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# Some Notes on the Hardening and Heat Treatment of Steel

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The object of this paper is to present in a reasonably simple form the metallurgical principles involved in heat treatment. The hardening and tempering of steel has been chosen for illustration as this material is by far the most common in engineering. It must be remembered, however, that the application of thermal treatments to any metal or alloy is based upon a similar series of structural changes, the basis of which is the heat equilibrium diagram.

As a natural sequence to the behaviour of carbon in iron, the influence of other metallic elements is discussed. No attempt has been made to discuss in detail the specific problems of any one industry, such as the size of components that are met with in marine engineering. The appendix attached gives in detail methods of test for heat-treated components.

The object of the paper has been to assist engineers by giving sufficient fundamentals to enable heat treatment of iron and steel to be more clearly understood and, it is hoped, to dispel the ideas still existing in some quarters that hardening consists of "heating the steel to cherry red and dipping in water".

#### INTRODUCTION

Any attempt to cover completely the field of hardening and heat treatment of all metals and alloys in a paper of this description would be futile. Modification of physical properties of metals and alloys can be achieved in two main ways, namely, by the application of heating and cooling cycles, and controlled deformation in metals at, or very slightly above, room temperature, the latter being known as cold working. Of these methods, structural modification by the application of heat followed by suitable means of quenching is the more widely used, particularly in the case of iron and steel. The application of heating and cooling as a method of modifying the properties, and hence the uses of metals, has been known almost as long as have the various methods of physical manipulation, but it is only in relatively recent times, owing to metallography and X-ray crystal analysis that the fundamental principles have been investigated, partially understood, and applied to initiate and develop the science of heat treatment. As a young science it is natural that a very considerable amount of work is still in progress on the more obscure chemico-physical phenomena involved, and it is for the reason of the vast amount of detailed information available that a complete survey in a technical sense would be impossible without writing many volumes of fact, theory or opinion. It is proposed, therefore, to indicate without too much detail, the fundamental factors influencing the reaction of ferrous metals to heat treatment, the

properties so developed, and the methods in general use in industry today.

Production of ferrous components can be divided (from the aspect of procedure in heat treatment) into two main categories, namely, small and medium components and on the other hand, large castings and forgings as are found in marine engineering.

In the case of the former it is true to say that design basically determines the specification of the material to be used and that efficient performance of a design involving heat treatment depends very largely upon the reproducibility of properties in successive batches. In the case of the large forgings and castings, however, it is often necessary to choose a specification which, although known to be suitable in the function of the part, is specifically chosen for the ability to manipulate such a large mass in subsequent heat treatment.

Whether the component be large or small, modern design of heat treatment equipment and furnaces has resulted in a maximum of control. The human element cannot be eliminated but modern methods aim at efficiency with a minimum of skill yet a maximum of control.

Production calls for close collaboration between the designer, whose main interest is satisfactory performance, the production engineer, who has to make it at a reasonable cost, the metallurgist, who can advise on the correct choice of material and its associated heat treatment, and the material supplier, upon whom depends to a great extent the ultimate success of the complete project.

The cost of many products is higher than need be, either due to the use of unnecessarily expensive specifications, or costly by service failures due to the lack of understanding of material and the properties that can be developed by correct heat treatment. It is hoped that the following will serve to indicate the type of information that is available to engineers and designers.

#### THE IRON-CARBON EQUILIBRIUM DIAGRAM

Before considering or discussing the methods of heat treating or hardening, it is advisable to study the changes that occur during heating and cooling an iron alloy. These changes can be produced graphically in what is known as the iron-carbon equilibrium diagram.

If a series of alloys with iron, and progressively increasing amounts of carbon between the range 0 per cent to 1.7 per cent could be prepared, slowly raising each composition to just below its melting point, at the same time measuring temperature at fixed time intervals, a curve, plotting these values would show at least two discontinuities until a composition of approximately 0.85 per cent carbon was reached, when there would be one (see Fig. 1). Having obtained curves for a comprehensive range of such alloys it would be possible to plot a second curve or diagram, namely, the temperature at which the discontinuity or discontinuities occurred, against the carbon content of the steel. These would produce a diagram of the form shown in Fig. 2. This diagram is a simple equili-



FIG. 2—Modified iron-carbon equilibrium diagram (Bullens)

brium diagram for the iron-carbon system, and represents changes that will occur in the steel during heating for the carbon range indicated.

The arrest points mentioned above indicate structural changes in the steel and the particular temperatures at which they occur are known as critical points or temperatures, usually referred to for brevity, as "criticals". As more than one critical exists, it is necessary to give them an identification which is done by referring to them as Ac1, Ac2, and Ac3, the letter "c" (derived from the French "chauffage") indicating that



FIG. 1—Diagrammatic illustration of the arrest points in the heating curves of simple iron-carbon alloys

they occurred during heating, and the number the order in which they occur. Thus Ac1 is the first critical passed upon heating the steel beyond a certain temperature. The lines in the equilibrium diagram, therefore, represent these criticals for the range of carbon 0 per cent to 1.7 per cent, and the space enclosed by them, areas of similar structure.

#### METALLOGRAPHIC CONSIDERATIONS

Iron and steel are crystalline substances. By suitable techniques involving polishing, etching and subsequent microscopical examination, at magnifications between 100 and 2,000, the structure can be seen and understood and provides, therefore, a method of studying changes that occur in the crystalline form as a result of heat treatment.

Before discussing structures to be found it may help the reader to discuss briefly and identify various phases to be found in a carbon steel. The structures between the ranges of 0 per cent to 1.7 per cent carbon can be classified as hypo-eutectoid or hyper-eutectoid, the dividing line between these two categories being the eutectoid composition which occurs at approximately 0.85 per cent carbon. Hypo-eutectoid compositions are those containing less than 0.85 per cent carbon, and hypereutectoid those containing more than 0.85 per cent carbon. Alloys containing more than 1.7 per cent of carbon are

Alloys containing more than 1.7 per cent of carbon are usually considered to be cast irons, although in certain special instances true alloy steels are used with carbon as high as 2 per cent, but only in the presence of large quantities of other alloying elements such as chromium.

Ferrite is the name given to iron in the crystal form that exists in a slowly cooled steel at room temperature. In such steels, providing the carbon is less than 0.85 per cent, the carbon is nearly completely combined to form the carbide, represented chemically by  $Fe_3C$ , which consists of approximately 7 per cent carbon and 93 per cent iron. This carbide is referred to as cementite.

During the process of cooling at a slow rate from above Ac3 this cementite forms a mechanical mixture with the ferrite in such a way as to contain a definite amount of ferrite, resulting in an ultimate lamella formation containing approximately 0.85 per cent carbon.

This mechanical mixture of ferrite and cementite is referred to as pearlite. At the eutectoid point, therefore (0.85 per cent carbon), the ultimate structure in a slowly cooled steel will be completely pearlitic. A hypo-eutectoid composition will consist of ferrite and pearlite, ferrite being in excess, and in the hyper-eutectoid series, pearlite and cementite, the latter being in excess. The constituents, ferrite and cementite, are the all-important phases upon which the hardening of the steel basically depends.

Consider the changes that occur when heating an 0.02 per cent carbon steel. No change occurs in the constituents on heating until the lower critical Ac1 is reached, which is approximately 725 deg. C. In passing through this critical there is a complete change in the pearlite, the latter being converted into an entirely new constituent, known technically as a solid solution, and is named austenite. It is called a solid solution because the dissolution of the iron carbide in the iron crystals to form this austenite occurs with all phases in the solid state. At this stage there is excess ferrite which remains unchanged.

