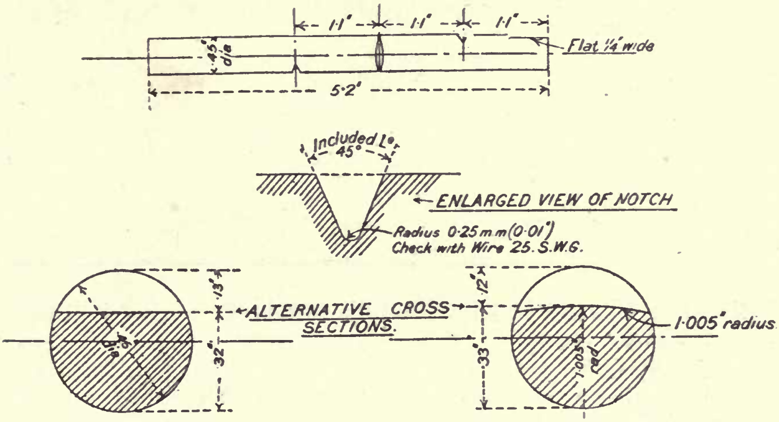

FIG. 14.

IZOD TEST SPECIMEN.

The impact results have no relation to either the tensile or the Brinell hardness tests. The fact that a material is said to give an impact result of 50 ft.-lb. is no criterion that the material in question is either good or bad. Other physical properties and the chemical composition must accompany the test before the usefulness of the material can be judged. If in an alloy steel the impact of 50 ft.-lb. were accompanied with a tensile strength of 75 tons and a ball hardness of 350, then the material would be extremely good; if, in the same class of material, it was only associated with a tensile strength of 40 tons and a ball hardness of 170, then the material would be decidedly poor. On the other hand, if an impact of 50 ft.-lb. along with 40 tons tensile and a ball hardness of 170 were obtained from an ordinary plain carbon steel containing, say, from 30 to 40 per cent carbon, then the impact figure would be a remarkably good one.

"Brittleness," in machine construction, is a feature which must be well considered; otherwise it is likely to become dangerous and cause failure at the critical moment. For instance, the study of a large number of failures of engine parts goes to show that steel with a bad Izod value fails more often than steel with a good Izod value. Brittleness may be due to the steel containing too high a percentage of sulphur and phosphorus. This is a very common occurrence in steels used in making nuts and bolts. If the sulphur and phosphorus content is over 1 per cent, the Izod value obtained would be in the region of 2 to 3 ft.-lb., whereas a similar steel with sulphur and phosphorus below .06 per cent would give an Izod test figure of over 40 ft.-lb.

20. Heat Treatment and Izod Result.—An interesting demonstration of the effect of heat treatment may be gathered from the Izod result. The following tests taken on a 5 per cent nickel steel clearly show the remarkable increase in toughness brought about by judicious treatment:

5 % Nickel Steel Specimen.	Y.S.*	M.S.*	E.*	R.A.*	Izod.	Brinell.
As rolled.	34	45	28%	55	40	207
Heated to 800°C. and quenched in oil. Tempered to 650°C.	44	51	28	65	75	241

21. The Charpy Impact Testing Machine.—A general view of the Charpy impact testing machine is shown in Fig. 15. The machine is, in most respects, similar to the Izod; but the test-piece is placed horizontally instead of vertically, and supported at both ends instead of only one. Also the test-piece in this case is placed in the machine with the notched side away from the pendulum instead of towards it as in the Izod, and is fractured by the pendulum striking it immediately behind the notch.

The Charpy machine is not so well known in England as the Izod, but it is extensively used in France. These machines are

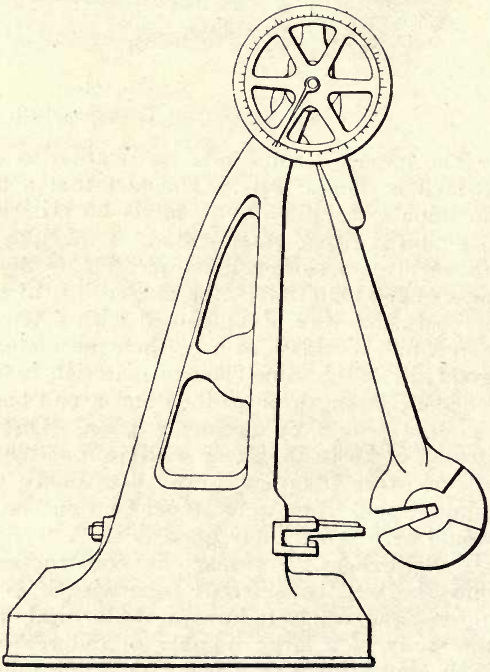

FIG. 15.
CHARPY IMPACT TESTING MACHINE.

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* Y.S. = Yield Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq in.; E = Elongation; R.A. = Reduction of Area.

made in capacities of from 25 to 200 kilogramme-metres, the larger sizes being in some cases furnished with electric control. Fig. 16 gives a diagrammatic representation of the form of the Charpy test specimen.

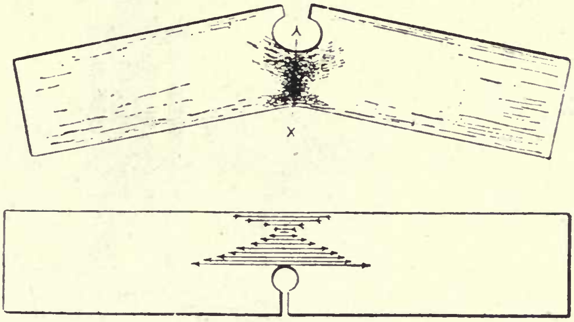

Fig. 16.

Diagrammatic View of Charpy Impact Test Specimen.

22. Impact Fatigue Tests: The Stanton and Eden-Foster Machines.—The machines used for carrying out impact fatigue tests are the Stanton and the Eden-Foster. Both machines are very similar in application. In principle, they attempt to combine the effects of the vibration of pure fatigue test and the impact or shock test, by testing a specimen to destruction by a method which produces both shock and reversals of stress. The results of tests by the Eden-Foster method exhibit a consistency not hitherto found in either the vibration or the shock test; therefore it appears that this test supplies something previously lacking in both these two methods, when carried out separately.

The Eden-Foster test, in its simplest form, consists in repeatedly dropping a hammer of known mass from a given height on to a specimen supported at either end in a horizontal position directly below it, the specimen being further arranged to rotate about its axis through 180 degrees between each blow.

The essential feature in which this method differs from the vibration method is that the stress is not applied gradually, but instantaneously, thus obtaining the " shock " effect. On the other hand, the method is something more than a mere impact test, since the rotation of the specimen between each blow produces, as will be explained later, a reversal of stress throughout the cross-section of the specimen.

Figs. 17, 18 and 19 show the Eden-Foster machine. The whole of the mechanism is secured to, and supported by, the main casting, which also acts as cover to the tank or box casting. Projecting through the side of the tank, but not seen in the illustration, is the main spindle, which may be driven by a one-inch belt from any convenient countershaft, or alternatively, by an electric motor with suitable gear or worm reduction. About one-tenth of a horse power is required.

The main spindle carries a dog clutch normally in engagement and driving a cam. A roller bears on the upper surface of this cam, and is attached to the power end of the rod H, being suitably guided so that it rises and descends at each revolution of the cam. Fixed on the rod H is an arm J, which engages with the lower face of the hammer M, so that when the rod H rises by rotation of the cam the hammer M is also lifted. The hammer slides freely between two sets of three-point guiding screws, these screws being covered by the two castings which, as shown in the illustrations, are attached to the standard G and its fellow on the opposite side.

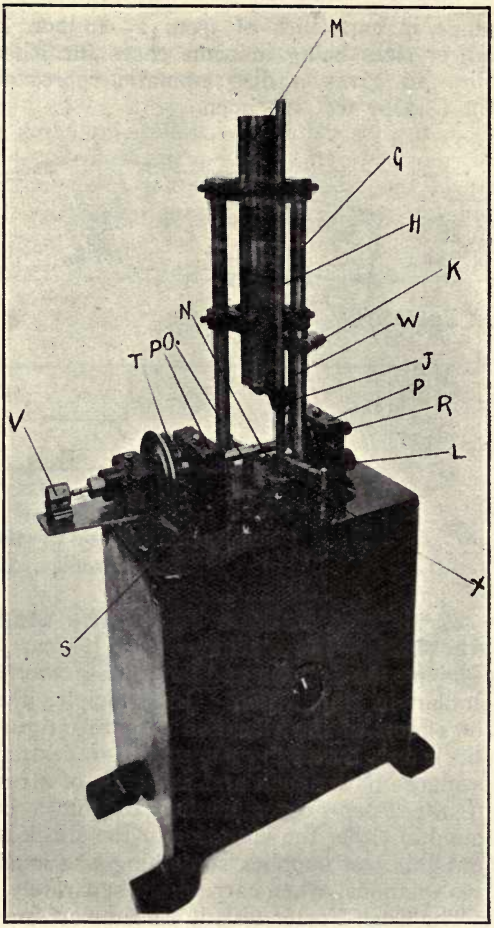

Fig. 17.
Eden-Foster Impact Testing Machine.

Mounted upon the standard G is a sleeve W, free to rotate about the standard, but normally held in a fixed position by the spring L. Clamped on the sleeve W is an adjustable catch K. As soon as the arm J has lifted the hammer M sufficiently, the spring L causes a partial rotation of the sleeve W, so that when the arm J again descends the hammer is held by the catch K. The further descent of the arm J brings its lower inclined face in engagement with roller arm N, attached to the sleeve W, in such a manner that the catch K releases the hammer M, allowing it to fall upon the test-piece O, which is carried by two hardened steel bushes in the plummer blocks P.

As already stated, the test-piece is rotated through 180 degrees between successive blows, this being effected as follows:

One end of the test-piece is slotted to engage with a universal joint drive, and is kept in engagement by a screw R. The universal joint is driven through a free-wheel and clutch T, by a length of chain S, one end of which is attached to the roller already referred to as bearing on the cam, the other end carrying a weight suitably guided. As the roller moves upwards the weight on the other end of the chain draws the chain over its sprocket, thus rotating the test-piece. When the hammer sinks, the chain and sprocket, of course, return to their original positions, but the free-

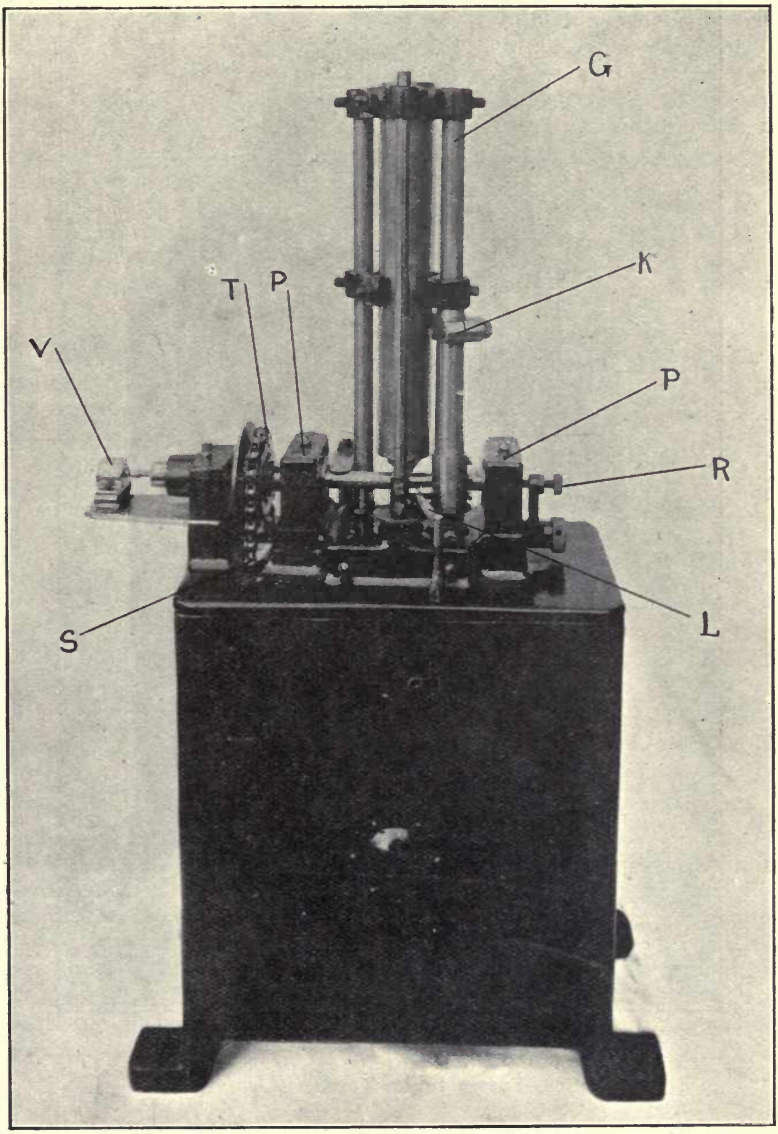

FIG. 18.

EDEN-FOSTER IMPACT TESTING MACHINE.

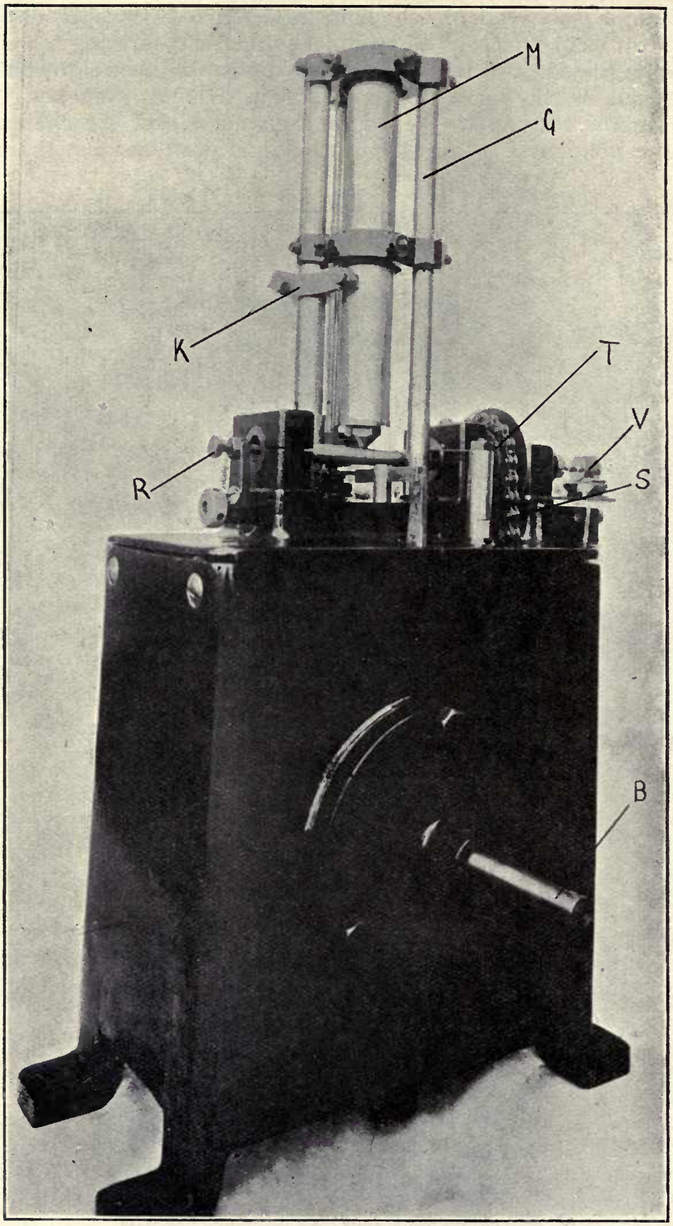

FIG. 19.
EDEN-FOSTER IMPACT TESTING MACHINE.

wheel " slips " on this backward motion, so that the test-piece is not turned back with them.

It will be observed also that the rotation of the test-piece begins and ends entirely between successive blows. The revolutions of the test-piece are recorded by a counter V, and, of course, the number of blows is found by multiplying the counter record by two. When the test-piece breaks, it comes into contact with an arm X, and thereby trips the clutch on the driving shaft, and stops the machine. The tank is partially filled with oil to provide efficient lubrication of the cam and other surfaces.

The hammer M is shod with a tip of hardened tool steel. The height of the drop depends on the position of the adjustable clutch K on the sleeve W, and may be varied from about 1 to 4½ inches (25 to 113 m/m). To allow a wide range of tests, two hammers are provided weighing 5 and 2 lb. (2.26 and 0.91 kilos) respectively. Using the 5-lb. hammer, the main spindle may be driven at any speed up to about 60 revolutions, or with the 2-lb. hammer up to about 90 revolutions per minute, giving 60 to 90 blows per minute respectively.

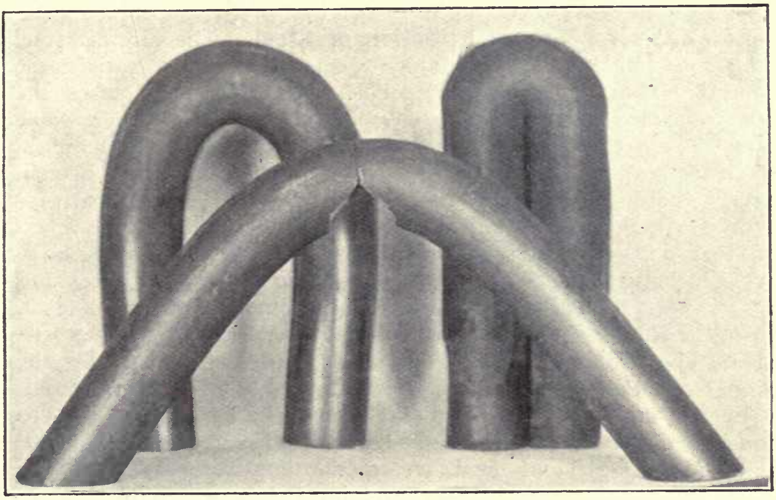

Fig. 20.
Results of Bend Tests.

23. Bending Tests.—Fig. 20 shows three bend tests, the front specimen broke at an angle of 90 degrees, the specimen on the left bent over a radius equal to its own diameter to an angle of 180 degrees without showing signs of fracture. This is the test usually expected of aircraft material with a tensile stress up to sixty tons per square inch. In commercial work the test is discontinued at this point; but, for experimental purposes, it is usually continued until the specimen either fractures or bends double as shown on the right.

CHAPTER III

DEFECTS IN STEEL

24. Basis for Proper Selection of Steel.—The aircraft steel maker is called upon to produce steels which must satisfy the conditions of very stringent specifications. In some cases the conditions are comparatively easy to attain, whilst in others some of the tests required are very difficult to accomplish, the material requiring expert manipulation during the manufacture. Considering that these steels possess widely different mechanical properties, it is a very difficult problem to decide which class of steel is the most suitable for a given part. It is possible, however, to learn a great deal of their relative properties by making a series of practical heat treatment and simple mechanical tests. The knowledge, gained by conducting such a series of experiments upon some of the various steels, provides a basis for the proper selection of the material best adapted for a given purpose.

Before attempting experimental investigation, it is well to consider the preliminary methods that should be recognized. First, a standard series of heat treatment temperatures should be adopted for each class of steel containing the same special element. By applying the same treatment it is possible to ascertain the effect of varying amounts of the special element. The process of heating and cooling the samples should be performed under conditions similar to those occurring in actual practice.

25. Workshop Difficulties.—The field of investigation of the manufacture and treatment of special steels is by no means exhausted. Although steels of dissimilar chemical composition are able, by judicious treatment, to attain the same standard of efficiency in the finished parts, some steels are liable to a larger percentage of waste during manufacture. And, in order to minimize the risk of the material being faulty, it is necessary to bestow greater care in the forging, annealing and heat treatment which consequently increases the cost. This increase in the cost of production does not materially benefit the steel user. From the aircraft constructor's point of view, the best steel to use, for a given purpose and high standard of efficiency, is the one that can be most easily obtained and replaced, and is easy to work and machine. Experiments, pursued on practical lines, often advantageously show that a less expensive steel will prove quite as suitable for a specific purpose as one of higher cost that was previously adopted. It is clear, however, that economy in the first cost of material is not to be recommended at the expense of efficiency.

Unfortunately, the present tendency of most investigators is to further develop the physical properties of special steels from a purely theoretical standpoint, and to leave the practical groundwork and shop difficulties unsolved. Although it is admitted that theoretical researches and developments are essential, yet, on the other hand, it is a matter for regret that more work has not been done with a view to finding new methods to help to alleviate the difficulties of the steel user. Many of these workshop difficulties have a simple origin, and, if understood, can be easily remedied in the initial stages.

It is proposed briefly to consider these difficulties, and see which of them are due to original defects in the raw material. For this purpose it is necessary to have a good knowledge of the defects that may be possible in steel bars, as delivered from the steel maker to the aircraft manufacturer; otherwise operations may be commenced and a lot of needless and expensive machining work done before it is realized that work is being spent on faulty material.

FIG. 21.

" PIPE " IN NICKEL STEEL INGOT.

26. Elimination of Sulphur and Phosphorus.—The steel maker is now thoroughly able to control the chemical composition of his material, so that cases of failure due to the injurious effects of chemical impurities are now rarely met with. Sulphur and phosphorus are fully recognized by the steel maker as harmful ingredients, which are introduced into the steel from the raw material. Therefore special attention is usually paid in the selection of the basis material with a view to keeping the amount of these elements as low as possible. They are usually present in such small quantities that their influence on the physical properties may be almost entirely disregarded.

27. Occluded Gases.—During the process of manufacture, the introduction of some gases, which exert an injurious effect on the steel, is not very easily stopped. All steels contain gases held in solution, which are known as *" occluded gases."* Some of these gases, the chief of which is nitrogen, exert a far more harmful effect than is generally recognized. The action of nitrogen, if present in a high percentage, is extremely injurious. The material then possesses characteristic properties of general unsoundness. It cracks and breaks up during hot working. Even if the nitrogen is present in only small quantities in a steel, the material is liable to suffer in consequence, and exhibits a marked tendency towards brittleness. The exact influence of nitrogen on the physical properties is not yet thoroughly established, but it is generally considered that the tensile strength increases with the proportion of nitrogen, whilst the ductility falls. If the percentage reaches 0.037 the ductility almost entirely disappears. On an average the material will only give about 0.5 per cent. elongation. If, however, such a percentage is met with in actual practice, it is not altogether safe to conclude that the material is valueless, because to some extent the deleterious influence depends upon the form in which the nitrogen exists in the steel. Some typical cases may be cited where a steel containing 0.025 per cent. of nitrogen has given fairly good results in elongation. It is important, when the nitrogen content reaches the critical limit, carefully to test for brittleness before use is actually made of the material.

FIG. 22.
" PIPE " IN NICKEL STEEL INGOT.

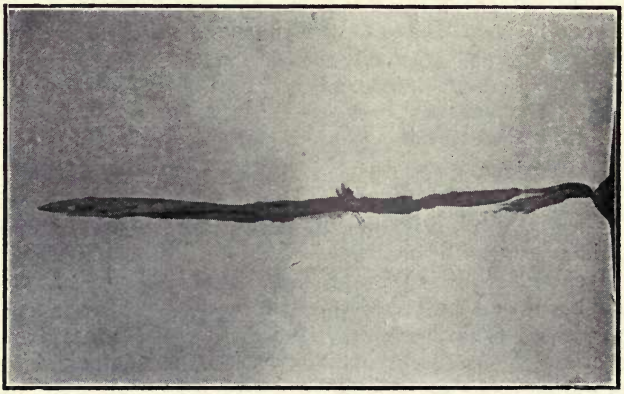

FIG. 23.
" PIPE " IN JOURNAL OF AERO CRANK-SHAFT.

In the case of hardened steels the deleterious effect of the nitrogen is considerably increased. Special steels are particularly liable to its injurious influence, and should, consequently, be freed from the element in the melting furnace.

Ferro-silicon is the chief cause of the occurrence of nitrogen in steel. During the melting process the additions of this compound to the molten metal should be made with extreme care. At steel melting temperatures, the nitrogen present in the ferro-silicon reacts on the silicon, and, unless the additions are carefully made, the nitrogen enters into solution with the iron. The use of vanadium is the safest means of eliminating nitrogen. At high temperatures the vanadium combines with the nitrogen, and thus frees the metal from the influence of this deleterious gas. Steel made by the crucible process is far superior to that made by other methods, for the simple reason that it contains very little occluded nitrogen.

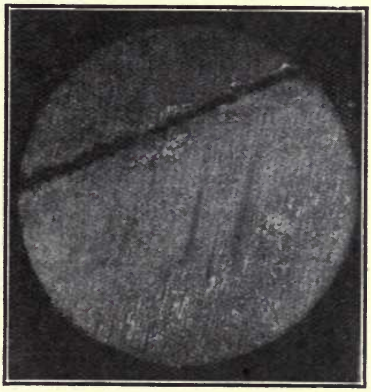

FIG. 24.

MICROPHOTOGRAPH OF "PIPE" IN TENSILE TEST-PIECE.

28. Elimination of Defects in Steel Ingots: Piping, Blowholes, Roaks, Laps.—Steel ingots always contain certain defects, which must be eliminated during the subsequent manufacturing processes. All these defects are under the control of the steel maker. By skilled manipulation, during the working-up processes, they can be entirely eliminated, so that, finally, it is possible to produce a thoroughly homogeneous material. The steel user should understand these preliminary defects in order that he may recognize them in a material, in which they may be present, before he commences to use it. It sometimes happens that they unavoidably escape detection during forging and rolling, and that, consequently, during the final stages of manufacture of the steel parts considerable annoyance is caused.

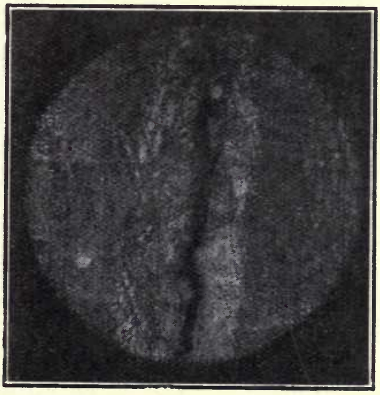

FIG. 25.

MICROPHOTOGRAPH OF "PIPE" IN TENSILE TEST-PIECE.

Although modern methods of steel manufacture have reduced the percentage of waste due to *piping* in the ingot to a minimum, all ingots, as cast, contain a certain amount of pipe. It is the usual practice of the steel maker to discard a certain percentage of material from the top end of the ingot in order to ensure that the metal is free from this defect. The pipe is caused by shrinkage during the solidification of the molten metal. Figs. 21 to 25 illustrate the appearance of pipe in steel. Fig. 21 shows piping in a 14-inch 5 per cent. nickel steel ingot. The appearance of its fractured surface shows that the ingot was cast at the correct temperature. Fig. 22 shows the fractured surface of a similar ingot; but, in this case, the temperature of casting was much too high. It will be noticed that, in addition to the piping, *blow-holes* are present to a fairly considerable extent, and, moreover, the growth of crystallization is very apparent from the outer edge. Fig. 23 shows the appearance of piping in an aero-engine crankshaft journal. This shaft failed in service. Figs. 24 and 25 are transverse and longitudinal sections respectively through the pipe found in a tensile test-piece of nickel-chrome steel.

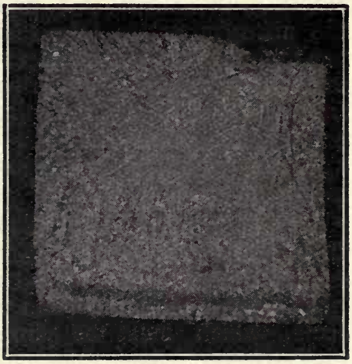

FIG. 26.
FRACTURE OF STEEL BAR SHOWING SEGREGATED CENTRE.

Immediately below the piped area there is always a certain amount of segregation which is quite as objectionable as the pipe itself. The fracture of a steel bar which exhibits a hard centre is a characteristic example, showing the result of rolling down an ingot containing an appreciable amount of segregation in the region immediately below the pipe. One of the contributory causes of segregation is the charcoal used for keeping the top of the ingot hot. It settles into the ingot and highly carbonizes the top portion. It is important that the top of the ingot should be cut off well below this unsound area. The remaining portion will then, practically speaking, be chemically homogeneous. Fig. 26 shows the appearance of a fractured steel bar with a segregated centre.

FIG. 27.
BLOW-HOLES IN NICKEL STEEL INGOT.

In present-day practice, blow-holes are not met with to any considerable extent in steel parts, but they are sometimes present in cast iron parts, such as cast iron cylinders or piston rings. In the case of small castings it is a very difficult matter to get rid of blow-holes, but in the manufacture of aircraft steels they are easily remedied during manufacture by thoroughly cogging and welding the ingots. Fig. 27 shows the appearance of blow-holes in the top half of a nickel steel ingot. To close up effectively these blow-holes, the honeycombed ingot should be heated to a wash welding temperature—say about 1,100 degrees C.—and well soaked until a uniform heat is attained. The heat should be sufficient to melt the scale on the surface. A flux composed of sal ammoniac and borax is generally used. This helps to clean off the surface scale, and prevents the oxidation of the internal walls of the blow-holes. It is important to keep a reducing atmosphere in the furnace during the heating operation, otherwise the walls of the cavities will be oxidized, and will consequently fail to weld up.

In the subsequent rolling of the cogged bars the oxidized subterraneous blow-holes simply extend with the rolling, and appear on the surface of the rolled bars as *roaks,* and penetrate the bars radially to the depth of the drawn out blow-hole. To some extent these defects can be overcome by chipping the surface of the cogged bars. When chipping is done, the bar should be nicely shallowed out, and not, as is sometimes the case, be cut too deeply. The evil caused by deep chipping is quite as bad as the original defect of the bar.

Fig. 28.
Microphotograph of Roak on Round Steel Bar.

The appearance of roaks on the surface of the rolled bars is one of the causes of cracking during the hardening operation. If the surface of the rolled bar is machined off before hardening, the presence of roaks may be practically ignored, as the removal of the skin removes the defect. However, in the case of aircraft steels there always remains the liability of cracks, because most of the steels are treated in the bar without machining off the outer surface. Fig. 28 shows a microphotograph of a roak in a round steel bar.

Laps are another form of surface defect that may cause trouble in the hardening operation. They originate in the rolling mill, and are due to the turning over and rolling in of fash. Round bars are more liable to this defect than those of any other section. The particular part of the rolling operation where the fault is likely to occur is when the bar is passed from the diamond to the oval shape. On close examination it will be seen that laps differ in appearance from roaks. They run obliquely into the

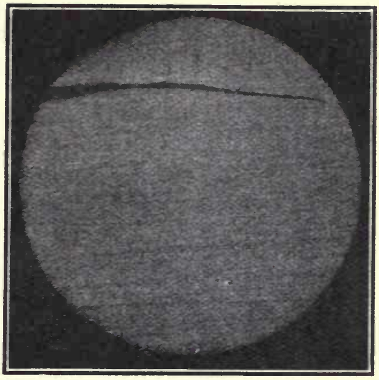

Fig. 29.
Microphotograph showing Lap in Round Steel Bar.

bar, and are always laid over. If examined under a powerful hand lens they will be seen to enclose a layer of scale in the envelope, formed by the laid over portion. Fig. 29 shows the appearance of a lap on the top edge of a round bar of nickel-chrome steel.

The presence of any of the foregoing defects renders the material liable to failure in the hands of the steel user. Therefore it is advisable for the user to examine thoroughly his material for the presence of any of these original causes of unsoundness before he commences to use it.

CHAPTER IV

THERMAL AND MECHANICAL TREATMENT OF STEEL

29. Heating Processes.—The steel, having been cast into ingots, is forged in billets of suitable dimensions. The billets are either drop stamped, or they may be rolled into bars of suitable section for machining purposes. After drop forging or rolling, it is necessary that the material should be either normalized or annealed. The various parts are then machined, and afterwards hardened and subsequently tempered, to suit the particular requirements of the duties they may have to perform. Therefore, after the steel has been cast into ingots, there are four or five heating processes to consider before the material of which the part is made is in a suitable physical condition to be assembled into the machine.

These processes are as follows :

1st. Heating for Forging.
2nd. ,, ,, Normalizing.
3rd. ,, ,, Annealing.
4th. ,, ,, Hardening.
5th. ,, ,, Tempering.

30. Forging Operations.—The close relationship existing between the final physical properties of a steel and its thermal and mechanical treatment, should be clearly understood. Forging or rolling is not only necessary for working the material into the required shape, but at the same time these processes change the structure of the material into one of more uniform grain. A comparison of Figs. 30 and 31 shows the refinement in the structure of a 0.30 carbon steel due to the closing up of the crystals by forging. Fig. 30 illustrates the microstructure, under a magnification of 200 diams., of a section cut from a 7-inch square forging, whilst Fig. 31 represents the microstructure after reducing a portion of this same forging down to 7-8th of an inch square.

The physical tests corresponding to these micro-photographs are :

	Y.S.*	M.S.*	E.*	R.A.*	Izod Impact.
7 in. square.	22 56	36.92	30.0%	55%	6
$\frac{7}{8}$ in. square.	31.20	40.80	28.5%	60%	71

The uniformity of the resulting structure of the material depends not only upon the uniformity of the heating to which it is subjected prior to its being forged, but also upon the actual temperature of the steel while it is being formed into shape. Uniform heating is of far greater consequence than a variation of a few degrees from the scientifically correct temperature. The heating should be carried out with due consideration to the chemical composition, the initial size of the material, and the amount of work that has to be done on it before it is reduced to the required shape. It is essential, when reheating metals, to have in the furnace an atmosphere slightly reducing in character. This condition is produced by restricting the air supply to the furnace.

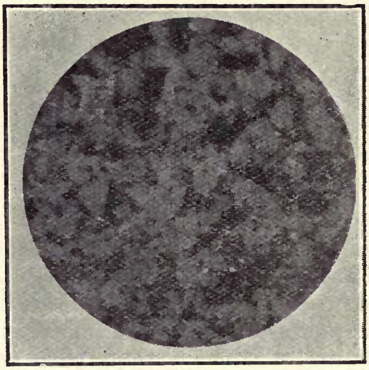

Fig. 30.
7 inch square .30 Carbon Steel in Forged State.

The proper temperature to which steel should be heated must be determined beforehand. To do this it is necessary to have a special set of apparatus known as the Pyrometer Recalescence Outfit.

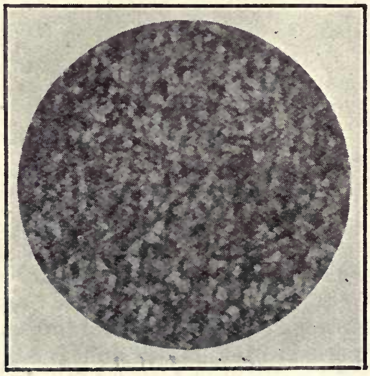

Fig. 31.
Microphotograph of 7-8th inch square .30 Carbon Steel in Forged State.

The physical effects that occur during the heating up of a piece of steel require consideration. This is best understood by means of the Diagram shown in Fig. 32. If the steel is heated up in a furnace, or muffle, in a uniform way, at the rate, say, of one degree per second, there will occur in the region of 730 degrees C. a period of so many seconds, during which, although the furnace is getting hotter, the temperature of the steel lags, or does not rise

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* Y.S. = Yield Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq. in.; E. = Elongation; R.A. = Reduction of Area.

at all. After this period of lag has elapsed, the temperature of the steel begins to rise again regularly. The procedure may be clearly followed by means of the Diagram. Take the line A, C, M, the lag is indicated by the kink at C. When the metal is cooled slowly the reverse phenomenon takes place. The cooling proceeds at first normally, until a point is reached at a temperature of about 690 degrees C. Then, again, there is a period of seconds during which the steel does not cool at all; it even may, during this period, get hotter, although all the time the furnace is actually cooling. The cooling process is a reversal of the changes observed in heating. These changes are indicated on the Diagram by the line M, R, B, with the kink at R. The point R is of equal importance to the point C. It is only when a piece of steel is heated above the change point C that it will harden on quenching. The point on cooling usually occurs at 40 degrees to 60 degrees C. below that observed on heating.

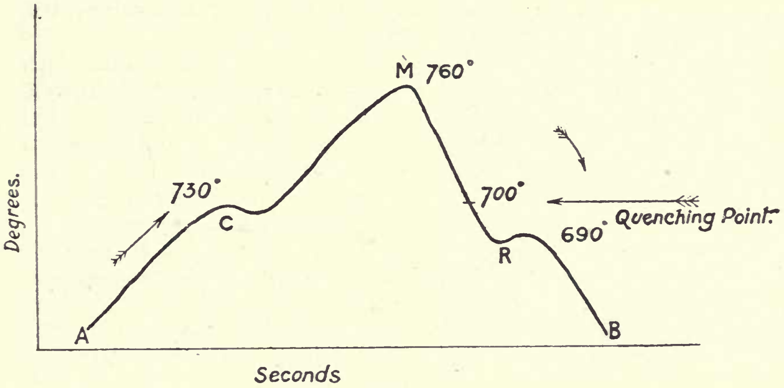

FIG. 32.

DIAGRAM SHOWING HEATING AND COOLING POINTS OF STEEL.

The exact temperature, at which the critical change points occur, depends upon the chemical composition of the steel. Generally speaking, the special elements, which are introduced into aircraft steels, have a tendency to lower their position. These change points have a direct relation to the physical changes which it is desired to obtain in the material after treatment. Unless the heating is extended above the point C, no change will take place in the structure of the material.

31. The "Burning" of Steel.—In the forging operation the steel should be heated to a temperature well above the point C, say about 200 degrees to 250 degrees above it; but, on no account must the temperature of the steel be allowed to extend beyond this, otherwise there is a great liability of burning the metal. If the metal is burnt it will become extremely "red short," i.e., it crumbles or cracks on the edges under mechanical pressure. A metal that has been burnt, through careless heating, is useless for any purpose whatever; it cannot be brought back to the normal condition by any means. It should be scrapped and remelted.

Steel is burnt by being heated to a temperature nearly approaching the melting point. The burning is caused by the evolution of the occluded gases. The atmospheric oxygen fills up the pores previously occupied by these gases, and, at the same time, combines with some of the carbon of the steel. The crystals, or grains, are oxidized, and are, therefore, mechanically separated by a layer of iron oxide. This explains the extreme brittleness possessed by steel in this condition.

To illustrate this point practically, an attempt could be made to weld, without the use of a suitable flux, two pieces of steel which have been heated in an oxidizing atmosphere. It will be evident before the experiment has proceeded very far that the task is a hopeless one, for no amount of hammering, or squeezing, will cause the adjacent surfaces to cohere.

The case of burnt steel is similar. The oxidized crystals lack the power of cohesion, and all subsequent hammering fails to weld together adjacent crystals. Hence the impossibility of restoring burnt steel. After the critical point is reached, each increment of heat corresponds to an increased coarsening of the grain. The final structure depends upon the maximum temperature, and the method of cooling. If a steel is forged from a high temperature, the action of the working breaks up all crystallization; if the work is finished near the critical point the steel will possess a comparatively fine structure. On the other hand if a steel is allowed to cool undisturbedly (i.e., without any mechanical working), from a temperature greatly exceeding the critical point, the resulting structure will be coarse.

Overheating may be caused by soaking the steel too long in the furnace, even though the temperature may be but slightly above the critical point. The coarsening effect will be greatly intensified if the soaking is followed by slow cooling, as in annealing.

Taking into consideration the size of the ingot and the size of the finished bar, the heating should be arranged so that the finishing temperature is just slightly above the critical point, *i.e.,* from 680 degrees to 750 degrees C., according to the chemical composition of the material.

It must be admitted, however, that these instructions present certain difficulties, because it is obvious that, in the case of large objects, if the finishing temperature is such that the outside temperature of the object is just slightly above the critical point, the temperature of the interior will exceed this point. During the slow and undisturbed cooling to atmospheric temperature, the structure of the interior will, therefore, coarsen. If, on the other hand, the finishing temperature of the interior is near the critical point, the outside will be below the point. And if working be carried too far, the outside portion will be structurally distorted, and will consequently suffer. The effect of uneven heating in a round bar of nickel-chrome steel is illustrated in Fig. 33. In the rolling operation the billet was not heated *right through,* with the result that there was a *" crushed centre,"* which is clearly visible in the illustration.

It sometimes happens that one end of the object attains its heat much quicker than the other. This difficulty can, generally, be overcome by turning the object round in the furnace. Good results cannot be secured by commencing the work when one end of the object is visibly hotter than the other. If the work cannot be done in one heat without causing the finishing to be done at too low a temperature, the metal should be partly reduced in size, and then returned to the furnace to be reheated before finally finishing. The second reheating temperature should not be as high as the first. It should be understood that steel deteriorates with too frequent heatings; therefore the number of heatings should be minimized. The metal should be reduced in size as much as possible during each heat.

As can be expected, the structure of a hot-worked steel depends upon the initial temperature and the finishing temperature. If the finishing temperature is but slightly above the critical point C, the structure will be comparatively fine; but if mechanical work is discontinued at a temperature greatly exceeding the critical point, then the structure will be relatively coarse. It is evident that, through forging alone, it is impossible to impart an absolutely uniform structure to steel objects of large cross section. The lack of uniformity in the structure of the material requires that it should be normalized or annealed before it is sent forward for machining operations.

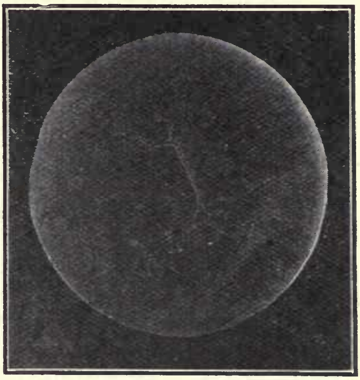

FIG. 33.
CRUSHED CENTRE IN ROUND NICKEL CHROME STEEL BAR.

32. Annealing.—The purpose of annealing is to remove all the internal stresses that have been induced by mechanical work, and also, at the same time, to change the heterogeneous structure into one possessing a uniformly fine grain. Annealing minimizes the liability of distortion in the hardening operation, for, when heated, the steel is then able to expand more easily. After annealing the metal possesses the maximum softness and ductility, and is in the best possible state for machining. The annealing operation consists essentially of three stages, viz., heating up, soaking and cooling. For a given steel it is desirable always to anneal at the lowest possible temperature. It is necessary to heat just above the critical point C (Fig. 32), and to keep the object, as near as possible, at that temperature throughout the process.

To ensure the refinement of the grain, the object should be kept at a constant annealing temperature until the desired structural changes have taken place in the steel. To bring about the desired effect the temperature should be maintained 1 to 4 hours according to the bulk of the object. On the other hand, the metal should not be kept at the maximum temperature any longer than is necessary for the heat to get right through it. Maintaining it, for a long time, at the temperature defeats the purpose of annealing by causing a coarsening of the grain.