As the temperature is raised still further above the Ac1, this newly formed austenite begins to absorb the excess ferrite, which dissolution continues as the temperature is further increased until the upper critical Ac3 is passed, at which time the ferrite is completely dissolved by the austenite, forming a single uniform solid solution. Austenite can dissolve and hold in solution anything from 0 per cent to 1.7 per cent carbon, depending upon the temperature reached for a given composition, the limits of which are shown in the equilibrium diagram by the line GSE (Fig. 2). It is not known with any certainty whether the austenite holds the carbon in solid solution as elemental carbon or in the form of the carbide; but from practical aspects of heat treatment this is completely irrelevant. The formation of the solid solution austenite is of paramount importance in the heat treatment of steel, as it is from this condition that quenching is used to retain the carbide in an alternative form to the pearlite or cementite, formed by slow cooling, and it should be clearly understood that the heating of the steel is a preparation for the subsequent cooling, and, unless the former is done correctly, the latter cannot achieve uniformity of results.

The first rule, therefore, in hardening or applying a heat treatment to a steel, involving a modification of structure, is that the temperature Ac3 must be passed before any quenching is attempted.

It is not intended within the scope of this paper to enter into any discussion of the modification of crystal forms that occur in the ferrite and cementite constituents or the various temperatures or methods of formation, but should anybody be interested in the crystallography of these changes, reference should be made to any well-known text book on the subject.

Austenite cannot be retained in a plain carbon steel by any form of quenching. Austenite is in itself known to be soft and ductile and as such, obviously has no use in a steel in which hardness is the first consideration. By quenching austenite as rapidly as possible a new constituent known as martensite is formed, which is usually regarded as a solid solution of the carbon or carbide in ferrite and as such is relatively unstable, particularly towards heat. Martensite is intensely hard and brittle and it is this constituent that bestows hardness upon a quenched steel. Subsequent heating of a martensitic structure results in further transition constituents, the first of which is known as troostite. Reference will be found in metallurgical text to two forms of troostite-primary troostite and secondary troostite. Primary troostite is the name given to a structure which may be an emulsion of ferrite or cementite with pearlite and which is derived direct from the austenite, and not via the hard constituent martensite. Secondary, or what is usually considered to be the true troostite, is the result of the tempering or break-down of martensite. Further application of heat to the troostite forms sorbite which is the ferrite and cementite of the pearlite in a non-lamella The name sorbite is usually reserved for structures form. derived from quenching and subsequent tempering.

It will be appreciated that there is no sharp line of demarcation between any one of these phases or structures and although the broad categories of martensite, troostite, sorbite and pearlite are referred to, there are equally as many, if not more, border line structures which could be referred to as troosto-martensite, troosto-sorbite, sorbitic-pearlite, etc., apart from the special structures such as Bainite, observed by special quenching techniques.

Starting therefore, with the hard, but basically unstable constituent martensite, the formation of any structure by applied heat, right down to the original form of pearlite in ferrite, is a continuous process.

As each particular constituent bestows a definite property upon the steel it will be appreciated that reproducibility of results must depend in the first place upon the successful formation of the hard phase martensite, by quenching, which in turn is dependent upon correct heating prior to such quenching.

The foregoing description is that of the simple case of a low, straight-carbon steel. The hardness derived from a quench is dependent upon the amount of carbon present. Thus, compositions up to approximately 0.25 per cent carbon will not develop any appreciable hardness on quenching, whereas a 0.25per cent to 0.45 per cent will toughen, whilst further increase of carbon up to 1.1 per cent will produce full hardness. From 1.1 per cent to 1.7 per cent no further increase in hardness is obtained, the excess cementite in this range bestowing other properties upon the steel.

Having seen that hardening and other manipulations involving heat treatment are dependent upon the manipulation of solid solutions of iron containing carbon, it is necessary to consider the effects of the addition of other elements.

#### ALLOYING ELEMENTS

The simplest alloy of iron will always contain six elements, namely, iron, carbon, manganese, silicon, sulphur and phosphorus. Of these, sulphur and phosphorus are virtually unavoidable impurities and except in very rare instances do not constitute true alloying elements, for which reason they are kept as low as possible, usually less than 0.05 per cent. Carbon is the all-important element. Manganese can be used in varying amounts for several distinct reasons, which will be discussed at a later stage in the text. The amount of silicon present also varies with the use to which the alloy is to be put.

The range of properties conferred upon carbon steels by the addition of any single element is limited, and it is, therefore, frequently necessary to resort to the use of two or more alloying elements to obtain properties beyond those specifically produced by the single element. Moreover, the elements used in forming these alloys vary in cost, and more often than not economical considerations necessitate replacement of the more expensive ones by alternative quantities of cheaper elements where similar or identical physical properties can be obtained by so doing.

To indicate individually or collectively the effect of the many elements that can be added would take far more space than is permitted in this paper, but the following summary<sup>(1)\*</sup> will serve to indicate the amounts commonly in use, with brief notes of their influence:—

- Phosphorus: Under 0.04 per cent in heat-treated steels, around (P) 0.10 per cent in some free-machining steels, up to 0.15 per cent in low-C, high-yield-strength steels.
- Sulphur: Under 0.055 per cent in heat-treated steels, 0.10-0.30 per cent in some free-machining steels in conjunction with high Mn. (Not an alloying element.)
- Carbon: 0.10-0.20 per cent in steels for carburizing, and (C) 0.07-0.15 per cent in high-yield-strength steels for welding; 0.20-0.40 per cent in most constructional steels and castings; 0.40-1.20 per cent in various spring and tool steels.
- Manganese: Over 0.25 per cent and under 2 per cent in most (Mn) structural steels, 12-14 per cent in austenite castings.
- Silicon: (Si) Very low in rimming steels, from 0.10-0.30 per cent in most steels, around 0.50 per cent in castings, up to 0.75 per cent in high-yield-strength steels, 1.0-1.75 per cent in graphitic steels, up to 2 per cent in spring steels, still higher in low-C steels for electrical uses.
- Copper: About 0.20 per cent in "copper-bearing" atmospheric-corrosion resistant steels, up to 1 per cent in high-yield-strength steels, 1 to 2 per cent in steels for precipitation hardening.
- Nickel: Usually 2.50-3.50 per cent when used alone, and (Ni) up to 5 per cent in carburizing steels, 0.50-3.75 per cent in complex steels. 8 per cent or more added to corrosion resistant Cr austenitic steels. Special uses for high Ni steels.
- Chromium: Under 1.50 per cent in most structural steels for (cr) heat treatment, 0.50-4 per cent in tool steels, larger amounts in still-tube steels, 12-30 per cent in corrosion-resistant "stainless steels".
- Aluminium: 0.01-0.10 per cent for grain-size control. Seldom (Al) used as ordinary alloying element, save 1-5 per cent in special nitriding and up to 5 per cent in special heat resisting steels.

Titanium: 0.01-0.20 per cent for grain-size control. (Ti) Vanadium: 0.01-0.20 per cent for grain-size control and

Vanadium :0.01-0.20 per cent for grain-size control and slight<br/>alloying effect.(V)alloying effect.0.25-5 per cent in tool steels.

\* See references p. 10.

Molybdenum: About 0.20 per cent in constructional steels, smaller amounts in high-yield-strength steels; (Mo) 0.50-1.5 per cent in steels for high temperature service, up to 9 per cent in tool steels.

Tungsten:Very rarely used in constructional steels. Around(W)1-2 per cent in steels for high-temperature service.vice.0.50-20 per cent in tool steels.

Except for the auxiliary elements aluminium, vanadium (and for molybdenum and tungsten in steels for high-temperature service) the amount of any one element will be reduced when others are added. This is especially true for carbon.

Sulphur, without the presence of manganese, forms an iron sulphide which tends to segregate to the grain boundaries of the steel, causing brittleness, whereas the addition of manganese forms the manganese sulphide which exists in random dispersion and acts as a chip breaker during machining, thus imparting good machining properties to the steel in question. For this reason sulphur with correspondingly high manganese is used up to 0.5 per cent for the special purpose of high machineability, but is not recommended in parts that have to be heat treated, in which case sulphur should be maintained at a maximum of 0.05 per cent. Manganese is the weakest of the carbideforming elements and acts largely in strengthening the ferrite.

Manganese markedly decreases the critical cooling rate and makes for depth hardening. Depth hardening is a very important factor in heat treatment of large masses and forgings, such as are to be found in marine engineering. Reverting to the earlier description of the metallurgical phases to be found by quenching, it will be remembered that martensite is the hardness producing phase. It can be said that the critical cooling rates necessary to produce this martensite, free from troostite, are roughly expressed by the terms "water hardening", "oil hardening", or "air hardening", rather than in the more scientific method of degrees per second.



FIG. 3—Depth hardening in carbon and alloy steels (Bain)

Depth hardening, or "mass effect" as it is sometimes called, can be illustrated by quenching test pieces of uniform sizes in various media, sectioning and plotting the drop in hardness from the edge to the centre (see Fig. 3). The ability to make steel harden by slow cooling rates, and particularly in the case of these large masses, is the most important reason for the use of alloys in steel, as it can be shown that a plain carbon steel will harden only to approximately 0.25 inch deep, no matter how rapid the quenching.

In order, therefore, to ensure uniform cross-sectional properties in a large mass, careful selection of composition must be made and the advice of the steel maker sought in arriving at the appropriate element to be used in the alloy to give a balanced combination of physical properties, heat treatment, and, of course, cost.

Although manganese has been mentioned for its properties of producing depth of hardening, other alloying elements produce the effect to a greater or lesser degree. All elements that depress the critical points have the similar effect of making the austenite to martensite transformation sluggish, until, in the case of the very high chromium nickel alloys, the austenite remains unchanged by quenching in any media. These are the well-known range of austenite corrosion-resisting, or heat-resisting steels.

To conclude these very brief notes on the effect of alloying elements, the following  $extract^{(1)}$  serves nicely to present the purpose for which the alloy or alloy combinations are used and the specific effects attributable to one or two particular elements.

Strengthen ferrite P, very strong. Si, Mn, strong. Ni, Cu, Cr, Mo, W, fairly strong. V, weak. Form carbides Ti, Cb, V, very strong. Cr, Mo, W, strong. Mn, fairly strong. P, Ni, Cu, Si, no carbides.

Confer depth hardening Mo, W, Mn, Cr, strong. Si, medium. Cu, Ni, weak. V, very weak. Stabilize martensite and troostite on tempering Mo, W, strong. V, fairly strong. Cr, weak. Mn, very weak. Others, no appreciable stabilization.

Restrain grain growth of austenite Al, very strong. V, Ti, Zr, fairly strong. Mo, medium. Cr, Si, weak. Mn, very weak. Ni, practically no action. Decrease eutectoid content Mn, Cr, V, considerable. Ni, Mo, W, somewhat. Si, Cu, Al, no appreciable effect.

#### Specific effects

Mo minimizes temper brittleness.

- Mo, W, confer high temperature strength, especially in company with other carbide formers.
- Ni confers toughness without brittleness, and especially confers low-temperature impact toughness.
- Cu over about 0.80 per cent confers ability to precipitation harden.
- Cu and Cu + P, even in small amounts, confer improved resistance to atmospheric corrosion.
- Cr in large amounts confers resistance to corrosion under oxidizing conditions and to oxidation on heating.

#### METHODS OF HEAT TREATMENT

In the parlance of the engineer, there are two methods of heat treatment, namely, straight hardening and case hardening. Both names fairly accurately describe their purpose. Straight hardening always infers that the section is hardened throughout its mass, whereas case hardening is equally as logical insofar as a surface hardness, not necessarily over the entire component, is developed by suitable means.

The earlier remarks on the effect on composition of alloying elements, critical rates of cooling, equilibrium diagrams, mass effects, etc., have been based upon a homogeneous alloy of iron and carbon containing the appropriate amount of the latter to give the desired structure. Treatment of such alloys is carried out by heating the mass uniformly and as slowly as is practical to a suitable temperature above the upper critical point, ensuring complete absorption of all ferrite by the austenite, and quenching in a suitable media, such as oil, water, brine (hot, warm or cold) to give the desired rate of cooling to form martensite, or a near hard constituent, which can be tempered subsequently to still yet another modification depending upon the properties desired. For example, components subjected to heavy wear conditions will be left in their maximum hardness, having been tempered sufficiently to remove stresses resulting from quenching. Components required to give medium wear conditions, but subject to a slight or moderate impact or bending may be tempered at a slightly higher temperature, resulting in a loss of hardness but an improvement in the degree of

toughness. Such components as axles, crank shafts, connecting rods, are made from materials chosen for toughness and high tensile properties and are invariably made from alloyed steels (in which a full martensite is not the result of quenching) and are then subjected to tempering at a temperature as high as 600 deg. C., which produces the best combination of tensile and impact properties. Where used as, or in conjunction with, rotating or moving parts, such components have, of course, to be used with suitable external bearing materials.

The equipment used for this type of heat treatment is well established and straightforward, consisting of gas, oil or electrically heated furnaces with automatic pyrometric control, designed for very uniform temperature in the heating zone, such furnaces more often being provided with a protective atmosphere to prevent oxidization and scaling.

The method of packing depends upon the shape of the component, which must be well supported, as it is distinctly plastic at high temperatures and its own weight will cause bending or sagging if the component is left free to move.

The required speed of quenching depends upon the alloys being heat treated; the more highly alloyed the steel the slower the critical cooling rate, or in other words, the less drastic the quench. This does not necessitate rapid transfer from the furnace to the quenching media, but, in the case of straight carbon steels in which maximum hardness is obtained by water quenching, heat lost between furnace and quench is important and the transfer must, therefore, be carried out in an absolute minimum of time. As quenching constitutes a danger from the point of view of further distortion, the actual method used again will depend upon the shape of the component. Thin, slender or long sections require careful handling or bending will result. Agitation of the quench is important because slow entry into a still medium will result in oil or steam bubbles adhering to the surface of the component being quenched, resulting in soft spots. Quenching produces considerable initial stress as a result of the volume change which occurs when austenite breaks down into any of the lower structures, and it is important, therefore, that tempering should be carried out as soon as pos-sible after quenching. The larger the component, the more important is this point, as obviously the stresses are higher. In fact, in the case of large components it is usual practice not to quench until absolutely cold, but to remove with as much heat left in the job as can be tolerated without having a tempering effect and reducing the hardness below that aimed at.

Cracking constitutes another danger, particularly in the case of fast-quenching materials, and it is often necessary to increase the temperature of the water used as high as is permissible without losing hardness in the quenched article.

It must be reiterated that unless heating is done properly and methodically, ensuring that soaking is carried out at a temperature above the upper critical for that steel, for the time necessary for complete dissolution of the ferrite, then the results of quenching will show considerable variation and will not produce the desired or optimum result.