33. Normalizing.—"*Normalizing*" a metal means heating it to a temperature exceeding the upper critical point C (Fig. 32), and allowing it to cool freely in air. The temperature should be maintained for about fifteen minutes, and should not exceed the point C by more than fifty degrees centigrade.

Normalizing an aeroplane fitting will improve its condition

(*a*) By refining the structure of the steel after it has been heated to a high temperature, as in forging, stamping, welding or brazing.

(*b*) By releasing the stresses left by cold working, as brought about by forging at too low a temperature, bending, pressing, etc.

(*c*) By releasing the stresses left by local heating or uneven cooling.

The parts to be normalized should be left in the furnace long enough to ensure that they have attained a uniform heat throughout. They should then be removed from the furnace and allowed to cool freely in the air. The effect of normalizing may be judged from the microphotographs shown in Figs. 34 and 35. These correspond to the same material after normalizing from 900 degrees C. as the microphotographs taken from the 7-inch and 7-8-inch square respectively, shown in Figs. 30 and 31. The physical tests corresponding to these microphotographs are:

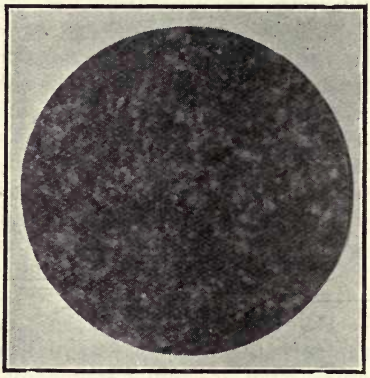

Fig. 34.
Microphotograph of Section cut from 7 inch Forging .30 Carbon Steel after Normalizing. Mag. 200 Diams. and Reduced.

	Y.S.*	M.S.*	E.*	R.A.*	Izod Impact
7 in. square.	23	38	31%	52%	12
⅞ in. square.	28	39	34%	60%	80

34. Hardening.—"*Hardening*" a steel means heating the material to its normalizing temperature and cooling rapidly in a suitable medium, *i.e.*, either water or oil.

The defects that appear in the material during the process of hardening, unfortunately, are numerous. Although we can trace the origin of most of these defects, it is sometimes a very difficult matter to determine, with certainty, what is really the main cause

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* Y.S. = Yield Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq. in.; E. = Elongation; R.A. = Reduction of Area.

contributing to a particular failure. However, since most of the difficulties met with are now understood, it only requires forethought in order to adopt preventive measures to counteract them. It does not necessarily follow that all cases of failure are due to bad material. Failure may arise through the use of unsuitable material; and, in quite a number of instances, it may be attributed to faulty design. For instance, sharp angular corners are always a source of danger in the hardening shop, and should, therefore, be avoided as much as possible.

The rate of heating and cooling influences the final physical properties of a material. Steel articles, that are subject to heat treatment, display some uncertainty in the uniformity of the results, which may be expected, after scientifically defining the treatment. Some objects possess thick and thin parts, consequently the thinner parts take the heat more rapidly than the bulky portions; and in the quenching operation they also lose their heat the quickest. This often accounts for a difference in the physical condition of different parts of the same article. Therefore it is obvious that each individual object should be studied with regard to its shape or volume in order to produce uniform results.

The chief difficulties met with in the hardening shop are distortion and cracking, both of which may be largely overcome by adopting proper methods of heating and cooling. Distortion is caused by uneven heating and careless quenching. It can be avoided by slowly heating to the required temperature, and soaking until a uniform heat is attained throughout the entire mass. During quenching, the object should be immersed in the bath vertically, in the direction of the main axis. If the object possesses thick and thin adjacent parts, the thick parts should strike the liquid first, so as to offer large surface contact with the cooling medium.

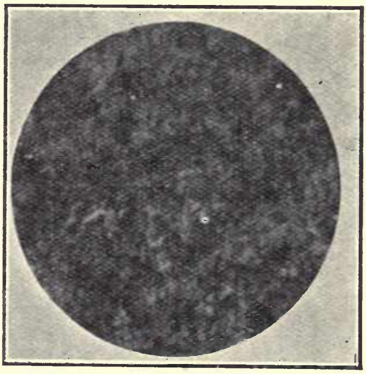

FIG. 35.
MICROPHOTOGRAPH OF SECTION CUT FROM 7-8TH INCH FORGING .30 CARBON STEEL AFTER NORMALIZING. MAG. 200 DIAMS AND REDUCED.

Provided that the material is free from original defects, cracks may be caused, during hardening, by uneven cooling in the cross section of the object. On quenching, the outside surface is transformed to the hardened state and, depending upon the thickness, the hardening influence gradually extends towards the centre, until the entire mass attains the temperature of the bath. If the object is withdrawn from the bath, before the centre is quite cold, there is a great liability of cracks forming. This is due to the contraction of the still warm centre, which exerts an enormous force on the outer surface, which, being in the hardened and brittle state, is unable to withstand the contractive force, and consequently fracture is caused.

Many misleading ideas are current with regard to the correct method of hardening steel. For instance, one branch of theorists advocate that the steel should be heated just through the critical range, and then cooled suddenly while the temperature is still rising. This method, they state, confers the finest possible structure on the material. Moreover, unfortunately, many practical steel-hardeners think that it is absolutely essential to quench the metal from the highest heat attained, and accordingly this method of procedure is the one largely followed in works practice. Herein lies the cause of a large percentage of hardening cracks. Let it be firmly impressed on the mind of the operator that *quenching should always be done on a falling heat,* otherwise the object is almost certain to crack in the bath. The falling heat permits the object to contract before it is put into the bath, and, in consequence, greatly reduces the risk of cracking and distortion. Once the material has been correctly heated to the hardening temperature, the heat may be allowed to fall considerably before quenching, without in the least affecting the hardness of the quenched object. The experiments given in Table II show, over a range of steels, that the temperature may be allowed to fall as much as 100 degrees C. without showing a material reduction in the hardness. The samples were heated to the maximum temperature shown, and then specimen No. 1 was quickly quenched out in oil, while

TABLE II

Table showing the Brinell Hardness Numbers obtained after Quenching from a Falling Temperature.

Type of Steel.	Quenched from ° C.					
	850	830	810	790	770	750
Ni.-Cr.	444	444	444	444	444	430
Do.	444	444	444	444	444	444
Do.	430	430	430	430	430	430
Do.	402	402	402	402	402	402
Do.	477	477	477	477	477	477
Do.	387	387	387	387	387	387
Do.	418	418	418	418	418	402
Cr.	340	340	332	340	340	340
Ni.-Va.	430	430	430	430	430	418
Cr.-Va.	600	600	600	600	600	555
	Quenched from ° C.					
	810	790	770	750	730	710
Ni.	444	444	444	444	418	418
Do.	512	512	512	512	512	512
Do.	340	332	340	332	332	332
Do.	248	248	248	248	248	248
Do.	460	460	460	460	460	444

the heat was still rising. The furnace was allowed to cool slowly, and the consequent specimens were quenched when the temperature had fallen to the required degree.

In works practice, the object should be slowly heated and soaked at the correct hardening temperature, and then allowed to cool, say 50 or 60 degrees in the furnace before it is finally quenched.

35. Tempering.—"*Tempering*" means heating the metal, after hardening, to a temperature not exceeding the critical point R. Tempering reduces the hardness, and increases the toughness, to a degree depending on the temperature used.

CHAPTER V

CASE-HARDENING

36. Importance of Case-Hardening.—Case-hardening is one of the most important heat-treatment operations. It affords the most satisfactory method of fulfilling the requirements of parts, such as camshafts, cams, gudgeon-pins, gears, etc., which must have an intensely hard surface to resist wear, and, at the same time, must be fairly tough and ductile to withstand shocks. A medium high-carbon steel, hardened in the ordinary way, can be made to possess the requisite hardness on the surface, and thus be capable of withstanding hard wear. But in this condition it will be too brittle to resist shock or excessive vibrations. If this same steel be tempered, with the object of making it tough, the hardness of the surface will be lowered, and the material will, consequently, be too soft for the purpose. If, on the other hand, a mild steel be heat-treated, it will perhaps possess the requisite toughness, but the surface will not be hard enough to resist wear. Parts requiring, as their ideal features, a good hard surface and a tough interior, should be submitted to the case-hardening process. By employing a material low in carbon, and heating it in contact with a suitable carburizing agent, and then, by subjecting it to a series of heatings and quenchings, the desired characteristics will be obtained, viz., a hardened high-carbon exterior, and a low-carbon toughened interior. The case-hardening process is divided into three separate stages, viz., the carburizing stage, the first quenching to refine the core, and the second quenching to refine the case.

37. Carburizing Compounds.—The carburizing operation may be carried out by either solid, liquid or gaseous "compounds." The substance by which carburization is effected must be such as easily gives up carbon. Carburizing substances can be divided into three classes: *firstly,* solids containing a large proportion of "fixed carbon," or in which the carbon is present as a gaseous hydrocarbon, or in a form from which gaseous hydrocarbon can be liberated; *secondly,* liquids such as molten cyanides; and *thirdly,* gaseous compounds such as carbon monoxide, hydrocarbons and cyanogen. For industrial purposes solid and liquid compounds are in general use.

A liquid bath of potassium cyanide can be used when a rapid rate of penetration is required, and the part to be case-hardened is only very thin in section. As liquids only give a superficial case, they are unsuitable for most classes of work. The molten cyanide rapidly deteriorates and loses its carburizing effect. Therefore it is necessary constantly to add new material to make up for the inertness of the old. Cyanide compounds are extremely dangerous to use, since the fumes given off by the molten bath constitute a deadly poisonous vapour. Hence, when these compounds are used, adequate provision should be made effectively to carry the fumes away from the operator. Fig. 36 shows an apparatus suitable for carrying out the carburizing process with molten cyanides.

38. Selecting a Carburizing Compound.—From the many solid compounds in use it is a difficult matter to select the one which is the most suitable for general purposes. A great deal is usually said by the makers of case-hardening compounds concerning the valuable properties possessed by their own particular brands, and of their inherent value over all other mixtures. The selection of a compound depends on the nature of the work to be handled. A mixture that is satisfactory for one class of work may be entirely unsuitable for another. On account of their high cost, shops dealing with a large quantity of work will not favour the use of those brands which are rich in volatile hydrocarbons. Although these compounds are very active when new, and give a quick penetration, they have only a comparatively short life, and are expensive in the initial cost. Moreover, when a good depth of case is desired an extremely active agent is unsuitable on account of its short life. The effectiveness of the carburizing agent is not altogether dependent on its speed of penetration: the most important factor is the amount of surface carbon that

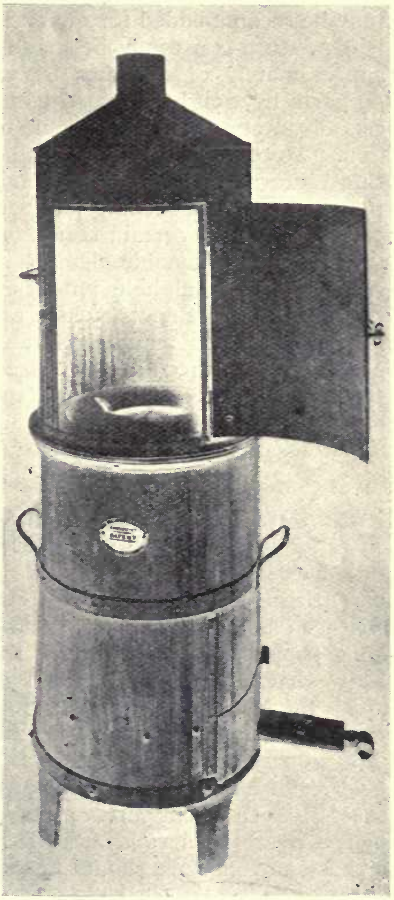

FIG. 36.

GAS FURNACE SUITABLE FOR HEATING MOLTEN CYANIDES.

will be absorbed from it by the steel. Wood charcoal is the chief constituent of carburizing mixtures which are used in ordinary work. If used alone, pure charcoal is not a very good carburizer; its rate of penetration is too slow for industrial purposes; and, moreover, it is not very effective at temperatures below 1,000 degrees C. If the casing operation were carried out at temperatures over 1,000 degrees C. it would result not only in a rapid deterioration of surface linings, pyrometers, etc., but it would also result in a deterioration of the steel being treated. However, when wood charcoal is mixed with some other elements, its effectiveness as a carburizer is considerably increased.

A variety of "compounds," with wood charcoal as an ingredient, can be produced that will suit all purposes. A mixture of wood charcoal and alkaline carbonates has found considerable favour for case-hardening purposes. A material sold as "*Hardenite*" may be recommended for general case-hardening work. An equivalent mixture can easily be made up on the spot. It is composed approximately of 40 parts by weight of barium carbonate, and 60 parts by weight of wood charcoal. It is inexpensive, and has the advantage of being capable of repeated use without deterioration. Moreover, it can easily be duplicated when necessary, so that uniform results can be obtained. It may here be mentioned that some case-hardening compounds contain an active amount of sulphur. Under certain conditions, during the carburizing operation, this objectionable element is diffused into the surface of the steel, forming sulphide patches. These sulphide inclusions are the origin of soft spots, which are often a great source of trouble in case-hardened work. Although, in some cases, the sulphide patches are removed in the subsequent grinding of the part, which relieves the ill effects of soft spots, their presence has also the tendency to start small cracks, which may extend into the object, and will not be removed by surface grinding.

39. Care required in packing parts to be Case-Hardened.— In order to obtain uniform results, the packing of the parts to be case-hardened must be done very carefully. A good layer of the carburizing compound should be placed in the bottom of the cast-iron box, and tightly rammed. For light parts the bottom layer should be about one inch thick; this should be increased for heavy articles so that they will not sink through the mixture and touch the bottom of the pot. It is extremely important to ensure that no two pieces should touch each other, or the sides of the box, at any point. The articles should be placed on the bottom layer, and allowance should be made for their own bulk of mixture between each part. A layer of casing mixture should be placed over the first layer of parts, and then alternate layers of articles and mixture should be continued until the box is filled to within about 1½ or 2 inches of the top. The cover of the box, which should fit inside, should be luted up with the wheelswarf or fire clay. This will prevent the gases from escaping out of the box.

Some articles are required to be left soft in places. This means that these places should be insulated from the carburizing gases. Several methods of insulation are in common use. The exact procedure depends largely on the nature of the part to be treated. The cheapest, and one of the most effective methods, is to cover the portions to be left soft with a thick paste made of sodium silicate and fine sand. This paste should be allowed to dry on the article before it is packed in the box. Another method, sometimes employed, is to cover the insulated portions with an electro deposit of copper. The copper has no affinity for carbon; consequently it prevents its passage into the steel. This method is, however, wasteful in time, and is too expensive for general use. A reliable method, and one which is largely adopted in industrial work, is to leave extra material on the portions which are to remain soft. After carburizing, the excess of material is machined, or ground off. The case is thus removed at the desired place, which will consequently remain soft after the final heat treatment.

40. Time and Temperature Factors in Carburizing Operations.—The two important factors in the carburizing operation are *time* and *temperature*. Both these are very difficult to determine in large furnaces. It is possible to vary regularly, and within fairly wide limits, the characteristic condition of the case by varying the time and temperature of the carburizing process. The specific carburizing effect exerted, by the compound used, on the steel at the carburizing temperature is due to a series of chemical reactions. The course and state of these reactions are controlled by the strict observance of definite temperatures. It is possible to obtain, with certainty, a predetermined result when using a casing compound whose activity is known. A carburized zone can be obtained in which the concentration of the carbon does not exceed a predetermined maximum limit, and varies in a well defined degree towards the centre of the zone.

The following considerations should be carefully noted, and applied to suit the conditions called for in the various parts. *The higher the carburizing temperature, the more rapid is the carbon penetration, and the higher the percentage of carbon in the case.* If the temperature is too high, the result will be a brittle casing which is liable to chip off when the part is in service. Moreover, a high carburizing temperature causes the core of the part to be overheated. The part will then be brittle and liable to failure under service shocks. To some extent, an overheated core may be remedied by using a higher refining temperature; in practice, however, there are objections to this procedure, because it is accompanied by a great liability to distortion.

For general work the safest temperature to use for carburization is 900 degrees to 950 degrees C. At about this temperature there is an active carburizing atmosphere in the box, and the steel itself is in a condition which will allow for a sufficiently rapid diffusion of the carbon to satisfy most conditions. By using this range of temperature there is no danger of injuring the core of the steel by overheating.

The depth of carbon penetration depends upon the length of time that the steel is held at the carburizing temperature. When using the same steel and casing mixture, experience will soon permit a definite estimation of the depth of penetration. *As a general rule, under normal circumstances, if the carburizing operation be carried on for five to six hours at* 950 *degrees C. it will give about* 1-16*th inch depth of case.*

41. Heat Treatment.—The final heat treatment of the carburized parts is the operation on which depends the ultimate success of the whole process. In order to obtain the best condition, both in the core and in the case, it is often a very difficult matter to devise the most favourable treatment. The difficulties which arise are due to the fact that, in the same object, two entirely different materials are present: the outer case which, for all purposes, can be considered as a high-carbon tool-steel, and the core as a mild steel. The desired purpose is to confer the best possible state of hardness on the case, and, at the same time, effectively to retain the maximum toughness in the core. To obtain either hardness or toughness alone is not a difficult matter; but to produce them together, in one single object, the greatest care must be exercised. Once the treatment for a given part has been determined, the specified temperatures should be strictly adhered to.

In order to obtain the two conditions, it is necessary that, after carburizing, the part should be subjected to a double treatment: one treatment to refine the structure of the core, and a second one to confer the necessary fineness to the structure of the case. The core of the carburized object is considerably coarsened by the long exposure at the carburizing temperature. In order to refine the structure with success, it is necessary to heat the articles to a temperature just slightly above the critical point of the uncarburized centre. When the core is heated above the critical point, an inter-diffusion of the structural constituents takes place, which destroys the pre-existing state of crystallization. To ensure the complete inter-diffusion of the constituents, the parts should be held long enough at the refining temperature to be heated right through at that temperature.

After imparting a fine structure to the core, the next process is to retain it. To accomplish this purpose, the object should be quenched in water or in oil. The quenching medium used depends upon the ultimate requirements of the part, and the nature of the material from which it is made. The finest structure is most effectively retained by water quenching, but, in certain types of work, this method is objectionable on account of the tendency of distortion in the part, and also of the great liability of the case splintering off in the quenching process. Therefore, although oil may be less effective for the desired purpose, it is frequently used in order to overcome the danger of mechanical defects. In the case of objects of even cross section, that is to say, if they do not possess sharp corners, or thick and thin adjacent parts, and are made from ordinary carbon case-hardening steel, water quenching will give the best results. Parts made from either nickel or nickel-chrome steel should, under no circumstance, be quenched in water, on account of the liability of these materials cracking if quenched too suddenly.

The heating and quenching that is applied to refine the core, at the same time confers hardness on the outer case, but, in a similar manner, as the core is coarsened by the high carburizing temperature, so is the case affected by the high temperature used to refine the core. Consequently, it is necessary to restore the overheated condition of the case, without materially affecting the toughness of the core. During the second re-heating, the maximum toughness of the core would be obtained by quenching from a temperature below the critical change point of the core, *i.e.,* somewhere in the region of 700 degrees C. Each increment of heat beyond this point results in a *decrease* in the toughness of the core. If the quenching be done from a temperature below the critical point of the case, no refinement of the structure will take place. Hence, it is necessary to sacrifice some toughness in the core, in order materially to gain a finer condition in the case. To refine the case satisfactorily, the object should be heated to a temperature just slightly above the critical point of the case, and then be quenched in water or in oil. If the parts are made from plain carbon steel, and are required to be glass-hard on the surface, the quenching must be done in water; but if a dead hard surface is not absolutely essential, and, if, moreover, the parts are to be worked under conditions where they are liable to shock, the quenching should be done in oil.

42. Selection of Material.—The selection of the material for case-hardening purposes is of considerable importance, if it be desired to obtain the best results with the finished parts, in actual service. No hard-and-fast rule can be set up regarding the class of steel best suited for a desired purpose. Many points have to be considered. For example, the size and shape of the part, and the nature of its subsequent application in service, influence the choice. Although, in most cases, it is desirable to obtain a fibrous fracture in the core, it does not necessarily follow that this condition is the best for all purposes. Too much attention is usually given to the supposed wonderful merits of a fibrous interior. If the essential object of case-hardening were simply to obtain a fibrous core, without any reference as to the ability of the core to support the outer case, then the best material to use for the purpose would be wrought iron, or steel exceptionally low in carbon. Either of these materials will display a fibrous fracture, even when quenched straight out from the casing box. However, the fibrous core in these materials is accompanied by extreme softness, and therefore, total inability to support the outer case under heavy crushing loads. It is obvious that such material should only be used for small parts, and, even then, these should not be expected to withstand heavy loading.

For general purposes the most satisfactory material to use, and one that will give reliable results, should possess about 0.15 per cent. carbon, 0.60 to 0.80 per cent. manganese, and the sulphur and phosphorus should preferably be not over 0.06 per cent. By careful treatment this material can be made to give a fibrous core, which, at the same time, possesses the requisite hardness to support the outer casing. The fibrous centre of the material is extremely tough, and will resist a high proportion of combined stresses. In parts where the outer casing has to withstand excessive loads, and a somewhat harder material is desirable, this can be obtained at the sacrifice of toughness by increasing the carbon content of the material up to 0.25 per cent. It is important that parts made from such material should only be used where they have to withstand heavy loads in compression; otherwise, owing to the comparative brittleness of the core, there is a grave risk of failure if employed in articles which are subject to bending, shock or torsional stresses.