Heating is only a preparation for the cooling.

#### ISOTHERMAL HARDENING

Perhaps the most attention in recent years has been paid to the development of what is known as isothermal transformation methods. Of the several processes generally classed under this heading, considerable work has been done on the possible application of martempering and austempering. Martempering and austempering, although rather different in their object and application both depend upon the rate of cooling of the steel in question, but in these instances, as distinct from conventional methods, a pronounced time effect is introduced.

The quenching media in this case are usually molten salts, the temperature of these and the time for which the component is soaked depending entirely upon the specific property to be obtained.

A curve can be built for a particular type of steel known as either an "S Curve" because of its shape, or more correctly,

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FIG. 4—A typical "T.T.T." or "S" curve

a "Time, Temperature, Transformation", or "T.T.T. Curve" (see Fig. 4).

The various structures produced by progressively increased cooling rates, and the times at a given temperature necessary to produce such a structure, can be plotted. The object of austempering is to avoid the formation of martensite, necessitating slow cooling, but nevertheless, fast enough to avoid the formation of pearlite. By so doing, with a steel of suitable composition, an intermediate emulsified structure is obtained, known as Bainite, named after Bain, an early worker in this field.

Bainite is characterized by unusual toughness in a hardness range of 35-50 Rockwell, not to be found in the same steel conventionally hardened and tempered to the same hardness. Unfortunately in the case of straight carbon and the lower alloyed steels, austempering can only be carried out in relatively thin sections and so finds its main application in such small components as springs.

Whether or not the steel can be austempered can only be decided from its T.T.T. curve, a study of which will determine the time available to avoid the pearlite change and the time required to achieve complete transformation.

The arrested quench temperature in the case of austempering is usually in the region of 350 deg. C., and it will be appreciated that by being able to apply such a relatively gentle quench distortion is minimized.

In the case of martempering, the temperature at which the article is quenched is slightly above the point of the austenitemartensite change and the temperature will, therefore, vary with the composition of the steel. The sole object of martempering is to obtain a maximum hardness with an absolute minimum of distortion, because, by arresting the quench immediately prior to the austenite to martensite transformation with its attendant volumetric change, any uneven dimensional movement is minimized during the subsequent cooling through the transformation temperatures. Such cooling must, therefore, be carried out in draught-free conditions, and on no account should any form of quenching or forced cooling be resorted to.

#### CASE HARDENING

An important and much used branch of heat treatment is concerned with the selective hardening of the surface of components made from steel of suitable composition. In a component the property of wear resistance is always confined to the surface and for a short distance below to allow for the normal amount of wear experienced in service. The core of such a component may have to withstand high stresses, either direct or alternating, in which case it is desirable to be able to control the toughness as distinct from the hardness. In order to produce this combination of hard surface and tough core case hardening is resorted to, during which process a tough, but relatively low carbon steel, has its surface enriched by increasing the carbon content very considerably.

Case carburizing, that is the manufacture of a high carbon layer upon the chosen steel, produces case hardening, or the heat treatment of the case, or of both case and core when quenched and tempered. Carburizing is essentially a chemical process in which carbon in an active state is absorbed by the steel and diffuses inwards to a desired depth which can be controlled. Such carbon can be supplied by a decomposition of carbon monoxide generated from solid compounds, or as in the case of gas carburizing from some hydro-carbons.

It will be remembered from the earlier description on the formation of structures and phases that it was mentioned that ferrite has almost no carbon dissolving powers, whereas austenite will dissolve up to 1.7 per cent. For this reason the process of diffusing carbon into steel has to be carried out above the upper critical point when the steel is fully austenitic.

By maintaining a plentiful source of active carbon at the surface of the steel, and holding it at the correct temperature, inward diffusion can be made to proceed to almost any depth, but it is unusual in normal practice to exceed  $\frac{1}{32}$  inch, but it may, on the other hand, be only a matter of a few thousandths of an inch. It has been shown that the rate of diffusion of carbon is greater the larger the difference between the carbon on the inside and that on the outside. For core toughness the ductility of the low carbon steels is sought, hence the bulk of steels used for surface hardening have a carbon content in the order of 0.1 to 0.2 per cent.

Alloys are also used in such steels, not only to hasten the rate of the carbon pick-up at the surface, which would necessitate the use of carbide forming elements, but also for the purpose of increasing core strength and depth of hardening in the same way as discussed previously in this paper.

It is sometimes desirable to maintain certain areas of the surface soft after quenching, for which purpose there are two or three methods of approach. Firstly, parts of the surface can be protected with inert materials such as copper, fire clay and proprietary paints, etc., which completely prohibit penetration of carbon, or secondly, by leaving excess material to be removed by machining after the carburizing and before the quenching process. Of these two specific methods mentioned, appropriately applied porous-free, electro-deposited copper is undoubtedly the best.

The temperature of carburizing has to be chosen to ensure that the rate of carbon absorption is at an optimum without the objection of excessive grain growth. The more common source of carbon monoxide is charcoal, usually energized and accelerated by various compounds such as barium or sodium carbonate, which tend to take up carbon dioxide, thus enriching the gas with all-important carbon monoxide.

Oils are sometimes added with the idea of displacing air in the box by the oil vapour generated before carburizing temperature is reached, so that primary scale, which it must be appreciated would seriously interfere with the surface reactions of the carbon monoxide, is avoided.

The actual method of carburizing is too well-known to warrant extensive description, but there are one or two precautions to be taken that are well worth mentioning.

The method of packing in solid compound will initially depend upon the shape and size of the article to be carburized. For example, long slender pieces should be packed vertically, thus minimizing the possibility of sag. Gears and similar pieces may be most suitably packed in tubes so that the same amount of carburizing material and the same degree and length of heating will influence all parts of the periphery in equal proportions.

If a non-energized compound has been used, as is sometimes the case where a high degree of control or cleanliness is required, it is unwise to use the compound a second time, but in the case of an energized compound the same may be used, providing new compound is added, usually in the ratio of one new to two old.

The box containing the parts must be well luted to prevent gas loss and heating should be gradual to prevent rapid expansion causing the lids to leak, apart from the objectionable fact that the steel will not heat uniformly throughout the box and will, therefore, not carburize evenly.

#### GAS CARBURIZING

A method of carburizing coming into favour in recent years has been that with the use of gas instead of solid compound, in which case the essential factors, are:—

- (a) A gas-tight retort with provision for inlet and outlet in the chosen atmosphere into which the work is laid in baskets or special carriers made of heat resisting steel.
- (b) Heating in most cases is by electricity with resistancetype elements, external to the retort, although the radiant tube type of heating is sometimes used.
- (c) Circulation of the atmosphere is brought about by a fan driven through some form of gas-tight seal by an external motor.

Much investigation into suitable atmospheres has been carried out and a considerable choice is available. Coal gas can be used raw, but is usually modified by additions of hydrocarbons such as propane or butane. Another method of obtaining a suitable atmosphere is to drip a suitable liquid or oil into the hot interior of the furnace where it is vapourized and "cracked" to give a satisfactory carburizing medium. In all cases, proper metering and control of the flow of gas and oil are necessary. The basic advantages in this method of carburizing over the pack or box method may be summarized as follows:—

- (1) The elimination of the cost and inconvenience of both carburizing compound and boxes and the consequent abolition of the waste of heat involved in heating these adjuncts of normal pack carburizing.
- (2) Much greater output for unit area occupied, due to the fact that work occupies a far greater proportion of the furnace area than in pack carburizing. The vertical type of furnace with its small floor area is particularly suitable for this method of carburizing.
- (3) This compactness, and the elimination of unpleasant ancillaries, such as compound packing and unpacking, makes it possible in practice to bring the heat treatment department out of the remote corners to which it is so often consigned and to place it more conveniently in the flow line of the production, with the consequent convenience and saving of transport.
- (4) Another outstanding advantage of this process is the greater control of the product quality which it renders possible. By suitable adjustment of the composition and flow of gas, time and temperature, the depth and characteristics of the case can be modified over a wide range. By reducing the flow or character of the carburizing atmosphere, the build-up of carbon at the surface can be halted and the case allowed to "diffuse" or even out.

There are, of course, certain disadvantages which must be considered when reviewing the possibilities of this process:—

- (i) The capital cost of a gas carburizing plant is appreciably greater than that of a corresponding conventional plant. The first cost of charge carriers is also high. Provision must be made also for replacement of retorts, etc., which, in spite of the great improvements achieved, still tend to have a limited life compared with the refractory lining of an ordinary muffle type of furnace.
- (ii) Sooting can become a serious problem if conditions are not properly controlled. Soft soot has only nuisance value, but the formation of hard, dense, adherent carbon deposits can lead to the sealing of the surface,

or parts of the surface, against the carburizing gases, resulting in "lean" cases and soft spots.

(iii) Parts packed in compound during pack carburizing receive naturally a general overall support if properly packed. This is not the case with gas carburizing and the method of packing frequently requires careful consideration if distortion is to be avoided. Particularly is this the case if fairly deep baskets or work carriers are used, in which case the lower parts often have to support considerable weight. Suitable supports can always be devised, but the use sometimes restricts the useful load and their first cost and maintenance must be borne in mind.

In all questions concerning packing, the necessity for thorough gas circulation around all important areas must not be forgotten.

(iv) The fact that greater control over quality is possible carries with it the proviso that greater care in control is also required. Generally speaking, however, the equipment supplied for gas carburizing is provided with well-developed facilities for automatic maintenance of a suitable work cycle once this has been arrived at. Labour charges for a given production can certainly be lower than for the same production by box carburizing.

#### SALT BATHS

A third medium used for surface hardening is salts, of which the most common by far are sodium or potassium cvanide Carburizing is again carried out in the austenitic range by immersing in the molten salts which break down at this temperature to release active carbon and nitrogen, both of which are capable of being diffused into the steel. The case derived from such a cyanide bath is a mixture of carbides and nitrides and is attractive for its application where considerable abrasive conditions are involved. It has the added advantage of producing extremely clean work by virtue of the fact that all air or oxidizing atmospheres are completely eliminated by the protection of the molten salt. The type of steels used for cyanide hardening are similar in every respect to those used for pack or gas hardening and can be quenched either direct from the carburizing temperature or cooled to room temperature for subsequent re-treatment.

Whichever method is used, carburized articles are at this stage virtually duplex steels or alloys in which the core has one carbon content and the case another, usually 6-7 times as much in the latter as the former.

By reference, therefore, to the earlier discussion on equilibrium diagrams it will be realized that to develop the optimum conditions, two distinct heat treatments must be applied at temperatures suitable to the core and the case.

Consider a core of 0.15 per cent carbon with a case of 1.0 per cent, the latter having been arrived at by carburizing and diffusion. Reference to the equilibrium diagram shows the upper critical of 0.15 per cent to be in the region of 900-920 deg. C., whereas the critical for the 1.0 per cent is about 780 deg. C. If, therefore, the steel is quenched from 920 deg. C., the core will produce a structure in which the small amount of carbon is fully retained in solution. During this process the case, with the lower critical temperature, will have been exceeded considerably, resulting in fairly extensive grain growth and hence, brittleness. If, therefore, the steel is re-heated to 780 deg. C. and quenched, the case will be refined, but as the core has not exceeded the upper critical by some 120 deg. C., no modification other than tempering will have occurred. This is a sequence known as core refining, which is usually accomplished by oil quenching, followed by case hardening in which maximum hardness is accomplished by water or oil quenching (depending upon the alloy in question) followed by suitable stress relieving temper.

#### NITRIDING

To overcome objections and difficulties associated with

quenching components, either on a straight hardening or a case hardening type, a range of steels is available which is capable of absorbing nitrogen (derived from cracked ammonia) to form extremely hard nitrides. Thus, the well-known nitriding process completely eliminates all necessity for quenching, the reaction and diffusion of nitrogen taking place readily at temperatures as low as 480 deg. C. Similar ranges of toughness can be obtained in the core of these types of steel by suitable pre-treatment, and after dimensional correction case hardnesses to nitrogen.

#### HIGH FREQUENCY

An even more recent development in the surface or local hardening of components is by the application of high-frequency induction heating. The use of eddy-current heating is by no means of recent origin, in fact it has for many years been used in steel melting and billet heating, in which case, energy is derived from motor generators at a frequency in the order of 2,000 to 10,000 cycles per second.

More recent progress in thermionic valves has considerably widened the application of induction hardening, by making available almost any frequencies. Induction heating of a metal is made possible by transfer of electrical energy from a conductor carrying the high frequency into the metal, which by virtue of its resistance, sets up an induced current within the surface of the alloy.

It will, therefore, be appreciated that by suitable design of inductors, heat can be applied to the surface of an article in only those areas it is desired to harden or treat (see Fig. 5).



FIG. 5—Control of hardened zone in a cam by suitable coil design

Frequency is a big factor in this type of heat treatment as it controls to a very great extent the depth of penetration for a given power. As an approximation the following ranges and applications should be noted:—

- 50-1,000 cycles per second for low temperature heating of large masses.
- 1,000-10,000 cycles per second—deep penetration and melting.
- 100,000-500,000 cycles per second—relatively deep surface heating of metals.
- 1 million-10 million cycles per second—very shallow penetration for sheet and wire.
- Up to 50 million cycles per second—for dielectric heating of woods and plastics, etc.
- In this range motor generation can be used up to 10,000 cycles per second, after which valve oscillators are employed.

In this country there is a tendency to standardize at about 500,000 cycles per second and most sets do not allow for a frequency variation, in order to keep the size and cost of the equipment to a minimum. The application of high frequency induction heating is not quite so straight-forward as may appear at first sight, for there are limiting factors, both technically and economically. The heat treatment of a given component depends largely upon the following:—

- (1) The power available.
- (2) The type of inductor used.
- (3) The coupling of the inductor to the work.
- (4) Penetration required.
- (5) The type of materials used.

The overall efficiency of the method will also obviously depend upon: ---

- (i) Automatic or semi-automatic methods of handling components.
- (ii) The method of quenching.
- (iii) Maintenance of limits affecting the air gap or the location of the component in the inductor.
- (iv) Maintenance of consistency of the analysis of the material in question.
- There are three main methods of heating a component: (a) By a simple water-cooled coil, roughly following the contour of the component.
- (b) By an eddy-current concentrator in which the surfaceflowing high frequency currents are concentrated at points or small areas relative to the part being treated (see Figs. 6 and 7, Plate 1).
- (c) By the more unusual method of using a high frequency transformer with a single coil inductor.

Simple components are usually handled by symmetrical coils with a suitable number of turns, whilst on the other hand, the concentrator consists of a simple multi-turned coil, embracing what is essentially a single turn secondary, which can be shaped so that the surface flowing current is made to flow over a narrow area coinciding with a specific area to be treated. Such a secondary is usually massive and can be arranged for water cooling and, if necessary, for pressure quenching of the work-piece through a concentrator crest.