If it be desired to obtain a greater toughness and higher tensile strength, a nickel steel must, and should, be used. A nickel steel recommended for case-hardening purposes contains 0.15 per cent. to 0.20 per cent. carbon and $2\frac{1}{2}$ per. cent. to 3 per cent. nickel. This material, when properly treated, will resist higher shock stresses, and will have a much higher tensile strength than it is possible to obtain from a plain carbon steel.

CHAPTER VI

EQUIPMENT USED IN THE HEAT TREATMENT OF METALS

43. Lay-out of Heat Treatment Plant.—The production of correctly-treated materials by the quickest method, and in the cheapest manner, is one of the problems which confront manufacturing engineers and steel makers. In order satisfactorily to solve it, the possession of a properly-designed and well-organized Heat Treatment Plant is essential.

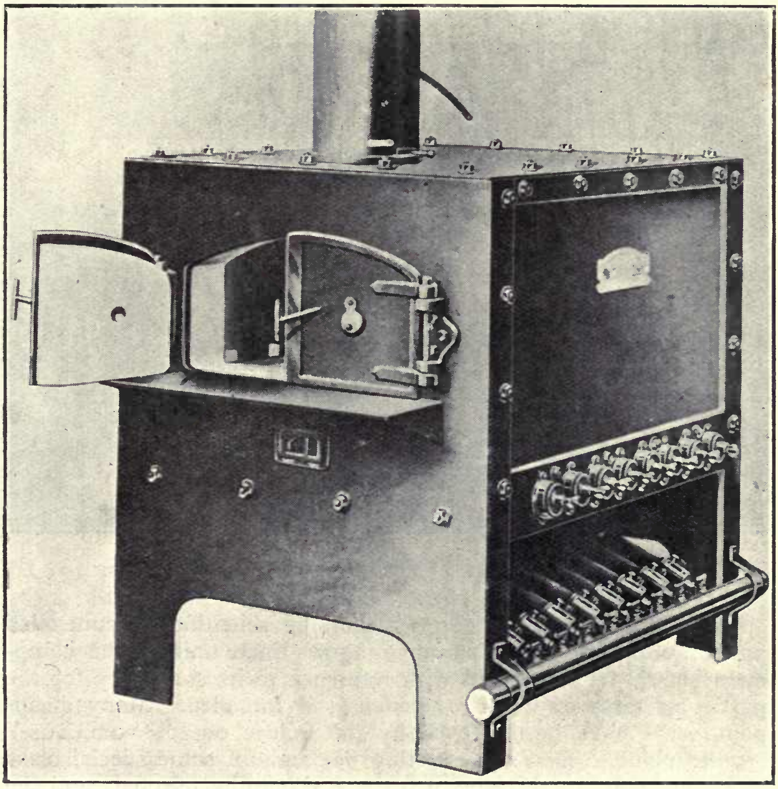

FIG. 37.
NATURAL DRAUGHT OVEN FURNACE.

The minor details influencing the lay-out of the plant must, necessarily, depend on the particular class of work with which it is designed to deal. The general principles underlying the planning are, however, practically the same in all cases. If the installation of a new plant is being contemplated, every feature of the equipment should be carefully considered with regard to the initial cost as related to the estimated out-put. The Heat Treatment Department, like the other sections of an engineering works, should, in the methods of operation, be scientifically controlled and organized to the best advantage. Each unit of the equipment should be considered with reference to its suitability for the particular class of work for which it is intended. Many disappointments have been caused by the failure of an "omnibus" type of plant to meet the exacting demands of some special class of work. The proper type of furnace should be selected; and the selected furnaces, along with the quenching tanks, should be placed in positions which would minimize the handling of the

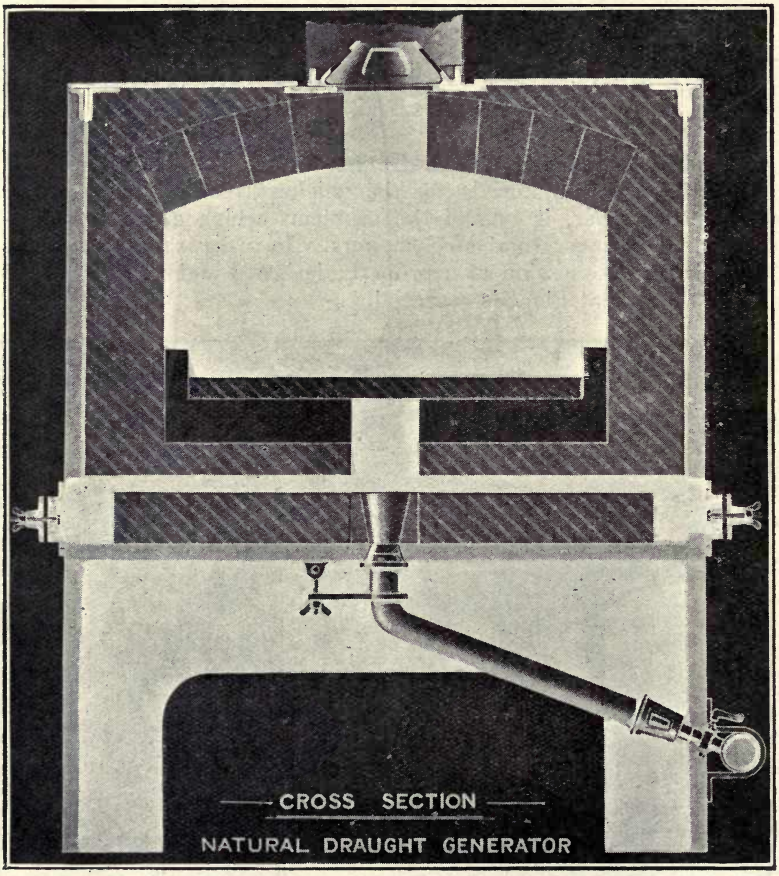

Fig. 38.

work. Unless proper facilities are provided with this end in view, much valuable time will be lost which could, otherwise, be profitably utilized.

44. Furnaces: Muffle and Oven Types.—Of the many different types of furnace available for the heat treatment of steel, the gas-heated furnace is, undoubtedly, the most suitable for work that calls for fine limits of exactitude in the finished product. In selecting a furnace, the most essential point to bear in mind is the capability of the furnace to attain a uniform heat throughout.

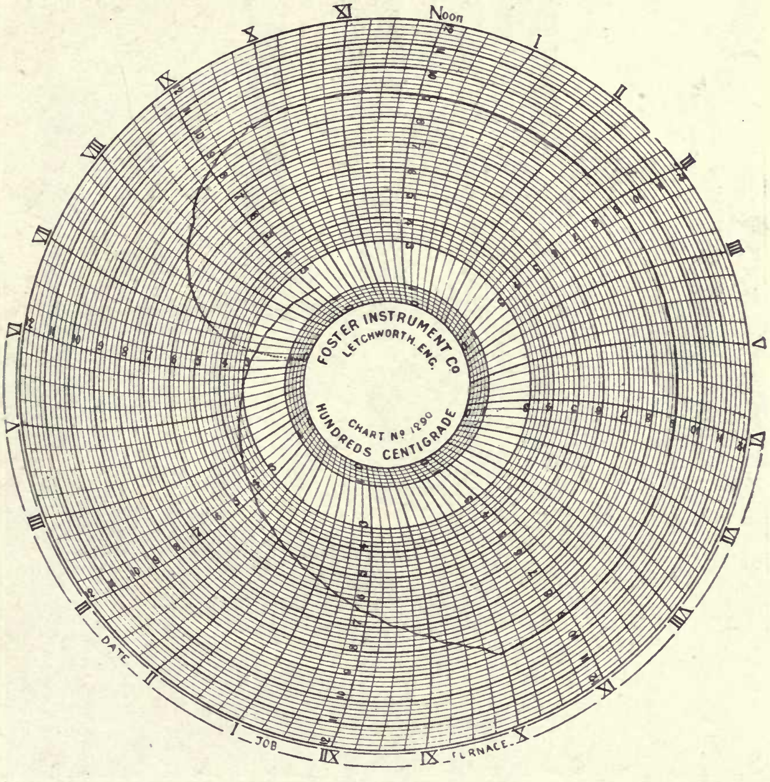

FIG. 39.
CHART SHOWING TEMPERATURE RECORD ON "RICHMOND" NATURAL DRAUGHT OVEN FURNACE.

The special features requiring consideration are: (1) whether the work must be slowly brought to the desired temperature, or heated quickly; and (2) whether it is essential that the products of combustion should not come in direct contact with the work.

Where it is desired to protect the work from the products of combustion, the muffle type of furnace should be adopted. In this type of furnace the heating flame encircles the muffle and is distributed evenly throughout the enclosed space. Muffle furnaces are fairly rapid in heating, and can be easily maintained at an even temperature. For industrial purposes, however, they are very expensive in up-keep, and do not, generally, warrant the extra working expenses over the other types of furnace. It is not usually necessary to prevent the products of combustion from coming in contact with the heated object. For general heat treatment work, therefore, the Oven Type is the most economical to use.

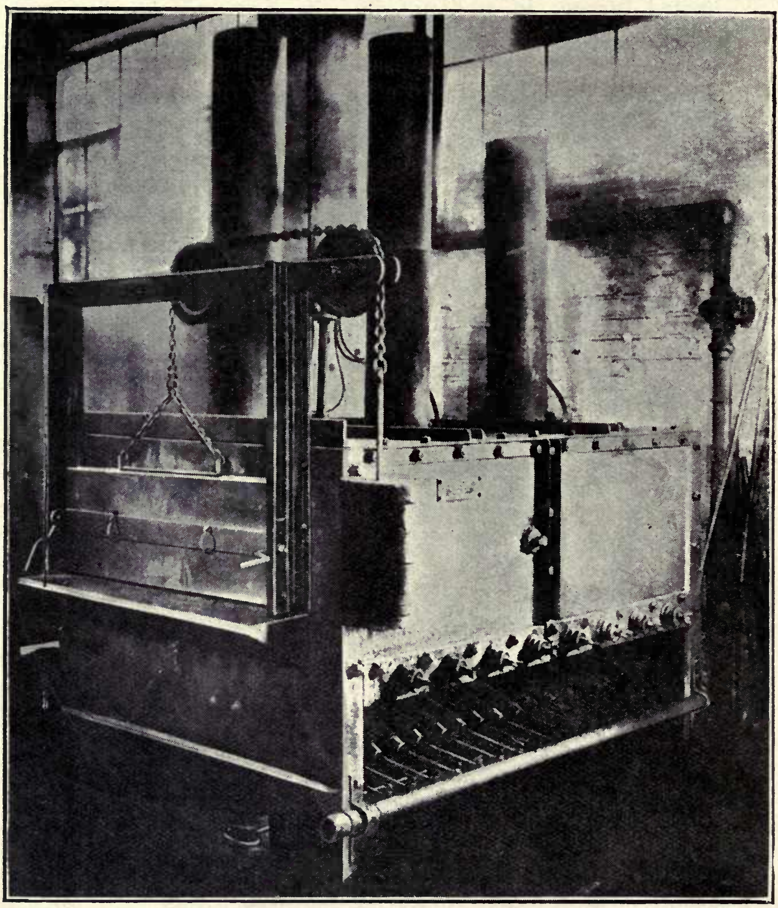

FIG. 40.
NATURAL DRAUGHT FURNACE FOR HEAT TREATING AIRCRAFT AND AUTOMOBILE PARTS.

45. Richmond Natural Draught Regenerative Oven Furnace. There are two types of oven furnace, both of which are capable of yielding excellent results. The Richmond Natural Draught Regenerative Oven Furnace is shown in Fig. 37, and, in cross-section, in Fig. 38. This furnace requires no air blast, or power; and, as regards gas consumption, can be worked more economically than the Gas and High-Pressure Air Blast Furnace. A reducing atmosphere can be obtained in the heating chamber, and this enables the metal to be heated without scaling. The temperature is easily controlled to the desired degree, and can be maintained for any length of time. Fig. 39 shows an actual heat record taken on a furnace of the type illustrated in Fig. 37. In this case, the temperature was maintained, without any appreciable variation, for a period of twelve hours. A regenerative furnace engaged on the treatment of aircraft parts is illustrated in Fig. 40.

46. Low Pressure Gas and Air Furnace.—A type of oven furnace, which is finding extended use, is the Low Pressure Gas and Air Furnace, made by the Richmond Gas Company. This furnace, which is shown in Fig. 41, and, in cross section, in Fig. 42, denotes a remarkable progress in furnace design. In principle, the gas enters the furnace from the gas main through a series of fire-brick tubes. Air, at a low pressure, comes into the furnace from the air main, and travels down the side and along the bottom of the furnace through tubes. The air, thus being pre-heated, meets the gas from the supply, and, on their meeting, combustion takes place. The pre-heating of the air ensures a hot flame, with the result that the furnace is economical in gas consumption. The gas flame passes along the underside of the furnace roof, and then the products of combustion pass through port holes, under the floor of the furnace, before finally entering the flues.

The gas and air supply is quite easy to control, and a smoky reducing flame can be maintained to a nicety. The Low Pressure Gas and Air Furnace is suitable for either high or low temperatures. It works quite efficiently at a temperature as low as 400 degrees C., whilst it can be made to attain a maximum temperature of 1,400 degrees C. in the heating chamber. It can, therefore, be used to harden high speed steel which demands about the highest temperatures required in heat treatment work. Fig. 43 illustrates a batch of Richmond L.P.G.A. furnaces installed for the treatment of aircraft parts.

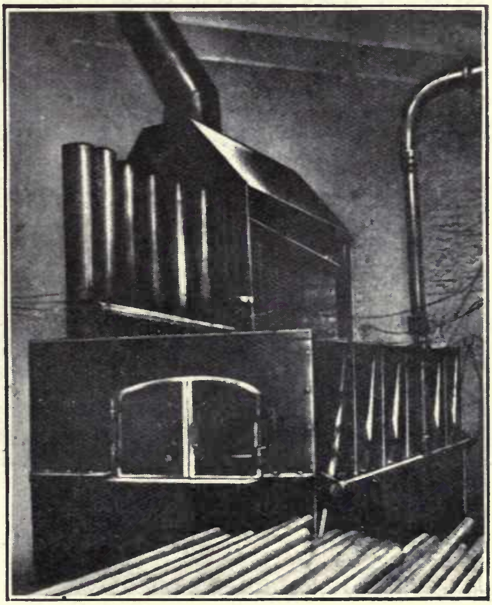

Fig. 41.

Large Low Pressure Gas and Air Furnace.

47. Salt Bath Furnaces.—For the hardening, or for the tempering, of small objects, in large quantities, salt bath furnaces are economical and efficient. Salts of suitable melting points should be selected for the range of temperatures over which the furnace is to be worked. It is desirable that the bath should become liquid at the lowest temperature, and that it should not appreciably evaporate at the highest temperature. The advantage of the salt bath is that it is easy to maintain at a given temperature. Each part of the work attains an even heat, and no portion can exceed the actual temperature of the bath. A thin coating, or film, of salt forms on the surface of the heated object, thus protecting it against oxidation while it is being transferred from the furnace to the quenching bath. The quenching liquid dissolves the film, leaving a clean untarnished surface on the steel.

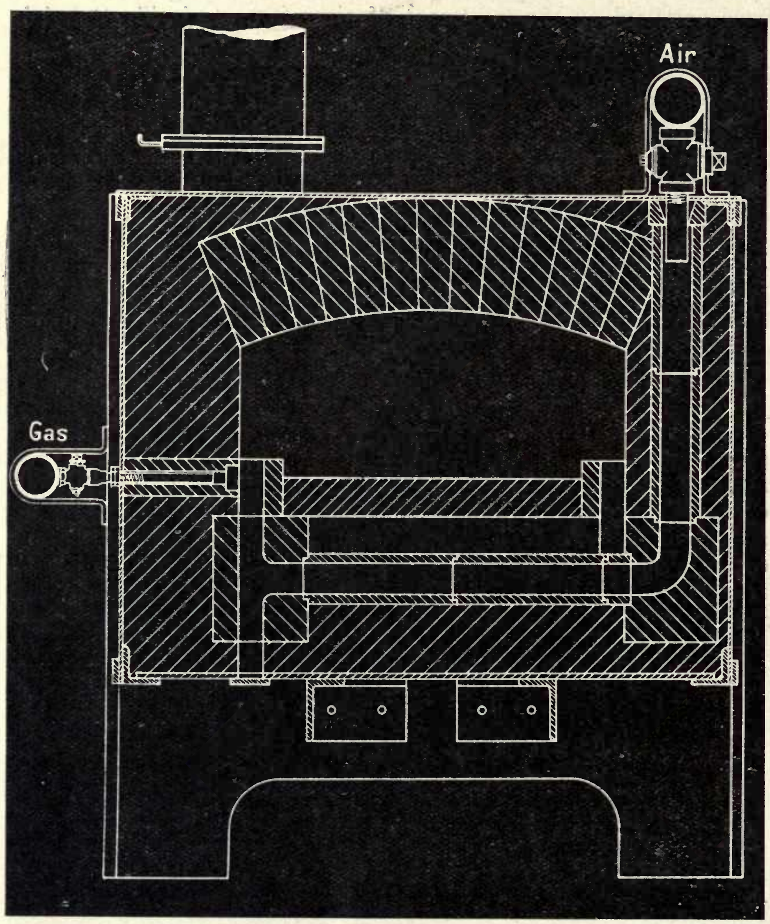

Fig. 42.

Cross Section of Low Pressure Gas and Air Furnace.

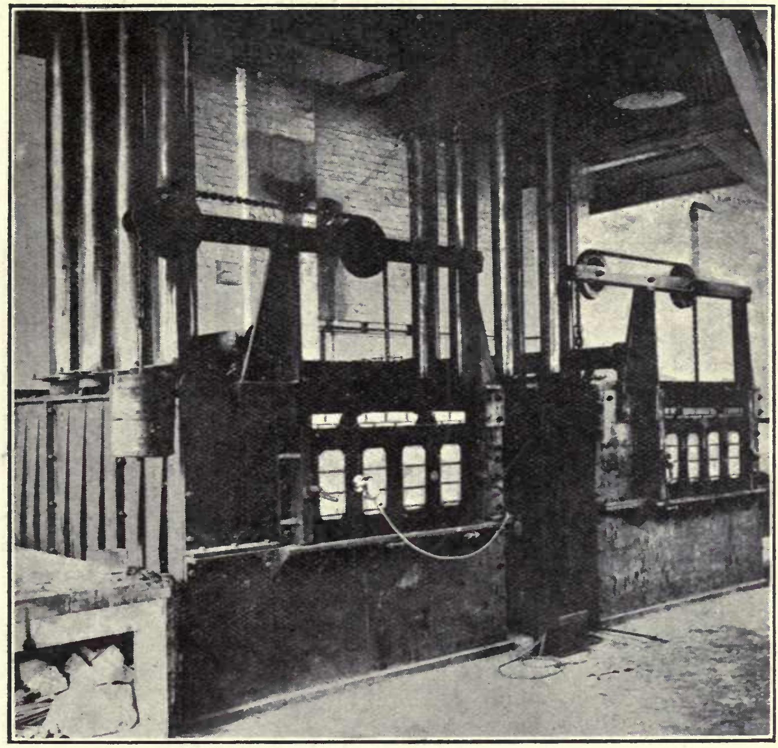

Fig. 43.
Low Pressure Gas and Air Furnace for Aircraft Engine Parts.

48. Oil Tempering Bath.—Some classes of work are best tempered in an oil bath, similar to that shown in Fig. 44. The parts to be tempered are submerged in the oil, in a wire basket, until the necessary temperature is attained. They are then withdrawn, and quenched in cold water, or allowed to cool in air, according to requirements.

49. Lead Bath Furnace.—A furnace, specially designed for annealing aeroplane stream-line wires, is shown in Fig. 45. In the annealing of stream-line wires it is essential to have absolutely uniform heating, so that no variation will occur in any part along the length of the wire. The furnace, shown in the illustration, is a long rectangular lead bath, the burners and flues of which are so arranged that it is quite an easy matter to maintain a uniform temperature throughout the whole of the bath.

50. Quenching Tanks and Quenching Media.—Proper facilities must be provided for quenching the work. It is not only important that quenching tanks should be properly designed, but also that they should be placed in the most convenient position, with a view to minimize unnecessary handling of the hot work. In some plants, where several furnaces are employed on small work, it is not deemed necessary to have a separate placed tank for each furnace, but this policy often causes inconvenience in the manipulation of the work. The difficulty may, to some extent, be overcome by having a tank on wheels, which may then be moved to any desired position. The size of the quenching tank depends upon the amount of work to be treated. It should have a sufficiently large capacity to accommodate the work without raising, to any great degree, the temperature of the quenching liquid.

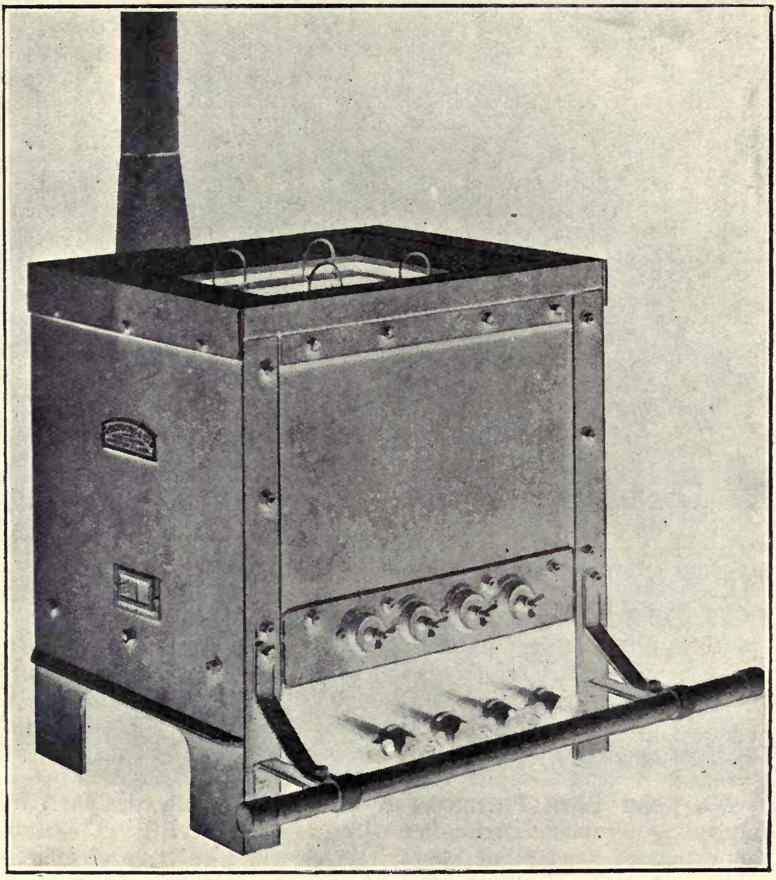

Fig. 44.
Oil Tempering Bath.

When water is used for quenching, the inlet should be at the bottom of the tank and the outlet near the top. An additional outlet should be provided at the bottom of the tank. This outlet is to serve only when it is desired to empty the tank for cleansing purposes.

The design of oil quenching tanks requires careful consideration. The installation of an efficient oil cooling arrangement, to meet the demands of some classes of work, is very often a difficult matter.

The essential point, in oil quenching, is to keep the bath at a uniform temperature and to ensure a constant circulation around it. To facilitate the uniform quenching, and also the subsequent handling of small objects, a sieve should be placed about half-way down in the bath.

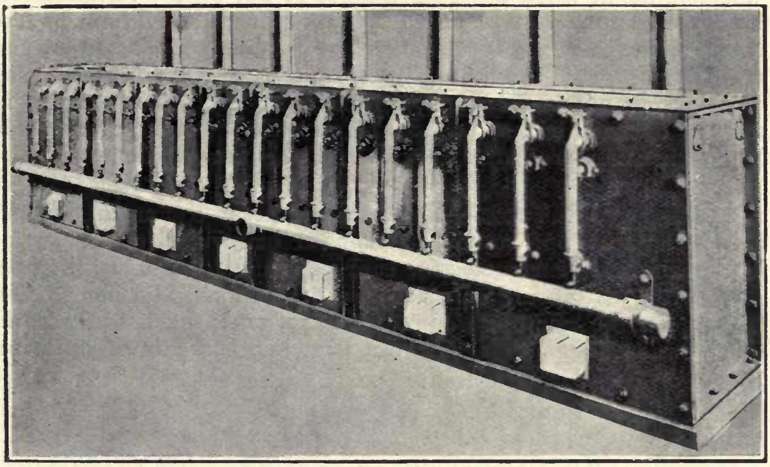

FIG. 45.
LEAD BATH FURNACE FOR ANNEALING AEROPLANE STREAM-LINE WIRES.

The selection of the quenching medium depends upon the nature of the work to be treated. The steels used in aircraft manufacture are invariably quenched in oil. The chief characteristics, which give to a quenching oil its value and efficiency, as a cooling medium, are its heat conductivity, viscosity, volatility, specific heat and flash-point. The conductivity and the viscosity of the fluid influence, to an important extent, the uniformity of the bath; and, the higher the volatility of the fluid, the higher is, in consequence, the temperature of the vapour bubbles formed around the hot quenched object. The specific heat should be as high as possible. Upon this property depends the number of heat units required to raise the temperature of a given quantity of the liquid, through a given number of degrees.

The oil quenching tank should, periodically, be cleaned out. After quenching a large quantity of material, a residue of scale and dirt collects at the bottom, which, if left there, would seriously affect the cleanness of the quenched work. In any case, the surface of the steel will be cleaner if a small quantity of sal ammoniac is put into the oil bath. To clean the oil off, the work, after hardening, should be rolled about in dry sawdust. In the case of small objects, the cleaning is better achieved by boiling them in a strong solution of water and ordinary common soda.

The heat-treatment equipment should include a number of boxes for case-hardening purposes. The actual case-hardening operation is not, in the least, affected by the material of which the boxes are made. They may be made either of cast, or of wrought, iron. Which of these two is actually the more economical is an open question. Cast-iron boxes are, initially, cheaper, but they do not last so long as those made from wrought iron. The life of a box, especially when it is made from cast-iron, depends a good deal upon the way it is handled. It should not be unduly knocked about when charging it into, or out of, the furnace. In any case, the material of which the box is made should not be too thick, as the thicker it is the longer it will take for the heat to penetrate through it. The boxes should not be too large, for then the work would not be uniformly carburized. For small articles, a number of small boxes can be used to better advantage than one large one: they are easier to pack, and save time in heating up.

51. Supply of Tools.—The heat-treatment equipment should also include a good supply of tools for manipulating the work. Tongs are best constructed for each particular size of work to be dealt with, and should be made to suit the man who has to use them. On the same job, some men can work much easier with one class of tongs than they can with another pair of different shape.

CHAPTER VII

CONTROL OF HEAT-TREATMENT TEMPERATURES

52. Importance of Pyrometer Records.—In all heat treatment processes the measuring, and regulating, of the temperatures used is a necessity. Pyrometers are designed for this purpose. They are as indispensable to heat treatment as a safety-valve is to a steam boiler. By their use, continuous reliable information is obtained which cannot be secured in any other way. Indicating pyrometers are useful to the workmen; but for operations lasting many hours, or several days, permanent automatic records are needed. Pyrometer records assist in reasoning out undue fluctuation in the quality of the finished product, and make the standardization of heat treatment in repetitive operations possible. Once the desirable relation of the time and heat factors has been determined for a given process, the pyrometer makes perfect duplication of the ideal process easy. It tells at any instant, from start to finish, whether the heat is above, or below, normal; and to what extent.

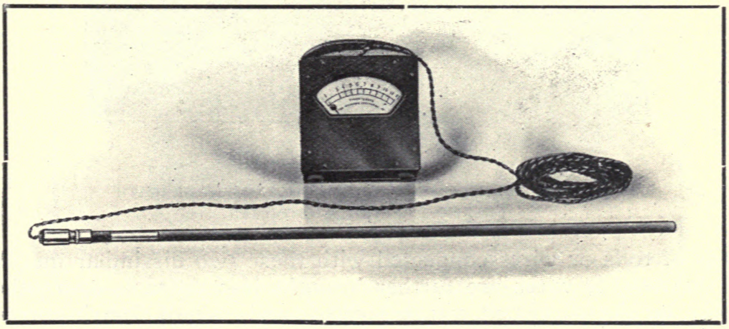

FIG. 46.
FOSTER PORTABLE THERMO-ELECTRIC PYROMETER.

Thermo-electric pyrometers are used for the majority of ordinary heat treatment processes. The Foster Base-Metal Thermo-Electric Pyrometer has found considerable use in its application to heat-treatment work in connection with the manufacture of aeroplane parts.

53. The Foster Portable Pyrometer.—The Foster portable pyrometer, illustrated in Fig. 46, is particularly convenient for general work. This apparatus, which is of great practical value, in addition to its application in heat-treatment processes, such as annealing and hardening, may be used in the foundry to measure the casting temperature of brass, bronze, copper or aluminium. It is particularly desirable to know the correct pouring temperature for these metals. Such knowledge reduces, to a minimum, the risk of spongy and defective castings being formed, due to improper pouring temperatures. The illustration in Fig. 47 shows a thermo-electric pyrometer being used to take the temperature of molten metal.

The operative principle of the thermo-electric pyrometer is based upon the fact that when two dissimilar metals, welded together, are heated, an electro-motive force is generated at the ends of rods or wires connected with these two dissimilar metals. If the rods or wires are further brought into contact, at another point, an electric circuit will be formed; and a small electric current will be produced, the intensity of which corresponds to the difference in temperature at the two ends of contact. The welded portion, which is called the " hot end," is placed in close proximity to the object the temperature of which it is desired to measure. The outside ends, commonly called the " cold ends," should be kept at a constant temperature. A good thermo-couple always generates the same electro-motive force at a given temperature, if the temperature of the cold ends remains constant.

Fig. 47.

Taking the Temperature of Molten Metal with Thermo-Electric Pyrometer.

Measurement of the current is effected by means of a sensitive galvanometer placed in the electric circuit. The pointer of the galvanometer, by moving against a scale graduated in degrees of temperature, performs, automatically, the conversion of the electromotive force into degrees of temperature. The thermo-couple is calibrated with the cold end at a fixed temperature, usually 30 degrees C., and, when properly connected with the galvanometer, and the latter adjusted, it will accurately indicate, or record, the temperature of the hot end.

As the electro-motive force, measured by the galvanometer, varies with the difference in temperature between the hot and the cold ends of the thermo-couple, and as a change in voltage is caused by a temperature change at either end, it follows that the cold end of the thermo-couple must be kept at a known fixed temperature. If the instrument is calibrated to give correct readings with a cold end temperature of 30 degrees C., it will read low if the cold ends are higher than the standard cold end temperature, and will read high if the cold end temperature falls below the standard. This "*cold end error,*" as it is called, will, unless corrected, impair extreme accuracy, especially where the temperature ranges are small, and where the "cold end" of the couple is located at a point of frequent, or of wide, variation of temperature.

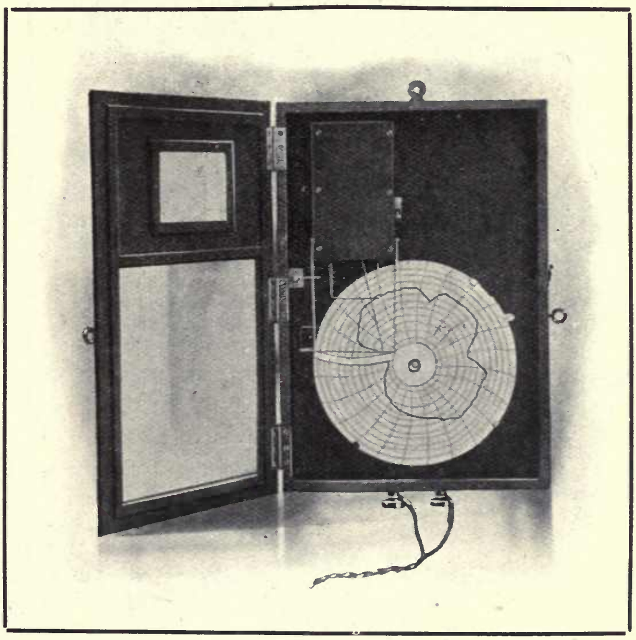

Fig. 48.
Automatic Recorder.

54. The Automatic Recorder.—Where a permanent record of the temperature has to be kept, an automatic recorder, such as the one illustrated in Fig. 48, is used in place of the ordinary indicating galvanometer. This instrument makes, on a paper chart, a permanent and indelible ink record. A chart of this kind is essential when constant repetition of results is desired. The temperature may, at any instant, be read on the recorder without disturbing the record. After the heating process is completed, the chart, showing the whole temperature history of the work, can be filed for reference.

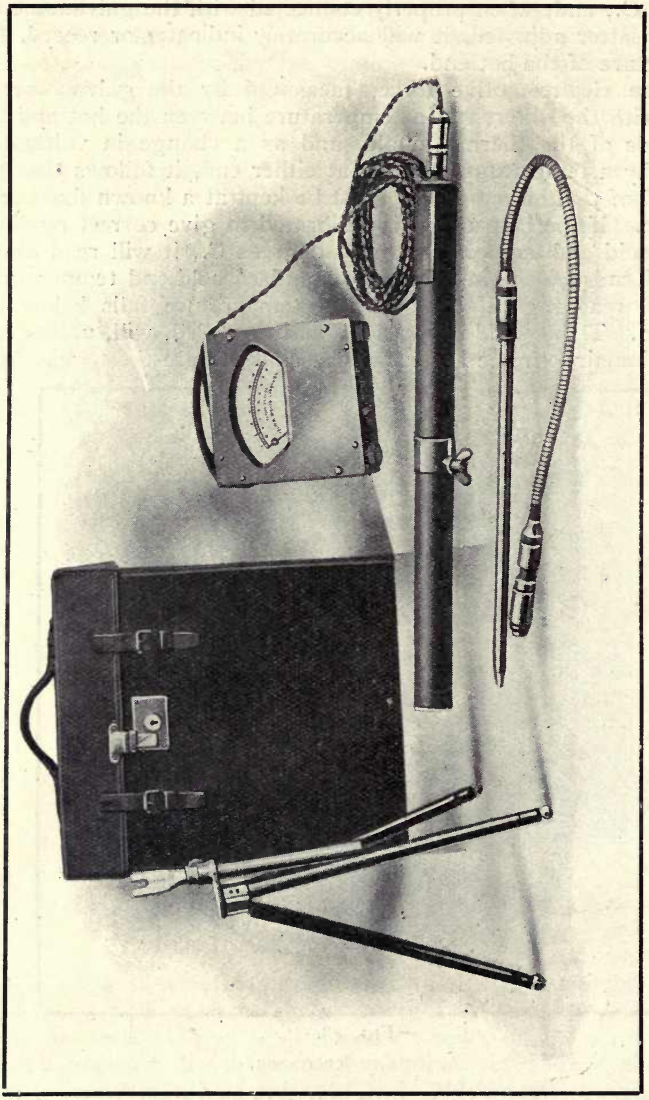

Fig. 49. Foster Fixed Focus Radiation Pyrometer.

55. The Radiation Pyrometer.—In some heat treatment processes it is impossible successfully to use the thermo-electric pyrometer. For instance, for the measurement of the temperature of hot objects in motion, such as flowing metal, steel in rolls, under the hammer, or in the process of drop stamping, it would be impracticable to use an ordinary thermo-couple. The Foster Radiation Pyrometer, illustrated in Fig. 49, is specially adapted for use in these processes of treatment. The instrument is seen in use in Fig. 50. Its operation depends on the focusing of the total heat radiations, emanating from the hot object, by means of a mirror, on to a sensitive thermo-couple, fixed at the back of the receiving tube. The small thermo-couple is connected to a suitable millivolt-meter, and is calibrated to give direct readings of temperature.

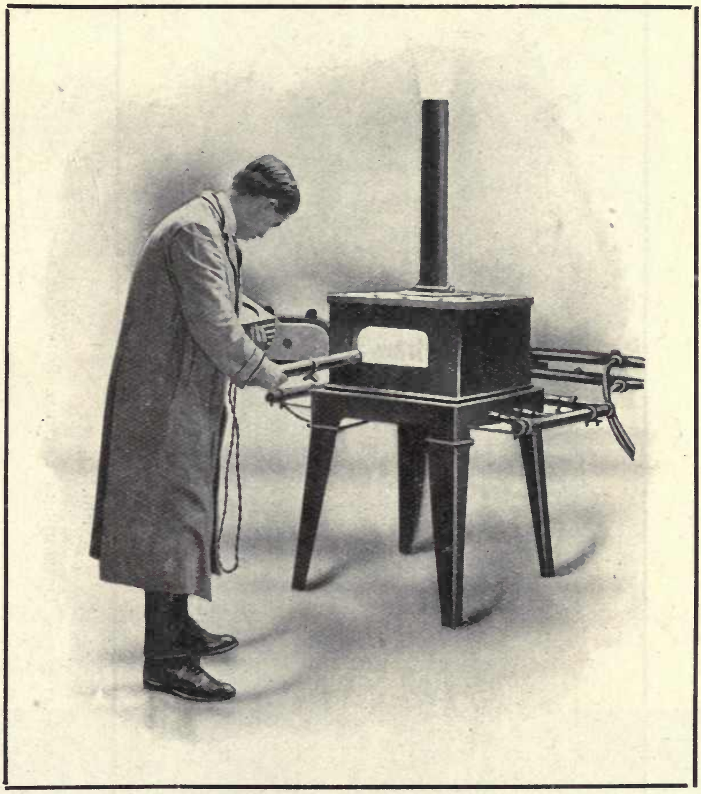

FIG. 50.
RADIATION PYROMETER IN USE.

With the Foster Fixed Focus Type, shown in the illustration (Fig. 49), focusing is eliminated. The manipulation is simple, and observations can be made with great rapidity. The focusing tube is simply pointed on to the hot object for five or six seconds, and the temperature read on the indicator. Since no part of the outfit enters the fire, the receiving end does not require frequent renewal.

As this type of instrument is wholly dependent upon radiation, its action and accuracy are affected by augmentation of radiations from intervening flames of temperature higher than the object under observation, or by the absorption of radiations by intervening opaque gases. Therefore, the Radiation Type of pyrometer should not be used where there is much smoke, or outrushing fumes, gases, or other transparent or semi-transparent bodies.

56. Determining the Thermal Critical Points of Steel.—An apparatus suitable for determining the thermal critical points of steel is illustrated in Fig. 51. The outfit consists of a pyrometer,

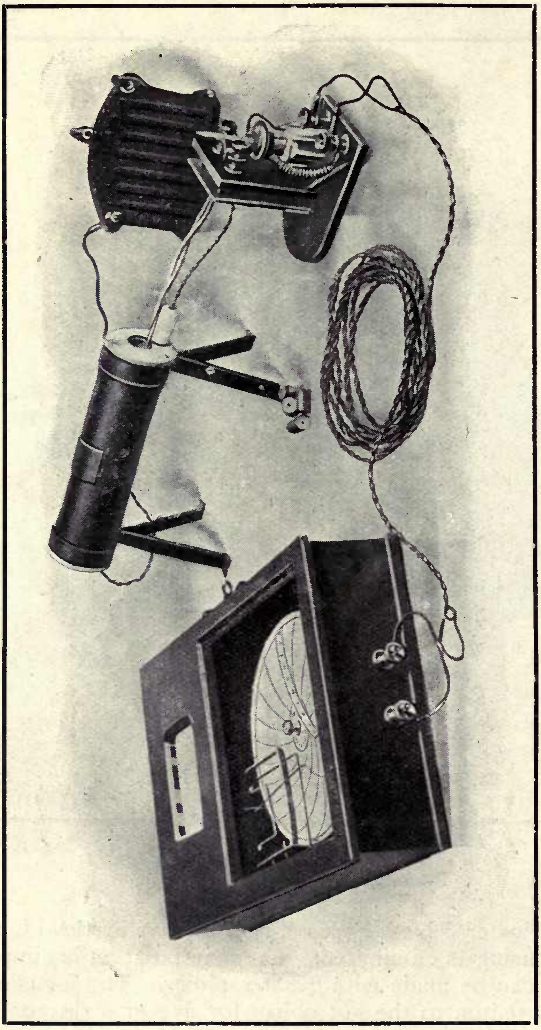

Fig. 51.

Apparatus for Determining Critical Points of Steel.

a small electric furnace, and a cold junction box. The test sample is prepared, say, $\frac{3}{4}$ inch long, 5-8th inch diameter, and is bored with 3-16th inch hole $\frac{1}{2}$ inch deep. The tip of the thermo-couple is inserted into the hole, and the sample is then heated in the furnace, and afterwards allowed to cool slowly. The chart, illustrated in Fig. 52, shows the complete operation of heating up and cooling down, and indicates clearly the critical points as they appear, when taken with this apparatus.

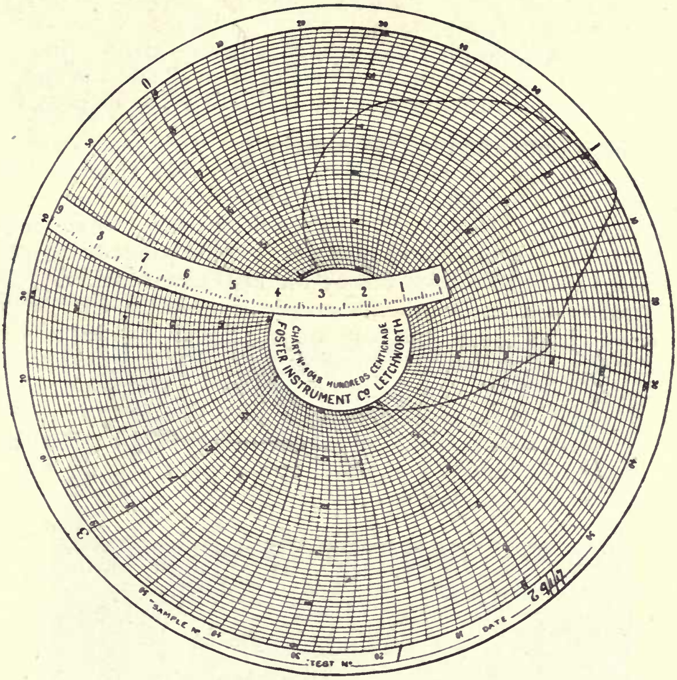

FIG. 52.
CHART SHOWING CRITICAL POINTS OF STEEL.