Thus, by suitable automatic magnetic valve control, the period between cessation of heating and commencement of quench is kept to an absolute minimum—an important point, as the rate of conduction of heat in the work-piece away from the heated surface is very high.

The technique of dropping the heated article into a quenching media is satisfactory for relatively deeply heated cases, providing the drop is short.

The high frequency transformer has a very similar application and in both cases it will be obvious that the efficiency of either depends upon the coupling or constant air gap with the component under treatment. This latter point is important, as only by its maintenance can an automatic time cycle produce the same results in consecutive pieces.

It must be remembered that the heat generated by eddycurrents varies inversely as the square of the distance. By attention to the shape of the inductor relative to the profile of the component, overheating of edges can be avoided and likewise variation in contour hardening can be effected.

The depth of penetration is primarily a function of frequency, the lower the frequency the deeper the penetration and *vice versa*. For a given frequency and power, the deeper the penetration, the higher the surface temperature, because to some extent the greater depth is derived from the induced current, but mostly from conduction of the surface heat into the mass.

Surface hardening by this method employs the use of carbon and alloy steels normally capable of straight hardening. From the author's experience it would appear that because of the very small heating times involved a balance between carbon and manganese to closer limits than normally maintained by commercial specification is desirable to overcome variation in the final product and to prevent cracking.

The type of steel usually used is BSS.EN.9, EN.10, or a similar steel with a range of carbon between 0.35 per cent and 0.55 per cent. It will be appreciated that because of the extremely high rate of heating by high frequency methods, over-heating is permissible without the attendant risk of grain growth because the latter is dependent upon time. Likewise, steels that normally would exhibit extensive cracking tendencies in mass after water quenching can be water quenched by high frequency methods by virtue of their relatively shallow heated



FIG. 6—Eddy-current concentrator for gear tooth hardening

FIG. 7—Concentrator designed for hardening one lobe at a time on a multi throw cam

FIG. 8—Coil arrangemen bases of four filters



FIG. 9-Decarburization at the edge of a section of spring steel

× 250



FIG. 10-Retained austenite in a troosto-martensitic structure



FIG. 11—Similar area to Fig. 10 after treatment at - 80 deg. C. Note "peppery" precipitate amongst the acicular structure



FIG. 12—Coalesced or spheroidized carbides in a sub-critically annealed 1.1 per cent steel



FIG. 13—The same steel as Fig. 12, annealed to produce lamella pearlite

zone. In other words, steels in the past kept exclusively for oil quenching can be case hardened by high frequency methods followed by water quenching.

High frequency induction finds very extensive use in soldering (see Fig. 8, Plate 1), local annealing, local tempering, and local hardening, but each component must be studied on its own merits. As a guide to the amount of power required, 10 kilowatts per square inch of surface to be heated are required for economical surface heating. The cost, therefore, of suitable equipment for hardening or treating large areas or forgings is made prohibitive by the initial outlay for the equipment.

Old and modern methods of heat treatment have so far been broadly outlined in their method and application. Having done so, it is opportune to enumerate a few of the more common defects arising from heat treatment. In the case of straight hardening steels the more common defects resulting from the entire procedure of heat treatment are distortion, quench cracking and decarburization.

Distortion is dependent upon the specification of the steel used, and consequently, the method of quenching adopted and upon the shape of the article being treated. Although distortion can be overcome to a certain extent by manipulation during processing, its elimination can only be effected completely by the choice of the right steel, permitting the most gentle form of quench. Where design requirements necessitate properties only obtainable by rapid quenching, it is often necessary to resort to quenching jigs.

Cracking during quenching is the result of rapid volume changes or stress movement, and can arise from locked stresses in the material, either as the result of processing during steel making, heterogeneity of the structure, tooling stresses, contamination of an oil quench by water, or the use of an incorrect quenching media suited to the analysis of the material in question. Cracking can also be aggravated by design of the article, particularly where notches and other sudden section changes are present.

Probably the most insidious defect arising from heat treatment is decarburization. Decarburization is the result of the loss of carbon from the surface layers (see Fig. 9, Plate 2) usually due to chemical action involving water vapour, hydrogen, carbon monoxide, or a combination of these three and is to be found most frequently as a result of treatment in certain types of so-called neutral chloride salt baths. The loss of carbon results in a skin of pure ferrite which can vary in depth. Such a skin is obviously detrimental in the case of articles subjected to abrasive service, and thin skins are often missed during testing such articles by the use of too heavy a load on the hardness machine. Consequently, scuffing occurs, resulting in failure of the component. Perhaps the biggest danger of decarburization is in the case of parts subjected to an alternating cycle of stresses. Owing to the weakness of the ferrite, fatigue strength or, in other words, the resistance of the material to withstand a cycle of stress may be reduced by as much as 45 per cent due to initiation of cracks in the weak ferrite becoming stress raisers in the part. In the question of case hardening, particularly by the pack method, the main defect to be found is subsequent spalling, resulting from a cementitic net-work in the case, due to the latter being too rich in carbon (see equilibrium diagram). Such cases are brittle and difficult to grind and even if spalling does not occur, surface grinding cracks become stress raisers, again to the detriment of the component, particularly if subjected to fatigue conditions. Soft spots in case hardened articles are invariably the result of dirty carburizing or incorrect quenching resulting from steam or oil gas pockets preventing a full quench locally.

#### SUB-ZERO TREATMENT

Some recent work has given the heat treatment engineer yet another tool which, when correctly used within its limitation, tends to improve the product. Earlier discussions in this paper have pointed out the effect of certain alloys on the transformation of austenite, namely, that they introduced "sluggishness". It is well known that in certain circumstances of

quenching with high alloy steels this sluggishness prevents the normal anticipated transformation to martensite to some extent, resulting in a structure mainly of the latter, but still containing undecomposed austenite, or as it is usually referred to, retained austenite (see Fig. 10, Plate 3). This retained austenite is unstable and by subjecting the component to temperatures in the order of -80 deg. C. can be made to precipitate more martensite (see Fig. 11, Plate 3). It must be borne in mind that the martensite so obtained is completely untempered, and any such treatment must always be followed by tempering at at least 150 deg. C. It will be appreciated that retained austenite in the structure of a hardened component implies dimensional instability, particularly if working conditions are conducive to a subsequent breakdown to martensite. For this reason it is highly desirable that a component subject to abrasive service should be free of this phase. Apart from these facts the presence of any appreciable quantity of austenite in the martensite matrix will reduce the overall hardness, which would be increased were the austenite broken down to martensite.

The more highly alloyed the steel the more the tendency to retain austenite. The case hardening steels of the S.82 type, die steels such as 2 per cent carbon-14 per cent chromium are particularly prone to this retention and, in these instances, the introduction of a sub-zero cycle is strongly recommended.

It will, no doubt, be pointed out that the process of subzero treatment was originally discussed in connexion with the hardening of high-speed steel in which there is an undoubted application for exactly the same reasons as quoted above, but, in the author's opinion, only made necessary by faulty initial heat treatment.

In the question of the high alloy steels mentioned, faulty heat treatment does not enter into the picture because it is the composition of the steel that determines the sluggishness, whereas in the case of the high-speed steels, retention is a result of either incorrect austenizing, quenching, or secondary hardening, and despite the fact that it is known that such retained austenite will tend to stabilize at room temperature, it can be broken down by adequate attention to the tempering operations.