57. The Sentinel Pyrometer.—The Sentinel Pyrometer, illustrated in Fig. 53, is a small cylinder made from salts which possess definite melting points. These pyrometers, or heat checkers, are made by The Amalgams Co., of Sheffield. If one of these Sentinels, having a melting point of 800 degrees C., is placed in a small porcelain dish near to the heated object in the furnace, it will keep its shape as long as the temperature does not exceed 800 degrees C.; but, when 800 degrees C. is exceeded, it will collapse completely, and will remain in the fluid condition at the bottom of the dish as long as the temperature remains over 800 degrees C. Below this temperature it will solidify. The

FIG. 53.
" SENTINEL " PYROMETERS.

illustration on the left of Fig. 53 shows the Sentinel before use; the middle view shows its appearance when it is just on the point of melting; and the right hand view shows the Sentinel completely melted. The Sentinel pyrometer is available for checking any desired temperature up to a maximum of 1,050 degrees C.

58. The Calibration of Pyrometers.—It is necessary that pyrometers should be calibrated at intervals in order to check their accuracy. The indicators and recorders are constant enough in their accuracy. Under ordinary conditions they do not require any alteration. In the event, however, of alterations being necessary these should be carried out by the instrument maker.

The calibration of the thermo-couple is quite an easy matter, and can be very satisfactorily accomplished in the workshop. The easiest method consists in comparing the couple with a standard thermo-couple kept for the purpose. The two couples should be placed together in the same furnace and the temperature readings compared. If this method is used, the test should be carried out over a range of temperatures which ordinarily covers the working range of the couple under test.

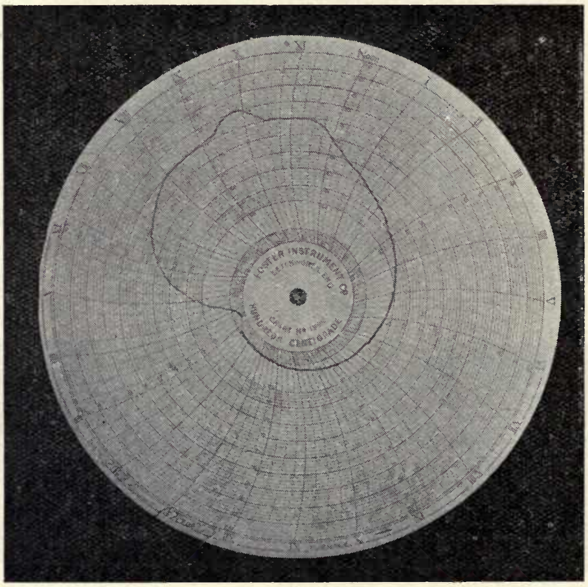

Fig. 54.
Chart showing Heating and Cooling Points of Common Salt.

When a number of thermo-couples are in use, it is very desirable to have special means of checking the instruments. The checking of large quantities of thermo-couples can be most satisfactorily accomplished by taking advantage of the fact that the freezing point of common salt is always constant at 800 degrees C. A small gas-heated furnace, of sufficient size to accommodate a suitable crucible, may be used. The temperature of the furnace should be raised until the salt in the crucible melts, and the couple should then be inserted in the salt. The bath of molten salt should be taken up to a maximum temperature of about 900 degrees C., and then allowed to cool. The cooling will proceed at a uniform rate until the freezing point of the salt is reached. At this point the temperature will remain stationary until the whole of the salt has solidified. It will then continue to fall again at a uniform rate. The temperature of the bath remains stationary, exactly at 800 degrees C. Therefore, this temperature should be denoted on the indicator, or recorder, at this period. Fig. 54 illustrates both the heating and cooling points taken on a large bath of common salt.

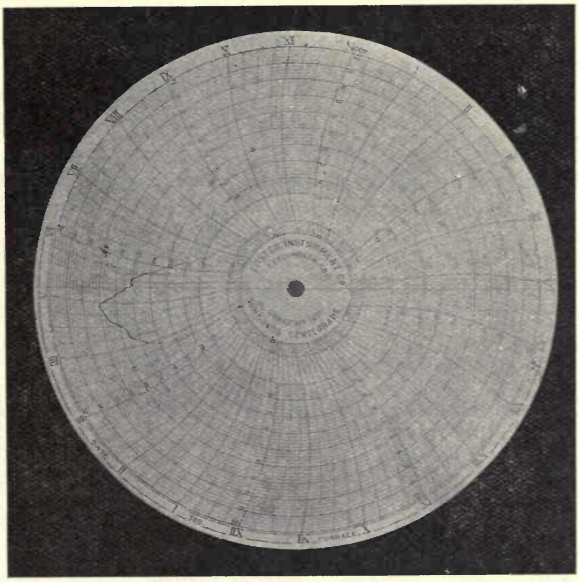

Fig. 55.
Chart showing Critical Points of Steel, taken on Works Recorder.

The critical points occurring in the heating and cooling of steel may also be used for checking the thermo-electric pyrometer. A large block of steel, say, six inches diameter and ten inches deep should be drilled with a suitable hole. The thermo-couple should be inserted in the hole and the block heated in a gas-fire furnace. Under suitable conditions, the critical points occurring both on heating and cooling are clearly observable. Fig. 55 illustrates a calibration curve on a carbon tool steel taken on a works recorder. Under standard conditions of heating and cooling, the critical points do not vary. They, therefore, form a definite basis for the calibration of the instrument.

Under workshop conditions, the Radiation Pyrometer is checked by focusing it directly on to a standard thermo-electric pyrometer, and comparing the readings of the two instruments.

CHAPTER VIII

THE APPLICATION AND CLASSIFICATION OF AIRCRAFT METALS

59. Detailed Classification of Aircraft Metals.—In this Chapter, under the different headings of paragraphs **60** to **94,** details are given of various metals and alloys used in the construction of aircraft, including their engines. In the majority of cases, there is indicated not only the composition of the material, but also the treatment which it should undergo in order that the parts, made of it, should be in the best physical condition to fulfil the requirements of actual service.

60. Case-hardening Steel for small parts requiring a soft core.—For small parts, such as small bushes, rolls and races, which require a soft core, a 0.10 per cent. carbon steel is used.

After normalizing the steel at 920 degrees C., the following minimum mechanical test results should be obtained :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
16	26	35%	60%	100	121

After annealing at 780 degrees C., it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
15	24	42%	70%	50	103

CARBURIZING TREATMENT.

Carburize at 950 degrees C. for 5 hours.

Reheat parts to 920 degrees C., and quench in water.

Reheat to 780 degrees C., and quench in water.

After this treatment the mechanical tests on the core should be not less than :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
28	38	30%	70%	45	163

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* Y.S. = Yielding Stress in tons/sq. in. ; M.S. = Maximum Stress in tons/sq. in. ; E. = Elongation ; R.A. = Reduction of Area ; Izod = Izod Impact in Ft. lb. (see § 17, page 30) ; Brinell No. = Brinell Hardness Number (see § 12, page 21).

61. Case-hardening Steel for Parts Requiring a Tough Core.—For parts, such as sliding shafts, counter-shafts, ball races, cam-shafts, swivel arms, steering parts, etc., which require a fairly tough core, a 0.15 per cent. carbon steel is used.

After normalizing at 900 degrees C., the following minimum mechanical test results should be obtained:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
21	32	33%	55%	80	156

After annealing at 750 degrees C. it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
19	28	38%	60%	40	121

CARBURIZING TREATMENT:

Carburize at 950 degrees C. for 5 hours.

Reheat parts to 900 degrees C., and quench in water.

Reheat to 780 degrees C., and quench in water.

After this treatment the mechanical tests on the core should be not less than:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
35	48	16%	35%	70	192

62. Steel having Good Wearing Surface and Core resisting large Crushing Load.—A 0.25 per cent. carbon steel is used for parts which demand a good wearing surface and a core capable of withstanding heavy crushing loads. This steel is fairly brittle, and will not stand working under conditions of shock.

After normalizing at 870 degrees C., the following minimum mechanical test results should be obtained:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
23	38	30%	50%	15	167

After annealing at 780 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
22	32	36%	63%	60	134

CARBURIZING TREATMENT:

Carburize at 950 degrees C. for 5 hours.

Reheat parts to 870 degrees C., and quench in water.

Reheat to 770 degrees C., and quench in water.

After this treatment the mechanical tests on the core should be not less than:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
40	55	10%	20%	30	248

63. Low Carbon 3 per cent. Nickel Steel for Parts demanding Tough Core.—A low carbon 3 per cent. nickel steel should be used for parts requiring to have a tough core, such as steering parts, moderately stressed gear wheels, gudgeon pins. The parts made from this steel can be lighter in section and yet take up

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* Y.S. = Yielding Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq. in.; E. = Elongation; R.A. = Reduction of Area; Izod = Izod Impact in Ft. lb. (see § 17, page 30); Brinell No. = Brinell Hardness Number (see § 12, page 21).

equal stresses in the ordinary 0.15 per cent. plain carbon steel (see § 61).

After normalizing at 900 degrees C., the following minimum mechanical test results should be obtained :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
26	35	34%	60%	75	153

After annealing at 720 degrees C., it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
24	33	40%	65%	40	143

Carburizing Treatment :

Carburize at 950 degrees C. for 5 hours.

Reheat parts to 870 degrees C., and quench in oil.

Reheat to 770 degrees C., and quench in oil.

After this treatment the mechanical tests on the core should be not less than :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
36	49	25%	60%	80	212

64. Low Carbon 5 per cent. Nickel Steel for Parts working under High Tension and Crushing Stresses.—A low carbon 5 per cent. nickel steel is used for parts which are required to work under conditions of high tension and crushing stresses. This material is not so tough as the 3 per cent. nickel steel. (See § 63.)

After normalizing at 850 degrees C., the following minimum mechanical test results should be obtained :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
27	40	35%	60%	40	—

After annealing at 700 degrees C., it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
25	37	40%	70%	35	157

Carburizing Treatment :

Carburize at 900-920 degrees C. for 5 hours.

Reheat parts to 820 degrees C., and quench in oil.

Reheat to 770 degrees C., and quench in oil.

After this treatment the mechanical tests on the core should be not less than :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
40	58	19%	40%	40	269

65. Steel for Parts subjected to very severe Working Stresses.—A low carbon nickel-chrome case-hardening steel is used for parts that are subject to very severe working stresses.

After normalizing at 900 degrees C., the following minimum mechanical test results should be obtained :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
65	85	15%	40%	40	375

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* Y.S. = Yielding Stress in tons/sq. in. ; M.S. = Maximum Stress in tons/sq. in. ; E. = Elongation ; R.A. = Reduction of Area ; Izod = Izod Impact in Ft. lb. (see § 17, page 30) ; Brinell No. = Brinell Hardness Number (see § 12, page 21).

After annealing at 700 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
32	56	24%	52%	48	241

CARBURIZING TREATMENT:

Carburize at 950 degrees C. for 5 hours.

Reheat the parts to 850 degrees C., and quench in oil.

Reheat to 750 degrees C., and quench in oil.

After this treatment the mechanical tests on the core should be not less than:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
52	67	14%	40%	57	293

66. Plain Carbon Steel for Nuts and Bolts.—An ordinary mild plain carbon steel containing about 0.20 per cent. carbon is used for nuts and bolts.

After normalizing at 900 degrees C., the following minimum mechanical test results should be obtained:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
21	32	33%	56%	70	156

After annealing at 820 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
20	30	38%	65%	65	134

After quenching in water from 900 degrees C., and tempering at 700 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
40	50	22%	60%	50	229

67. Plain Carbon Steel for Cylinders.—A plain carbon steel containing about 0.45 per cent. carbon is sometimes used for cylinders.

This material is used in the normalized state.

After normalizing at 820 degrees C., it should give the following mechanical test:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
27	45	24%	42%	6	207

68. General Purpose Plain Carbon Steel.—A plain carbon steel containing 0.35 per cent. carbon can be used for cylinder nuts and bolts and general purposes where an alloy steel is not required.

After normalizing at 870 degrees C., the following minimum mechanical test results should be obtained:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
22	36	31%	50%	15	163

* Y.S. = Yielding Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq. in.; E. = Elongation; R.A. = Reduction of Area; Izod = Izod Impact in Ft. lb. (see § 17, page 30); Brinell No. = Brinell Hardness Number (see § 12, page 21).

After annealing at 800 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
21	34	35%	60%	10	156

Heat treated by quenching in water from 870 degrees C., and tempered at 550 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
36	44	25%	63%	95	201

Heat treated by quenching in oil from 870 degrees C., and tempered at 550 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
31	42	26%	63%	10	201

69. Mild Steel for Sockets, Clips, etc.—An ordinary mild steel containing 0.15 to 0.25 per cent. carbon is used in the form of sheets for strut sockets, strut ferrules, clips, ribs, wiring plates, etc.

After normalizing at 900 to 950 degrees C., test pieces taken from the sheets should give a minimum tensile test of:

Y.S.*	M.S.*	E.*	R.A.*
32	38	10%	49%

70. Nickel Steel for Axles, Connecting Rods, etc.—A 3 per cent. nickel steel may be used for pins, axles, control arms, and connecting rods.

After normalizing at 850 degrees C., the following minimum mechanical tests should be obtained:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
30	45	27%	55%	40	212

After annealing at 700 degrees C., it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
28	38	34%	65%	85	163

Quenched in oil from 850 degrees C., not tempered, it should give:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
102	108	9%	20%	9	477

After quenching in oil from 850 degrees C., and tempering to 650 degrees C., the following test results should be obtained:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
50	55	24%	61%	60	255

71. 5 per cent. Nickel Steel.—A 5 per cent. nickel steel is used for axles, connecting rods and any parts requiring combined hardness and toughness.

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* Y.S. = Yielding Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq. in.; E. = Elongation; R.A. = Reduction of Area; Izod = Izod Impact in Ft. lb. (see § 17, page 30); Brinell No. = Brinell Hardness Number (see § 12, page 21).

After normalizing at 770 degrees C., the following test results should be obtained :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
33	46	26%	55%	45	212

After annealing at 680 degrees C., it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
29	44	27%	56%	40	187

Quenched in oil from 800 degrees C., not tempered, it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
98	110	9%	20%	12	477

Quenched in oil from 800 degrees C., and tempered to 650 degrees C., it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
50	55	25%	65%	75	255

72. Nickel-Chrome Steel for Maximum Toughness and Hardness.—For parts such as crankshafts, propeller-shafts, axles for severe service, and pistons, which require the maximum toughness combined with the greatest hardness, a nickel-chrome steel is used.

After normalizing at 850 degrees C., it should give the following mechanical tests :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
64	74	11%	30%	25	321

After annealing at 780 degrees C., it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
55	65	16%	42%	16	269

Quenched in oil from 850 degrees C., not tempered, it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
104	110	11%	30%	20	477

Quenched in oil from 850 degrees C., and tempered to 600 degrees C., it should give :

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
52	60	22%	61%	60	269

73. Air Hardening Nickel-Chrome Steel.—Under special circumstances, air hardening nickel-chrome steel is sometimes preferred by constructors for gears, crankshafts and pistons. On account of the great difficulty in working this steel its use is not to be recommended for general practice.

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* Y.S. = Yielding Stress in tons/sq. in. ; M.S. = Maximum Stress in tons/sq. in. ; E. = Elongation ; R.A. = Reduction of Area ; Izod = Izod Impact in Ft. lb. (see § 17, page 30) ; Brinell No. = Brinell Hardness Number (see § 12, page 21).

After normalizing at 820 degrees C., the following test results should be obtained:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
90	100	9%	20%	10	401

After annealing at 700 degrees C., it should give the following tests:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
45	58	20%	60%	20	277

Heated to 850 degrees C., and cooled in air and then tempered to 300 degrees C., it should give the following mechanical tests:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
100	106	11%	36%	5	444

Heated to 850 degrees C., and cooled in air and then tempered to 600 degrees C., it should give the following test results:

Y.S.*	M.S.*	E.*	R.A.*	IZOD*	BRINELL No.*
56	62	20%	60%	30	285

74. Nickel Steel for Valves.—A 25 per cent. nickel steel is suitable for valves. It may also be used in the sheet for clips, brackets and engine plates. It resists corrosion, and is non-magnetic. This steel does not harden and temper like other steels. Toughened by quenching in water it will give the following mechanical tests:

Y.S.*	M.S.*	E.*	R.A.*
15	40	45%	50%

75. Tungsten Steel for Valves.—Tungsten steel is supplied for valves. This material is capable of withstanding high working temperatures in the exhaust, without showing any appreciable change in its physical properties.

The valves should be treated by heating to 950 degrees C., and cooling in air, and then reheating to 800 degrees C., and again cooling in air.

In this condition the material should give a Brinell hardness number in the region of 269.

76. Non-Rust Steel.—In view of the unreliability of such materials as wood for use in the construction of aeroplane wing spars, there is a tendency to depart from the employment of this material in favour of steel. Until quite recently, steel was considered unsuitable for the purpose of spar construction, not so much on account of its greater weight compared with wood, and of the difficulty of making satisfactory joints, but, especially, on account of its inability to withstand corrosion. This latter objection is now, however, almost entirely overcome, for the non-rust steel, recently introduced, is practically unaffected by weather.

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* Y.S. = Yielding Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq. in.; E. = Elongation; R.A. = Reduction of Area; Izod = Izod Impact in Ft. lb. (see § 17, page 30); Brinell No. = Brinell Hardness Number (see § 12, page 21).

The use of steel for constructional purposes is far more desirable than wood. As a structural material it is much more durable. It possesses greater reliability than wood. A steel of definite composition can easily be reproduced and made to possess definite mechanical properties, whereas, in the case of wood, the final properties depend not only upon the conditions of growth, but also upon the method of weathering. The latter treatment is not under the same definite control as the treatment of steel. In consequence, the final properties of wood vary considerably. For this reason, among others, the principles underlying the steel construction of aircraft are being continuously studied and extended.

Physical tests made on a commercial brand of non-rust steel show that, when treated under suitable conditions, it possesses a fairly wide range in its physical properties, and that it compares very favourably with the ordinary high tensile steels already in use in aircraft work.

Questions of facility of working, under the various conditions of practice, are not easily ascertained by laboratory investigations. Therefore, the real decision as to the relative merits of non-rust steel for aircraft construction must rest with actual experience.

The following mechanical tests are now being regularly obtained on commercial brands of non-rust steel :

TREATMENT.	Y.S.	M.S.	E.	R.A.	Izod Impact.	Brinell No.
Normalized 820°C.	109	115	6	15	8	444
Annealed 780°C.	36	50	25	60	30	217
Harden 870°C.—Oil Tempered 250°C —Air	80	87	13	30	13	402
Harden 870°C.—Oil Tempered 650°C.—Air	49	56	18	55	40	241

77. Steel for Tubes.—The steel tubing used for socket tubes, induction and exhaust pipes, and for small tubes under $\frac{3}{4}$ inch diameter, where strength is not essential, is usually made from 0.15 per cent. carbon material. This class of tubing is usually cold drawn, and partially annealed. It is sufficiently ductile for the usual bending, flattening, and cold working operations. Although it is made from mild steel, it has considerable stiffness due to being cold drawn. This cold working stiffness can, however, be removed by heating to redness. It is largely used for small parts; also for tubes on edges of planes.

For washers that require machining, and for other machined parts that must be soft, black finished tubing with suitable machining allowance is adopted.

78. Tests for Tube Steels.—Tubes made from 0.15 per cent. carbon steel should give an ultimate tensile strength of not less than 20 tons per square inch, and a yield stress not under 11 tons per square inch. They are annealed between 870 degrees and 920 degrees C. before the final pass in the drawing operation. They should also comply with the following flattening, crushing and bending tests :

Flattening Test.—The tubes should be flattened at the end, or at any point where defective material is suspected, by a few blows (not more than 6) till the sides are not more than three times the thickness of the metal apart, if the tubes are half hard. Annealed tubes should be flattened close. They must stand this treatment without cracking.

Crushing Test.—Specimens of the tubing should be selected and crushed endwise, until the outside diameter is increased in one zone by 25 per cent., or until one complete fold is formed. The samples must stand this treatment without cracking.

Bending Test.—Tubes of less than ¾ inch diameter, and all trailing-edge tubes must stand being bent through 90 degrees round a radius not greater than 10 diameters, without serious deformation or showing signs of failure.

Tubes which are heavily stressed in service should be made from 0.30 per cent. carbon steel. In cases where the tubing has to be brazed or heated to permit of its being severely bent or otherwise worked, and is still required to have the maximum strength, it must be used in the hard-drawn and blued condition. If the tubes have to be bent or worked in the cold state, they should be used in the annealed condition. The annealing should be done at a temperature between 550 degrees and 650 degrees C.

Tubes made from 0.30 per cent. carbon steel should give an ultimate tensile strength of not less than 28 tons per square inch, and a yield stress not under 18 tons per square inch. These tubes should also withstand the same flattening and crushing tests as described for the 0.15 per cent. carbon steel.

79. Carbon Steel for Axle Tubes.—Carbon steel for axle tubes should be used in the hardened and tempered condition. After heat treatment the tubes should be capable of withstanding the following mechanical tests :

Proof Load.—All axles should be tested by having a proof bending moment applied to them at one end. A suitable apparatus, recommended by the Air Ministry, for applying the bending moment is shown in Fig. 56. The load should be applied in two parts, the first part being any convenient amount between one-quarter and one-half of the proof load. After the first part of the load has been applied, a gauge is adjusted to a standard distance from the tube at B (Fig. 56); the second part of the load is then added and allowed to remain on for at least five seconds, and then removed. If any set is produced, the tube will not return to the standard distance from the gauge at B. The set should not be more than one-eighth of an inch. Any tube giving a greater set should be re-treated. Contact between the tube and the support at A should not extend for more than three-quarters of an inch along the tube. The proof loads which the various sizes of tubes should withstand are given in Table III (p. 92); the leverage is also shown.

Flattening Test.—A test-piece, one or two inches long, cut from the axle, should be capable of being bent into an oval section by pressure, until its diameter is reduced when under load to 0.85 of the original diameter, without showing signs of cracking.

Destruction Test.—A sample axle from each batch, heat treated together, should be bent to destruction. The test axle should be first tested under the proof load, to make sure that it will stand that test. The sample should then be tested, in the same apparatus, by increasing the lever arm, till the gap at B reaches the value given in Table III (p. 92). It should stand this test without cracking.

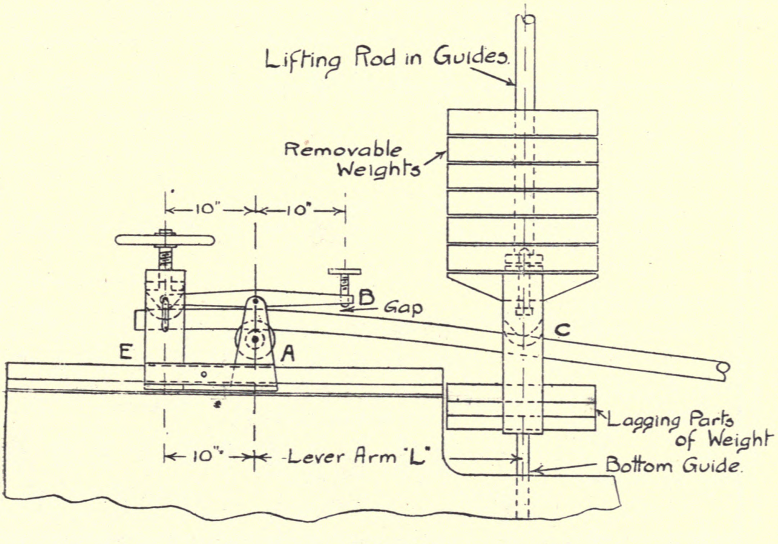

FIG. 56.

DIAGRAM OF AXLE TESTING APPARATUS.

80. Nickel-Chrome Steel for Axle Tubes.—The tubes are hardened by quenching from a suitable temperature in oil. They are afterwards tempered at a temperature of about 250 degrees C., and should satisfy the following tests:

Mechanical Test.—Every axle should be tested under proof load, in the manner described for carbon steel tube axles. The proof load, which the various sizes of tubes should withstand, is shown in Table III (p. 92). The set produced on these tubes should not be more than one-sixteenth of an inch.

TABLE III

Carbon Steel Axle Tubes.						Nickel-Chrome Steel Axle Tubes.				
Nominal Diameter. Inches.	True Outside Diameter. Inches.	Thickness. Inches.	Proof Load Lbs.	Proof Load Leverage L Inches.	Destruction Test. Min. Deflection without crack. Inches.	Nominal Diameter. Inches.	True Outside Diameter. Inches.	Thickness. Inches.	Proof Load. Lbs.	Proof Load Leverage L Inches.
2.375	2.362	0.120	2080	34.65	1.5	2.375	2.368	0.128	2410	35.0
2.165	2.152	0.130	2080	30.00	1.5	2.165	2.158	0.128	2290	30.0
2.165	2.152	0.090	1527	30.00	1.5	2.165	2.158	0.104	1930	30.0
1.750	1.743	0.120	1475	25.0	2.0	1.750	1.743	0.128	1730	25.0
1.750	1.743	0.090	1160	25.0	2.0	1.750	1.743	0.104	1460	25.0
1.750	1.743	0.072	960	25.0	2.0	1.750	1.743	0.080	1170	25.0
1.750	1.743	0.056	766	25.0	2.0	1.750	1.743	0.064	964	25.0
1.50	1.493	0.090	960	21.7	2.5	1.500	1.493	0.080	966	21.7
1.50	1.493	0.072	795	21.7	2.5	1.50	1.493	0.064	797	21.7
1.50	1.493	0.056	638	21.7	2.5	1.50	1.493	0.048	620	21.7
1.10	1.093	0.090	795	13.2	3.0	1.10	1.095	0.080	807	13.2

Tensile Test.—The axles should have an ultimate tensile strength not less than 85 tons per square inch, and an elongation not less than 5 per cent. on two inches, and 3 per cent. on four inches.

Half-hard tubes and hard-drawn tubes resist damage much better than fully annealed tubes, and can be bent to a moderate extent without any wrinkling of the walls or loss of section, much better than fully softened tubes can. Hard drawn tubes may be bent round a radius of about 10 tube diameters without harm. Where sharp bends are necessary, the tube must be softened by being heated to redness and allowed to cool, and, in this state, it must be supported on the inside while being bent. When the requires them to be in the softest state, at any point, it is generally desirable that the softening should be local, so that the tube may be hard and strong elsewhere.

81. Copper Tubes.—The copper used in the manufacture of tubes should be new, and should assay not less than 99.3 per cent. severity of cold working, to which the tubes have been subjected, Copper tubes are classified A, B, C, and D.

Class.	Seamless or Brazed.	Use.	Condition.	Water Pressure Test.
A.	Brazed.	General purposes.	Not Annealed.	Pressure Test as ordered.
B.	Seamless.	Oil, Petrol and General purposes.	Annealed.	100 tons per sq. in. or as ordered.
C.	Seamless.	Air Pressure or Power transmission	Annealed.	4,000 lbs. per sq. in.
D.	Seamless.	Oxygen Connectors.	Annealed.	6,000 lbs. per sq. in.

The tubes are required to comply with the following mechanical tests:

Tensile Test.—A test-piece, consisting of a short length cut off the tube or of a strip cut longitudinally from the tube, should give the following results in the annealed state:
Ultimate Stress (annealed) not less than 14 tons per square inch.
Elongation: not less than 35 per cent. on two inches.

Crushing Test.—(To be applied to seamless tubes only.) A sample of the tube, one-and-a-half diameters long, is to be crushed endways to half its original length. The sample must stand this test without splitting, or cracking.

Bending Test.—Strips are to be cut longitudinally and transversely, and are to be bent cold. If the strips are cut from unannealed tubes, they must stand bending double round a radius equal to the thickness of the strip without cracking.

Pressure Test.—All tubes of class *D* are to be tested to 6,000 lb. per square inch. All tubes of class *C* are to be tested to 4,000 lb. per square inch. All tubes of class *B* are to be tested to the pressure stated in the order, or, if no pressure be stated, to 100 lb. per square inch. Tubes of class *A* are only to be tested under pressure if so ordered. The tubes must stand the test without sign of failure or leak.

Tubes of class *D,* items 3 and 4, are to be tested to make sure that they are not blocked in the bore.

82. Brass Tubes.—The brass used in the manufacture of tubes should consist of :

Copper, 70 per cent.
Zinc, 30 per cent.

The tubes should be seamless and solid drawn, and should comply with the following mechanical tests :

Tensile Test.—A test-piece, consisting of a short length cut off the tube must give the following results :

Ultimate stress, not less than 18 tons per square inch.
Elongation, not less than 50 per cent. in 2 inches.

Crushing Test.—A sample of the tube, one-and-a-half diameters long, should be crushed endways to half its length. The sample must stand this treatment without splitting or cracking.

Pressure Test.—Each tube is to be tested internally by water pressure to 100 lb. per square inch, and must stand this test without leakage, or permanent practical increase in diameter.

83. Aluminium Tubes.—These tubes should be solid-drawn and seamless, made of aluminium assaying not less than 98 per cent. They should satisfy the following tests :

Tensile Test.—A test-piece, cut from the tube, should give an ultimate tensile strength not less than 10 tons per square inch, and an elongation not less than $2\frac{1}{2}$ per cent. in 2 inches.

Crushing Test.—A sample of the tube, one-and-a-half diameters long, should be crushed endways to half its length, and should stand this treatment without splitting or cracking.

84. Duralumin Tubes.—These tubes should be solid-drawn and seamless, and made of the alloy (see § 94, p. 98) of specific gravity not exceeding 2.85. They should satisfy the following tests :

Mechanical Tests.—A tensile test-piece consisting of a short length cut off the tube should give the following minimum result:

	Ultimate Stress.	Yield Stress.	Elongation % on 2 in.
Tubes up to .06 in. thick	25 tons/sq. in.	16 tons/sq. in.	8
Tubes between .06 and 0.1 in. thick	25 ,,	16 ,,	10
Tubes over 0.1 in. thick	25 ,,	16 ,,	12½

85. Stream-Line Wires.—The steel, used for the manufacture of stream-line wires, contains:

Carbon, between 0.45 and 0.52 per cent.
Manganese, between 0.60 and 0.90 per cent.
Sulphur and Phosphorus, not over 0.06 per cent.

Stream-line wires should satisfy the following mechanical tests:

Tensile Test.—A sample should be cut from every coil, or from selected straight lengths, and, when tested, must give the following results:

For wire rods of sizes from 4B.A. to 11/32 inch inclusive: ultimate stress not less than 55 tons per square inch.

For wire rods of sizes from 3-8ths inch to 5-8ths inch inclusive: ultimate stress not less than 52 tons per square inch, nor more than 62 tons per square inch.

Bend Test.—A sample should be cut from every coil, or from selected straight lengths, and subjected to the following bending test:

The sample should be fixed in a vice, or between dies of which the inner edges are rounded to a radius equal to three times the diameter of the wire. The projecting end is then bent at right angles to the fixed part, and again bent, backwards and forwards, through an angle of 180 degrees, till it breaks. The wire must stand, without breaking, the following number of bends through 180 degrees (the first bend through 90 degrees is not counted):

For wire of sizes:

4 B.A. and 2 B.A.	Minimum number of bends 6
¼ in., 9/32 in. and 5/16 in.	,, ,, ,, 5
11/32 in., 3/8 in. and 13/32 in.	,, ,, ,, 4
7/16 in. and upwards	,, ,, ,, 3

86. Bearing Metals.—Bearing metals are divided into two groups, viz., *white metals,* which are composed of varying proportions of tin, copper, antimony and lead, and *phosphor-bronzes,* which contain copper, tin and phosphorus. The characteristic requirements of a good bearing metal demand that it should be sufficiently soft and plastic to accommodate itself to the inequalities of the moving parts, and thus afford them an even bearing, while it must also present a surface of sufficient hardness to prevent abrasion. A combination of these two requirements, hardness and plasticity, can only be obtained by having a body consisting of small hard particles embedded in a plastic matrix. This result is most easily produced by alloying a soft metal, such as lead or tin, with one or more metals which form definite compounds, capable of crystallizing out in the cooling mass. This is the composite structure of anti-friction alloys. Much depends, however, on the size and number of the hard crystals. As regards the relative merits of white metal and of phosphor-bronze bearings, it is frequently stated that white metal is superior; but it is clear that the conditions of use are an important factor in the question. In cases where accuracy of adjustments of the moving parts is impossible, or where variable forces come into play with a tendency to irregular wear, the superior plasticity of white metal is an invaluable property. On the other hand, where accuracy of adjustment is possible, and the rotary motion regular, plasticity is of secondary importance, and phosphor-bronze gives equally good practical results.

87. White Metal for Bearings.—The copper used for this alloy is to assay not less than 99.3 per cent. All other ingredients should be of best quality, and in the following proportions:

Tin not less than 90 per cent.
Copper between 3 and 5 per cent.
Antimony ,, ,, ,, ,, ,,
Lead not more than 1 per cent.

The total of all the other constituents, including all impurities, is not to exceed 0.5 per cent.

88. Phosphor-Bronze Castings for Bearings.—This alloy should have the following composition:

Copper between 85 and 89 per cent.
Tin ,, 10 ,, 13 ,,
Phosphorus ,, 0.5 ,, 1 ,,
Total impurities not more than 0.75 per cent.
Zinc 0.25, not over.
Lead 0.25, ,,
Tensile Test: not less than 10 tons per square inch.
Elongation: not less than 1½ per cent., and not over 4 per cent.

89. Iron Castings for Valve-Guides and Air-Cooled Cylinders.—The castings should have the following chemical composition:

Combined carbon	between	0.50 and 0.80	per cent.
Total carbon	,,	2.70 and 3.5	,,
Silicon	,,	1.20 and 2.0	,,
Sulphur, not over		0.12	,,
Phosphorus ,,		0.80	,,
Manganese, between		0.50 and 1.20	,,

The castings should give a mechanical test of not less than 12 tons per square inch ultimate tensile strength.

90. Iron Castings for Pistons and Water Cooled Cylinders.—The castings may be made of material having either of the two following analyses:

Total Carbon	2.70-3.50	per cent., or	2.70-3.30 per cent.
Combined Carbon	0.50-0.80	,, ,,	0.50-0.80 ,,
Silicon	1.20-1.80	,, ,,	1.20-1.80 ,,
Manganese	0.35-0.80	,, ,,	0.60-1.20 ,,
Sulphur, not over	0.12	,, ,,	0.12 ,,
Phosphorus ,,	0.80	,, ,,	1.10 ,,

The castings should give a mechanical test of not less than 12 tons per square inch ultimate tensile strength.

91. Cast-Iron Piston Rings.—The cast-iron, of which the rings are made, should have the following composition:

Total Carbon between	2.8	and 3.50	per cent.
Combined ,, ,,	0.5	,, 0.90	,,
Silicon ,, ,,	1.5	,, 2.20	,,
Sulphur, not over	0.12 per cent.		
Manganese, between	0.50	and 1.00	,,
Phosphorus ,,	0.50	,, 1.40	,,

The finished rings must stand being sprung apart to a distance equal to seven and a half times the mean thickness of the ring, without showing signs of fracture. This test should be made by pressing the ring over a cone.

92. Aluminium.—Aluminium alloy castings are largely used for crank cases, cylinders, etc. A good alloy for this purpose consists of:

Zinc not less than 12.5 per cent. nor more than 14.5 per cent.
Copper ,, 2.5 ,, ,, ,, 3.0 ,,
Aluminium—remainder.

The following minimum mechanical tests should be attained with this alloy:

Ultimate tensile strength not less than 12 tons per square inch.
Elongation not less than 4 per cent.

The strength of aluminium castings depends considerably on the rate of cooling the metal in the mould. The faster it cools, the stronger it becomes, so that chill castings are considerably stronger than sand castings; and thin parts, which cool the quickest, are stronger than thick parts.

If an aluminium casting is found to sweat under water pressure, or spirit pressure, it may be treated with a solution of water glass. A solution of water glass is prepared by dissolving one part of sodium silicate (water glass) in three to five parts of hot water. The casting should be plugged up in such a way so that it can be filled with the solution under a known pressure, making certain, as far as possible, that the solution reaches one side only of the porous sections. Small porous castings are treated before or after machining, as is most convenient in manufacture. Where a large mass of metal has to be machined off, or where the porous sections after machining are very thin, the casting should be treated after machining. When the casting is ready, the hot solution should be poured in, and pressure applied by means of a water pump. If the casting is strong enough, about 70 lb. pressure per square inch is suitable. The pressure is maintained until the sweating ceases, or, if the solution does not sweat through, for about 10 to 20 minutes. The temperature, at which the solution should be put in, depends on the relative mass of the casting and of the solution. The correct temperature, to use for any particular casting, is best found by experiment. The lowest temperature that will stop porosity should be used. This is usually between 40 degrees and 60 degrees C. After this treatment, the casting should be thoroughly washed out with hot water, any adhering white deposit should be brushed off, and the casting allowed to stand until it is thoroughly dry.

93. Enamelling Aluminium Cylinders.—A coating of hard-stoved enamel, on a hot rough-cast aluminium surface, considerably increases the rate of flow of heat from the aluminium to the air, or water, in contact with the surface. Enamel increases the transmission of heat, from a cast aluminium-alloy surface to air, by about 15 per cent., and to water by between 4 per cent. and 8 per cent. It increases the transmission from cast-iron to air by about 7 per cent., and from steel to air by about 2 per cent. It does not increase the transmission from copper.

Cylinders, which have been treated with sodium silicate, should be heated, before they are enamelled, to a temperature at least as high as the temperature which will be used for drying the enamel. Cylinders should be enamelled, and stoved, before final machining. A temperature of at least 260 degrees C. should be used for stoving. If this be done, the growth and distortion which occurs when an aluminium cylinder is heated will take place before the final machining, instead of during the running of the engine. If the enamel used will not stand a stoving temperature of 260 degrees C., air cooled cylinders should be annealed at 300 degrees C., and water cooled cylinders at 260 degrees C. for five hours before being enamelled.

The enamel used must be hard, and smooth at the temperature at which it is to work. A stoved enamel is much better than any form of paint. The colour of the enamel is of little importance; black gives very satisfactory results. Not more than two coats should be used. The best enamel, which has, so far, been found, is made of hard fossil copal in linseed oil, in the proportions of about 12 lb. of copal to 1 gallon of oil. Two coats of this enamel, each stoved for four hours at 260 degrees C., give an effectual coating. The enamel is coloured by the addition of about 13 ounces of carbon black per gallon of oil.

94. Duralumin.—Duralumin is an aluminium alloy with 90 per cent. aluminium. The specific gravity varies between 2.77 and 2.85, according to the composition. The melting point is about 650 degrees C. Duralumin can be rolled, forged and drawn in either the cold or hot state. The alloy can be changed in composition, so that it may give a material of great elasticity and a degree of low hardness, or very great resistance with a corresponding low elastic limit.

The following Table gives the limits within which the properties of duralumin, subjected in the main to the same treatment, change with corresponding change of composition :

Specific gravity	2.77 to 2.85
Yield Point	10 to 16 tons per square inch
Ultimate strength	18 to 28 ,, ,,
Elongation	15 to 20 per cent.
Reduction of Area	25 to 34 ,,
Brinell Hardness	98 to 125

The above values apply to sheets 0.2 inch thick.

The mechanical properties change according to the nature of the alloy.

Joints should be made by means of rivets and screws of the same material. Welding or soldering reduces the strength. It is essential never to heat finished parts above 150 degrees C. When using cutting tools, of the same material, they should be lubricated or cooled with some suitable lubricant, such as turpentine oil.

For forging, rolling, pressing, in the hot state, duralumin is heated to a temperature ranging from 400 degrees to 450 degrees C. At this temperature the material is very plastic, and easily worked. After pressing or rolling, the material must be reheated to 500 degrees C., and quenched in water under 30 degrees C., and then exposed to the air for four or five days. Drying or stoving in a warm place should be avoided.

Although, in this heat treatment, there is a large amount of play given in regard to the temperature, it is necessary to keep the final temperature of 500 degrees C., with 10 degrees on either side., i.e., temperatures from 490 degrees to 510 degrees C. are permissible. The heating is best done in a salt bath, composed of a mixture of sodium and potassium nitrates taken in equal quantities.

Like all other metals, duralumin allows a much smaller reduction of form in cold treatment than in the heated state. Several annealing periods are necessary, more so than, for example, brass and steel. Annealing for further treatment in the cold state is done at 400 degrees C. Reheating temperature latitude lies between 380 degrees C. and 420 degrees C. Annealing can be done in the muffle, or in the salt bath. The metal should be quenched in water after annealing.

If a higher yield point and greater ultimate strength are needed of the metal, then, after reheating, annealing and quenching from 500 degrees C., it should be further treated in the cold state by rolling or pressing. This cold treatment should take place only four or five days after annealing.

If duralumin is pickled in a 10 per cent. luke-warm solution of sodium hydroxide, rinsed in water, and dipped in nitric acid, and then again rinsed in water, it will have a beautiful silver-white colour.

CHAPTER IX

AUTOGENOUS WELDING

95. Repairing Worn or Broken Steel Parts.—This Chapter is included in this volume in response to questions put to the author by Mr. Norman A. Grandage, A.M.I. Mech. E., A.F. Aer. Inst., R.A.F. Station, Fort Grange, Gosport.

Mr. Grandage raises important questions relating to:

(*a*) The possibility of "building up" worn parts, e.g., crank pins (journals), valve stems, tappets, etc., by autogenous welding.

(*b*) The process of carrying out the above by electric deposition.

Another point referred to is the advisability of welding up and heat treating damaged steel fittings removed from "crashed" aeroplanes, e.g., undercarriage fittings.

Mr. Grandage concludes: "The subject is intensely interesting, wrapped up as it is with the question of suitable heat treatment prior and subsequent to welding. The foregoing questions are involved in the important problems of aeroplane salvage, which is bound to affect commercial aviation."

96. Reliability of Construction and Welding.—An examination, from the point of view of the steel maker, of the questions raised in the preceding paragraph, would suggest that the most satisfactory means of dealing with worn or broken steel aircraft, or aero-engine, parts is to sell the scrap metal for remelting purposes, and let the steel maker supply new material to take the place of the old. From financial reasons, however, it may be that this procedure would not, in many cases, meet with approval.

As regards reliability of construction, it should be remembered that the inherent possible defects arising from any process of welding are such that, in no case, can a welded part be guaranteed as satisfactory as a similar part would be without the welded joint.

The safety of aviation depends, very largely, upon absolute reliability of construction in every part of the machine. With this fact in mind it is extremely doubtful whether the welding of broken or worn aircraft parts should be encouraged. For instance, if the part has failed in ordinary service, the cause of failure may, broadly speaking, be attributed to either a defect or initial weakness in the material in the area where fracture occurred, or, alternatively, it may be due to a fault in design which has subsequently been the cause of a concentration of stress on the particular portion of the part where rupture took place. In any case, it is obvious that, if the part has failed in *ordinary service,* it cannot be recommended that the broken part be welded and put back into service to work under the same conditions which caused its original breakdown. Instead of putting the part back in a possibly weaker condition, it is evident that it should be made stronger than before by either adopting a new and stronger material or making some change in the design.