#### NORMALIZING AND ANNEALING

Little mention has been made of the two treatments of normalizing and annealing. Normalizing involves heating the material to some 80 deg. C., above the upper critical point which, of course, fully austenizes the material, and cooling fast enough to allow re-crystallization without holding the carbide in solution, so that the ultimate structure consists of pearlite and ferrite. Annealing on the other hand may, or may not, involve passing the upper critical point. Fully annealing, the object of which is to produce the softest possible condition in a given analysis, does consist of exceeding this point followed by very slow furnace cooling, whereas normalizing usually involves cooling in still air.

Various other types of annealing involve maintaining just below the lower critical for long periods or fluctuating just below or just above the same, with the object of coalescing the carbide of the lamella pearlite to produce what is known as a spheroidized structure (see Fig. 12, Plate 4) which although not necessarily the softest condition of the material, considerably improves the machineability over the same composition in the lamella form (see Fig. 13, Plate 4). Subsequent heat treatment may not be quite so easy to achieve due to the tendency for the spheroidized carbides to be sluggish in going into solution compared with the lamella pearlite, but for practical commercial production this objection can be ignored in view of the greatly improved properties to be obtained by the treatment.

Normalizing a suitably alloyed material, particularly in large masses, can produce the same physical conditions as will hardening and subsequent tempering, and it is, therefore, quite common to find components used in the normalized condition, thus saving additional heat treatment, with its attendant dangers of cracking and distortion.

#### CONCLUSIONS

The reader will realize from the brief notes on the various aspects mentioned hitherto, how deep is this subject of heat treatment. No attempt whatsoever has been made to correlate the effect of various pre-treatments, such as annealing and normalizing on the final heat treatment, or to discuss the numerous fine points of detail in connexion with composition, machineability, hardenability, factors governing distortion or movement during the heat treatment, special alloys, precipitation hardening, strain hardening, critical grain growth, etc., nor has it been possible to amplify the principles involved. It is trusted that the foregoing will give sufficient information to enable the engineer to appreciate the function of the metallurgist, who is ever-willing to apply his knowledge to production.

Production today is essentially a combined effort but it is appreciated that there are times when it is necessary for the engineer to be able to apply heat treatment in the same way as it is necessary for the metallurgist to apply engineering, and the brief fundamentals discussed in this paper have as their object a means of assisting engineers who have to carry out thermal treatments.

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#### APPENDIX

#### TEST METHODS

The principal factor controlling the selection of an alloy, and consequently the method of heat treatment, is the purpose for which the part is to be used, and therefore the definite properties to be developed by such a heat treatment.

These properties can be fairly well defined and tested in appropriately selected test pieces to ensure continuity of quality. It is not intended here to enter into the significance of the various properties used in design, but for the benefit of the reader a few notes on the definition of these properties will serve to indicate generally the conditions that can be modified

by heat treatment to suit the particular purpose in mind.

Probably the most important properties in any steel article are: strength in tension, ductility (shown either by bending, elongation, or reduction of cross-section area) and hardness. For the purpose of definition of these terms and a brief description of the method of arriving at them in test procedure, the following extract from the British Steels Institution<sup>(2)</sup> could not be bettered : ---

## TENSILE TESTS

Definition of Testing Terms (a) Limit of Proportionality Stress. This is the stress (load divided by original area of cross-section of the test piece) at which the strain (elongation per unit of gauge length) ceases to be proportional to the corresponding stress. In practice it is determined by inspection of a load elongation diagram (obtained by plotting extensometer readings) and is the stress at which the load elongation line ceases to be straight (see Fig. 14).



FIG. 14—Load-elongation diagram (B.S.I.)

Note: In order to determine accurately the limit of proportionality, a high degree of sensitivity and accuracy of both extension and load readings is necessary.

(b) Yield Stress. This is the lowest stress at which the elongation of the test piece increases without increase of load. For practical purposes the yield stress is defined as the stress at which a visible permanent increase occurs in the distance between gauge points on the test piece observed when using dividers; or at which, when the load is increased at a moderately fast rate, there is a distinct drop of the testing machine lever, or, in hydraulic machines, a hesitation in the movement of the gauge finger.

Note: In general, yield stress applies to mild steel and wrought iron. In the case of those materials which do not show a definite yield stress, a determination of proof stress is sometimes specified.

(c) Proof Stress. This is the stress which is just sufficient to produce a permanent elongation equal to a specified percentage of the original gauge length.

It can be determined (i) by direct measurement of the gauge length after various loads have been applied to the test piece and removed, or (ii) from the load-elongation curve by drawing a line parallel to the straight portion of the curve and distant from it by an amount representing the required permanent elongation, thus determining the load at which the line cuts the curve (see Fig. 14).

Alternatively, if the specification does not lay down a maximum value of the proof stress, the material shall be deemed to have passed the proof test if, when the specified proof stress is applied to the test piece for a period of 15 seconds and removed, the test piece shall not have acquired a permanent elongation greater than the specified percentage of the gauge length.

(d) Ultimate Tensile Stress. This is the maximum load reached under the prescribed testing conditions divided by the original cross-sectional area of the gauge length of the test piece.

(e) Percentage Elongation. This is the percentage increase

of the standard gauge length obtained by measurement of the fractured test piece.

The full value of the percentage elongation may not be obtained unless fracture of the test piece has occurred at a section situated between the gauge marks and at a sufficient distance from the nearest gauge mark. Usually the fracture is required to take place within the "middle half" of the gauge length.

Care should be taken to ensure proper contact of the broken parts of the test piece when making the measurement.

(f) *Percentage Reduction of Area.* This is the greatest percentage decrease of the original cross-sectional area obtained by measurement of the fractured test piece. To obtain accurate results the measurement should be made using a knife-edged vernier or a conical or ball-pointed micrometer.

(g) Young's Modulus of Elasticity. This is the value of the increase of stress divided by the corresponding increase in strain for the straight portion of the load elongation curve (see Fig. 14). Some materials do not give an exactly straight load elongation line, and it is general for the limits between which the apparent modulus of elasticity is determined to be stated.

#### Hardness Test

This form of test is particularly useful for indicating certain properties of the material when it is not possible to obtain sufficient material to provide test specimens for carrying out the previously mentioned tests.

Briefly the test is a measure of the resistance of a material to deformation under an indentor of standard form and, as such, offers a very efficient aid to the control of engineering and metallurgical products by a simple, easily applied and nondestructive test which can be made at any desired stage of manufacture.

There are three established methods for indentation hardness tests in this country: ---

(a) Brinell.

(b) Diamond pyramid.

(c) Rockwell.

Brinell Test. In this test, a steel ball is pressed into the material and the Brinell hardness number is expressed as the quotient of the applied load divided by the spherical area of the impression. The spherical area can be calculated directly by measuring the diameter of the impression (the mean of two readings at right angles) and the hardness number is therefore given by the following formula:—

$$H = \left(\frac{P}{D^2}\right) \left(\frac{-\frac{2/\pi}{1-\sqrt{1-\frac{d^2}{D^2}}}\right)$$

Where P = load, kilograms.

D = diameter of ball, mm.

d = diameter of impression, mm.

H = hardness number.

Balls of 1 mm., 5 mm. and 10 mm., may be used, though the last is the one which is most common in commercial testing.

The load applied may be such as to give  $\frac{P}{D}$  ratios of 1, 5, 10 and 30 respectively.

A low ratio should be used with a material of low hardness number, and the higher ratio for a material of a high hardness number, as follows:—

Materials of hardness number up to

20 (lead, tin and their alloys)... 
$$\frac{P}{D}$$
 ratio of 1.  
Materials of hardness number 20 to

60 (copper and aluminium) ...  $\frac{P}{D}$  ratio of 5.