97. Area of Altered Molecular Structure.—Whatever may be the process by which two metals are welded together, there must always be an area, more or less sharply defined, of altered molecular structure. Just as heat-treatment alters the structure of steel in a manner which is unmistakable, so it is obvious that the local heating to the high temperatures, required for mechanically satisfactory welds, leaves its impression upon the steel in a manner which shows unmistakable non-uniformity of structure in the welded area.

98. Autogenous Welding, really a Casting.—It should be realized that an autogenous weld is, in truth, only a casting, and that, even with the best possible work, the weld will not be as strong as the original piece. If a forged, or pressed, steel part fails in service, it may be possible to weld it so that it will be strong enough. This would be particularly the case if there were space enough sufficiently to reinforce the weld. On the other hand, if the welded piece has to be machined to the original size, the chances are that unsatisfactory results will be obtained in service. This is particularly true of alloy steels, such as nickel and nickel-chrome steels. As these materials are used to a large extent in the manufacture of aircraft parts, it is particularly important to mention that, under no circumstances can parts made from these materials be welded and rendered nearly as strong as they originally were. It should be remembered that steel in the cast condition is never as strong as rolled or forged steel. . It is hardly possible, therefore, to go wrong in judging as to the advisability, or otherwise, of welding. In the details of aircraft construction it is far better to err on the side of safety than to take chances.

99. Alternating Stresses in Aircraft Parts.—Many aircraft parts are, in service, subjected to severe alternating stresses. The life and safety of these parts depend upon keeping the magnitude of these stresses below the " yield point " of the material. If the " yield point " is exceeded, fracture will occur in the course of time. It is well known that the " yield point " of cast steel, no matter how good, is much lower than that of forged or heat-treated steel, particularly than that of alloy steels. It is obvious, therefore, that fracture will occur much sooner in the case of a weld than in the case of the original piece, even if the weld is sound. As will be seen in the case of the experiments (see p. 105 § 109) on the welding of mild sheet steel, much can be done in the way of strengthening a weld by the subsequent application of correct heat-treatment; but, nevertheless, in spite of all, in the case of commercial aircraft work, welding is a doubtful proposition.

100. Each Welding Problem to be judged on its Merits.—It will, perhaps, never be possible entirely to eliminate all the inevitable defects likely to occur in welds. On purely scientific grounds, it would thus seem that all welds should, for the sake of greater security, be condemned. But the influence of the commercial aspect of the case is too complex to allow the subject to be so summarily dismissed. Sound practice demands that each problem of welding should be considered on its particular merits as it arises.

The question of saving cost is always an important factor in any commercial or industrial undertaking. Autogenous welding possesses, in certain circumstances, such great advantages that, whether the process meets with scientific approval or not, its use is bound to continue and extend.

Autogenous welding is the process whereby two pieces of metal are united by melting the adjacent edges of the metal together. The melting of the edges of the metal to be joined is, generally, accomplished by means of the heat produced from an oxygen-acetylene flame.

The use of the welding apparatus is a comparatively simple matter, and can be easily learned by very short practice. To become an expert welder is, however, more difficult. In order to execute welding in the correct manner, and to produce the best possible results, the operator should have a thorough understanding of the properties of the gases used, and of the metals to be welded. The knowledge of the properties of metals is necessary in the preparation of the parts to be welded, and it is often due to the lack of adequate preparation that comparatively simple operations in welding prove to be failures.

101. Precautions in Welding.—In order to attain successful results, certain precautions are necessary. The acetylene, for instance, should be free from any lime dust, or other impurities; and the burner should be large enough to ensure that the acetylene gas does not issue at too great a speed, and thus work with an excess of oxygen. The added metal should be of the best quality, and the drops should not fall in the joint until the metal at that point has been properly fused by the burner. Without this precaution no proper weld can be obtained, since the adhesion between the metals may, to some degree, be compared to the one that exists between wood and sealing wax.

The temperature of the oxy-acetylene flame is approximately 3,200 degrees C., and to secure the complete combustion of acetylene 2.5 volumes of oxygen are, theoretically, required to one of acetylene; but, in actual practice, it is found that the proportions are approximately 1.4 to 1.0.

The mixture of the two gases is made in a special blow-pipe, or torch, and the combustion of the two gases results in a very small but powerful flame. If the gases are mixed in incorrect proportions, the results of a weld may be very unsatisfactory. If there be an excess of oxygen, the flame produced will have an oxidizing effect. If, on the other hand, an excess of acetylene is introduced, the flame will have a carburizing effect. In this case a hardening of the metal in the region of the weld will result, and, in consequence, the finished part will be brittle. The correct flame for welding is one that is half-way between an oxidizing and carburizing one, i.e., a neutral flame.

102. Preparation of Parts for Welding.—The preparation of the parts to be welded requires very great care and forethought. In some cases great ingenuity is needed. This is especially so when a heavy part with an irregular fracture is to be dealt with. It is neither desirable, nor comfortable, to handle heavy pieces, especially when they are hot. After the work has once been set up, it is not advisable to turn a heavy piece over, as, then, the weld is liable to break. Also a sudden change of draught may crack the piece outside the weld. Frequently, it is necessary to set up parts in a fire, either because they are too heavy to weld otherwise, or because expansion, or contraction, causes them to break if welded cold. Such parts as cylinders and crank-cases should be kept hot all over, during welding.

103. Control of Expansion and Contraction.—One of the greatest difficulties to be overcome in welding is the one arising from expansion and contraction due to differences of temperature in different portions of the parts to be welded. Cast-iron being comparatively brittle, is very liable to cracks caused by temperature strains. But all other metals have also such strains in them, in a greater or less degree. Whilst they may not actually crack, they change their shape and become distorted if care is not taken to handle them properly. There is no definite rule for providing for expansion and contraction strains. It should be remembered that they are always present; and it is a matter of experience to know in what way they will manifest themselves.

104. Welding Rods and Wires.—In order to replace any metal that has been taken away, either through damage or for preparation of the part to be welded, additional material is necessary, and the material to use for this purpose depends on the nature of the metal of which the parts to be welded are made. The additional material is, usually, in the form of welding wires or rods, from 1/16 to 3/8 inch diameter.

In using welding rods care should be taken to ensure that no impurities are introduced into the weld; for example, the rods should be kept free from dirt or rust.

In welding steel parts, a rod of mild steel should be used of approximately the following composition:

C.	Si.	Mn.	S.	P.
0.10	0.15	0.60	0.04	0.04

For welding cast-iron, a rod of an iron alloy known as silicated cast-iron is invariably used. This material contains a fairly high percentage of silicon, which tends to reduce the brittleness of the weld by reacting with the carbon in the iron.

105. Fluxes.—To clean the surface of the metal to be welded, a flux is used. Fluxes are usually in the form of a powder. In the melting of metals, the impurities are invariably left in the solid condition after the metal has reached the fusing point; also it often happens that oxides form, which have a higher melting point than that of the actual metal. The purpose of using a flux is to dissolve off the impurities, or to produce a de-oxidizing effect which will retard the forming of oxides and, therefore, keep the metals clean for welding together. A liberal allowance of the flux should be spread over the surfaces to be welded. A flux recommended for use in the welding of cast-iron, malleable cast-iron, and steels is composed of:

Carbonate of soda	40 to 42.5	per cent.
Bi-carbonate of soda ...	40 to 42.5	,,
Borax	10 to 15.0	,,
Precipitated silica	5.0	,,

The salts should be chemically pure and anhydrous. They should be intimately mixed, and the mixed flux should be used in a sufficiently finely divided condition that it will pass through a 50 mesh sieve.

106. Welding Cast-Iron.—Cast-iron is the easiest metal to weld. A difficulty is sometimes encountered in the formation of blowholes extending some distance down in the weld to the surface. These blowholes, however, are generally small, and in the majority of cases are not of much importance. A frequent trouble in cast-iron welds is the inclusion of "hard spots." If good welding rods are used, these "hard spots" are the result of carelessness in welding, and they generally occur at the points where the old and new metal join. They are easily avoided by making the new metal, at the edge of the weld, a little higher than the surface of the old metal, and then melting the old metal and new metal, allowing the new to run into the old. If this is properly done, there will be no "hard spots" at that point.

Cast-iron welds are often stronger, and less brittle, than the original material. An explanation of this is to be found in the fact that it is finer grained and, inasmuch as the welding rods have to be made of good material, it is generally of a better quality than the original casting.

107. Welding Steel.—No attempt should be made to weld steel containing over 0.50 per cent. carbon. When welding steels, it should be remembered that they solidify very quickly. There is, in consequence, a danger of the metal not being thoroughly united at all points. The welding wire, on account of its comparatively small section, is liable to become burnt. Therefore, extreme care is needed in the handling of the torch. On account of the danger of burning the steel, it is important to use the correct size of tip in the torch. It should be neither too large nor too small.

It should also be remembered that steel has a strong affinity for oxygen at high temperatures. The welding flame should, therefore, be neutral. Moreover, care should be taken to avoid any oxygen escaping from the torch, and combining with the molten steel.

108. Heat-Treatment of Welds.—Provided that a really satisfactory weld has been made, the condition of the steel in the welded area may, somewhat, be restored by suitable heat-treatment. Table IV (p. 107) gives the results of some experiments on welded mild steel sheet test-pieces. The results obtained from the specimen marked B show that, in the welded condition, without subsequent treatment, a considerable lowering of the yield point occurs; but, after applying the treatment defined for the specimen D, the metal is practically as strong under tension loading as the original material. However, in most cases, no matter what treatment is applied after welding, it usually follows that the material is less capable of resisting vibration and shock stresses; and this fact should be kept in mind when deciding upon the advisability of welding specific parts.

109. Welded Joints Investigation.—An investigation into the strength of oxy-acetylene welded joints, in mild steel plates, was completed some time ago at the University of Illinois, and is described in the University Bulletin, No. 98.

For joints made with no subsequent treatment after welding, the joint efficiency, for static tension, was found to be about 100 per cent. for plates half an inch in thickness, or less, and to decrease with thicker plates. For static tension tests, the efficiency of the material in the joints, welded with no subsequent treatment, was found to be no greater than 75 per cent. The joints were strengthened by working the metal after welding, and were weakened by annealing at 800 degrees C. For static tests and for repeated stress tests, the joint efficiency sometimes reached 100 per cent; the efficiency of the material in the joint was always less. This indicates the necessity of building up the weld to a thickness greater than that of the plate. Impact tests show that oxy-acetylene welded joints are decidedly weaker under shock than the original material. For joints welded with no subsequent treatment, the strength under impact seems to be about half that of the material.

110. Aluminium-Zinc Alloys.—The surface of aluminium alloys is very easily oxidized. When exposed to ordinary air, alloys containing a high proportion of aluminium become covered with an impervious thin neutral film. This oxide covering, as in the case of other metals, is a serious obstacle to welding and soldering operations. Its complete removal is necessary in order to secure a homogeneous metal-to-metal joint. The great difficulty in the welding of aluminium alloys lies in the fact that the action of a flame, of any kind, tends to oxidize the metal as rapidly as it can be cleaned.

The melting point of these alloys is about 650 degrees C. When they are melted an oxide known as alumina forms, and to melt this oxide a temperature of about 2,800 degrees C. is necessary. Unless the oxide is cleaned away during the welding operation, a satisfactory weld cannot be made. The tendency is for the oxide to become mixed with the molten metal and weaken the weld.

On account of its chemical inertia it is difficult to decompose the oxide by means of a flux. Fluxes for this purpose have, therefore, to be very strong, and chemically active.

111. Flux Powders for Aluminium Alloys.—The following are the compositions of several flux powders in use with aluminium alloys :

1.	*Sodium Chloride*	30 per cent.
	Potassium Chloride	45 ,, ,,
	Lithium Chloride	15 ,, ,,
	Potassium Fluoride ...	7 ,, ,,
	Sodium Bisulphate	3 ,, ,,

2.	*Lithium Chloride*	33 per cent.
	Potassium Chloride	33 ,, ,,
	Sodium Fluoride	33 ,, ,,

3.	*Lithium Chloride*	20.8 per cent.
	Potassium Chloride	62.5 ,, ,,
	Sodium Chloride	12.5 ,, ,,
	Potassium Bisulphate ...	4.0 ,, ,,

4.	*Potassium Chloride*	79 per cent.
	Sodium Chloride	16 ,, ,,
	Potassium Sulphate	5 ,, ,,

5.	*Potassium Chloride*	83 per cent.
	Sodium Chloride	17 ,, ,,

6.	*Lithium Chloride*	23.5 per cent.
	Potassium Chloride	56.0 ,, ,,
	Sodium Chloride	6.5 ,, ,,
	Sodium Sulphate	4.0 ,, ,,
	Cryolite (Aluminium-Sodium Fluoride)	10.0 ,, ,,

As will be seen, these fluxes are composed of a mixture of alkaline chlorides in various proportions. In their dry form the powders are very hygroscopic, and are liable to deteriorate by the absorption of moisture. The melting point of the flux must be somewhat below that of the metal, so that the former will melt and flux away the oxide just before the metal begins to flow.

TABLE IV.

SHEET STEEL WELDING EXPERIMENTS.

Analysis:	C.	Si.	Mn.	S.	P.
	0.21	0.037	0.50	0.06	0.06

Sheet: 22 *Ga. thick. All specimens taken across the sheet. Welded by oxy-acetylene method.*

Mark on Specimen	Treatment after welding	Tensile Test				Remarks on Fracture
		Y.S.*	M.S.*	E.%*	R.A.%*	
A.	As rolled (not welded).	32.62	38.88	10.5	49.4	Silky.
B.	As welded.	26.58	33.38	7.0	50.4	Silky. (Broke clear of weld).
C.	Normalized at 930°C.	22.31	26.12	5.8	37.4	Broke across the weld, partly along it 90% Silky. 10% Finely granular.
D.	Heated to 930°C. cooled in water. Reheated to 700°C. cooled in water.	31.37	37.29	12.5	55.7	Silky. (Broke clear of weld).
E.	Annealed in charcoal at 750°C.	17.13	26.52	11.8	53.9	Silky with a trace unsound

112. Use of Flux for Aluminium Alloys.—In actual use the flux powder is moistened down with alcohol, otherwise it will be scattered by the draught from the blowpipe. Some welders employ the flux in the form of a core to the feeding stick, which is made hollow for the purpose. This method can, as a rule, only be used as supplementary to the flux pasted on the joint. Feeding sticks should be of the same composition as the alloy. Although it is theoretically advisable to use a flux when welding aluminium and its alloys, and while in case of sheet aluminium it is necessary to do so, there are practical reasons in the case of repair jobs to

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* Y.S. = Yield Stress in tons/sq. in.; M.S. = Maximum Stress in tons/sq in.; E. = Elongation; R.A. = Reduction of Area.

some castings why no flux is used. In some cases where the condition of the surface before welding makes the use of a flux very difficult, it very often happens that a weld can be made without the use of a flux in less time than it would require to prepare the work so that a flux could be used.

113. Constitution of the Oxy-Acetylene Flame.—In common with almost every gas flame, that of the oxy-acetylene torch has three zones. The first zone, the one immediately next to the blowpipe nozzle, is a luminous jet burning with a white flame. In it the oxygen and the acetylene are in process of combustion. The next is the reducing zone. This is the useful part of the flame; in it the combustion is complete, and there is neither an excess of oxygen to oxidize the work, nor an excess of carbon to deposit soot. The third zone is the oxidizing one. In it, on account of its proximity to the surrounding air, there is an excess of oxygen.

For welding aluminium alloys the work should always be in the reducing zone about half-an-inch from the tip of the luminous jet. In adjusting the flame, excess of acetylene will cause a luminous greenish envelope to form round the white jet. If the acetylene valve is throttled down until this just disappears, the flame will be found just right for welding, as the gases would be then in their correct proportions.

114. Preparation for Welding Aluminium Alloys. — Before commencing to weld, the edges of the joint are carefully squared, cleaned and fluxed. Most classes of work, except very light gauge sheets, are butted; thin sheets are lapped or hooked. The flame is usually applied at an angle of about 45 degrees to prevent burning, but for thick sheets of 3-16th inch, and upwards, it may be directed perpendicularly on to the work. It is important that the operator should run down the joint very quickly, with torch and feeding stick, at a uniform rate.

115. Expansion and Contraction of Aluminium Alloys.—The expansion of aluminium due to heat, is about 0.148 inch per foot length for every 540 degrees C. by which the temperature is raised. On account of this high expansion coefficient, a certain clearance must be left when commencing to weld. This clearance will of course close up as the work proceeds. Owing to the high thermal conductivity of aluminium, the heat is rapidly carried away from the seam, and, for this reason, somewhat larger blowpipes should be used for welding aluminium alloys than are required for other metals.

There is considerable shrinkage in an aluminium weld. This defect should be remedied, as much as possible, by leaving the full thickness of the section. In some cases it is possible to spring a part to allow for contraction; but in many cases this is not possible. The narrower the weld, the less is the contraction and distortion of the piece. Hence, the smaller the amount of metal removed before welding, the better.

In order to minimize contraction strains, large castings should be pre-heated to about 250 degrees C. Before pre-heating, the part should be covered with asbestos sheeting. After welding the casting should be reheated and allowed to cool very slowly.

116. Impurities in Aluminium Alloys.—Aluminium alloys contain certain impurities, such as iron and silicon, which, together with aluminium, form a brittle and hard alloy. If the impurities are present in a high percentage, say, 1 per cent., the quantity of the alloy formed is sufficient to form a network round the grains of metal. This may cause the weld to fracture. Therefore, it is necessary that, in the primary stages of manufacture, the impurities in aluminium alloy castings should be kept as low as possible. Attention to this matter, in the manufacture of new parts, provides for the possibility of welding these parts if accidentally fractured in service.

117. Solders for Aluminium.—On account of the resultant distortion, the heating of aluminium alloy parts to the relatively high temperature necessary to join them by means of autogenous welding is, in many instances, inadvisable. In such cases one has to consider the question of soldering, both as regards the method to be adopted, and the metals or alloys to be used.

The United States Bureau of Standards* has gathered data on the subject of aluminium soldering, based upon current experience, and has made special tests, the results of which may be summarized as follows:

All metals, or combinations of metals, used for aluminium soldering are electrolytically electronegative to aluminium. A soldered joint is, when exposed to moisture, therefore, rapidly attacked and disintegrated. There is no solder for aluminium of which this is not true. Joints should accordingly never be made by soldering unless they are to be protected against corrosion by a paint or varnish; or unless they are quite heavy, such as repairs in castings, when corrosion and disintegration of the joint near the exposed surface would be of little consequence.

The surfaces to be soldered should be carefully cleaned with a file or with emery, and should then be "tinned" or coated with a layer of the solder by heating the surface and rubbing the solder into it. Solders are best applied with a flux. The composition of the solder may be varied within wide limits. It should consist of a tin base with addition of zinc, or both zinc and aluminium, the chief function of which is to produce a semi-fluid mixture within the range of soldering temperatures. Tin-zinc solders may range from 15 to 50 per cent. of zinc, with the remainder tin. Tin-zinc-aluminium solders may have a varying composition of zinc, 8 to 15 per cent.; aluminium, 5 to 12 per cent.; and the remainder tin.

The higher the temperature at which the tinning is done, the better the adhesion of the tinned layer. By using the higher values of the recommended zinc and aluminium percentages given, the solder will be too stiff at lower temperature to solder readily, and the workman will be obliged to use a higher temperature, which

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* Circular No. 78.

secures a better joint. A perfect union between solder and aluminium is very difficult to obtain. The joint between previously tinned surfaces may be made by ordinary methods, and with ordinary soft solder. Only the tinning mixture need be special for aluminium. There is no reason why a good solder for aluminium need be brittle, as several commercial varieties are. In fact, it is very undesirable that it should be. The tensile strength of a good aluminium solder is about 7,000 lb. per square inch. The strength of a joint depends upon its type and upon the workmanship. Too much dependence should not be placed upon the strength of a soldered joint.

118. A.W.P. Process of Welding.—This is the name given to the method of welding devised by The Alloy Welding Processes Ltd. It is a means of electric arc welding in which one pole of the arc is formed by a metal electrode, which is covered with the necessary welding flux in correct proportions. The compound used for coating the metal electrode is used not only as a flux, but as a means of enclosing the molten metal, and thus protecting it from oxidation during its transit from the electrode tip to the work.

To give satisfactory results the composition must melt away at the same speed as the metal of the electrode, and in a liquid state form a complete protection to the molten metal during and after its transition to the work. The coating also gives a directional control of the deposited metal which is lacking in the bare electrode, and it can be made a means of imparting certain constituents to the weld metal, and so adjusting the physical characteristics of the weld.

The main constituent of the coating of A.W.P. electrodes is selected so that it effects a reduction, in the weld metal, of phosphorus, sulphur and silicon, all of which are detrimental to the ductility of the weld. In addition, the electrodes are provided with a supplementary coating of a deoxidizing character that assists in keeping the weld free from oxide inclusions, and causes the metal to flow smoothly and evenly. The resulting weld by this method is, therefore, of a very fine structure, and free from slag and oxide inclusions, forming a strong and ductile joint.

Special attention has been given to the problem of welding and depositing special steels by this method. Electrodes of similar composition to the material to be repaired are used. The process is specially adapted to the repair of crankshafts and similar objects, where the cross section of material must not be increased.

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