Materials of hardness number 60 to 160 (copper alloys and alumin-

ium alloys) ... ...  $\frac{P}{D}$  ratio of 10.

Materials of hardness number above

160 (steel, cast iron) ...  $\frac{P}{D}$  ratio of 30.

For any given class of material, a close relationship between the Brinell number and the tensile strength can be established.

- (a) The test should be made on a smooth flat surface.
- (b) The test piece should be of adequate thickness, i.e., ten times the depth of the impression.
- (c) Any impression should be at least two and a half times the diameter of the impression from any edge.
- (d) The test load should be applied for 15 seconds.
- (e) The testing machine used and the microscope for measuring the diameter of the ball should all have an accuracy of 0.5 per cent.

Diamond Pyramid Hardness Test. This test is similar in principle to the Brinell except that a sharp pointed diamond pyramid (angle of 136 deg.) is used instead of a ball. The pointed indentor enables the test to be used on a range of materials considerably harder than those for which the Brinell test is satisfactory.

The diamond pyramid hardness number is, as before, the quotient of the applied load divided by the pyramidal area of the impression.

The pyramidal area can be calculated from the size of the square impression made, and for this purpose the mean of two readings of both diagonals is determined, and the diamond pyramid hardness number is given by the formula:—

$$H_{\rm D} = \frac{2P\sin\frac{136 \text{ deg.}}{2}}{d^2}$$

Where P = load, kilograms.

d = diagonal of the impression, mm.

 $H_{\rm D}$  = diamond pyramid hardness number.

The loads normally employed are 5, 10, 20, 30, 50, 100 and 120 kilograms. The points enumerated above to be observed when making a Brinell test apply also to this test.

The Rockwell Test. This method of testing indicates directly the hardness number of the scale attached to the machine. In this test a minor load is applied to a penetrator and causes an indentation in the test specimen.

While the minor load is still operating it is augmented by a major load with resulting increase in the depth of indentation, after which, when the major load is removed, still retaining the minor load, partial recovery in the depth of indentation eliminates the indication of the deflexion of the structural members during the application of the load.

This test can be done either with a diamond cone with rounded point, or with a hardened steel ball. Rockwell hardness numbers are read directly on an indicator and are derived from measurement of depths of the impression in the following manner: —

$$\frac{H}{R} = E - e$$

Where e is the difference of the depths of penetration before and after the application and removal of the major load, and while the minor load is in operation in both cases.

The value of e is expressed in units of 0.022 mm.

E is an arbitrary constant. Its value depends upon the form of penetrator used, as shown in the accompanying table.

Scale	Form of penetrator	Minor load, Kg.	Major load, Kg.	Value of E	Uses
A	Diamond cone	10	50	100	Thin hardened steel strip and very hard materials.
В	1.558  mm. $(\frac{1}{16} \text{ inch})$ ball	10	90	130	Mild steels, medium car- bon steels, steel sheet and soft steel bars.
С	Diamond cone	10	150	100	Hardness steels and har- dened and tempered alloy steels.

In making a test of this type the following are points of particular importance to be observed:—

- (a) The machine should be accurate, and this may be checked by the use of specially calibrated steel blocks.
- (b) The load must be applied axially to the penetrator.
- (c) The specimen shall be rigidly supported, and the surface on which the impression is made shall be smooth and clean.
- (d) The impression shall be at least two and a half times the diameter of the impression from the nearest edge.

As the three hardness systems given in the foregoing text are all in general use in industry today it is convenient to be able to translate the results of one in terms of the hardness units of the other. There is, however, no general theoretical relationship and any empirical formulæ devised from experiments hold closely only for materials of approximately similar composition and in a similar condition.

Of other tests those most commonly used are cupping, impact, creep and fatigue.

Of these, creep refers to the properties of materials in tension or compression under conditions of elevated temperature, whereas fatigue relates to the application of cyclic stresses.

In both cases the amount of information available is very appreciable and it is not intended to amplify in this instance.

The cupping test is invariably reserved for the measurement of ductility in sheet metal.

In the case of the impact test there is considerable variation in opinion as to its value, but nevertheless it must be considered to be an important contribution towards the measurement of quality of heat-treated materials, particularly as a measure and control of brittleness, as well as the behaviour of components in which it is necessary by design to have to tolerate notches or other stress raisers. An impact test invariably consists of breaking a test piece suitably notched with a hammer with a known force or kinetic energy, and measuring the amount of energy absorbed in fracturing the test piece.

The indulgence of the reader is asked for the length of the foregoing description, but in the author's opinion no heat treatment can be intelligently undertaken without some basic knowledge of what will happen to the steel. Having done half the job well, it is always wise to check that what was required has, in fact, been achieved. If this is not done, one is assuming the correctness of the steel or the several metallurgical conditions previously discussed that are a result of heat treatment.

# Discussion

DR. J. E. GARSIDE, who opened the discussion, said that in present times when productivity was so very important, it was really vital that those concerned should know how to use correctly the materials available, and so far as metals were concerned, heat treatment should play a very important part indeed.

It was true that one knew how to harden steel and how to control the hardness precisely, but it was all rather empirical. He did not wish to criticize, but he wondered whether those concerned really knew why hard steel was hard. Again, did those concerned know what was meant by "hardness" itself? The more one thought about it the more it seemed that a very difficult problem was being faced, and it merited much further thought and study.

It was gratifying to note that the author appeared to stress the importance of employing metallographical techniques. He had literally writhed on a number of occasions when attending lectures to note how prone were many lecturers to throw electron micrographs on to the screen. They looked very impressive, but one might ask whether they went very far. In his view not enough was known about those things yet, and it was gratifying to see reference made and illustrations shown of differing types of micro-structures. It might be as well to take the hint which the author had given and think more about the metallographical side rather than delve too far at present into the more academic side of electron microscopy.

There were a number of points in the paper which perhaps merited a little further consideration. With regard to nitriding, which was a very important process of surface hardening, it could not be stressed too much that that process could be carried out on a wide variety of steels. It was not necessary to use only specific steels. Nitriding could be carried out on high-speed steels and austenitic steels. That opened a much wider field of use for nitriding which permitted the final heat treatment being carried out at a temperature of approximately 500 deg. C., which was well below the critical range and below any temperature at which any appreciable distortion could take place. Again, the process of nitriding was useful in as much as it did, in many cases, give a much better resistance to corrosion. When nitriding a piece of steel it was not often necessary to harden the whole of the surface, but it was necessary to carry out some process of coating as in the case of carburization to protect those parts of the surface which finally must remain soft. Normally most people used tin coating, and he wondered whether the author would venture an opinion on the various advantages or relative merits of the processes of tinning, such as hot tinning, electro-deposited tin, and so forth.

It had become very important in recent years to heat-treat the surface of steels by high frequency induction heating, and reference was made to that process. In general, most of the smaller units were of the thermionic valve oscillator type, and it would be interesting to have an opinion regarding the reliability of those particular types of oscillators. He had had little experience in using one, his work being very limited in the academic world, and it would interest him to know how long his set was likely to last! Difficulty was also found in forming any useful idea of the relative costs of treatment with the high frequency hardening as compared with what seemed to be a more simple method, namely, "Shorterizing". In his view this latter process was so simple in many ways that it merited a good deal of attention. One also ought to keep in mind that in the matter of surface hardening one could think of chromium plating, but there were other processes of surface hardening. It was possible to carry out the processes of chromizing in which steel was heated in an atmosphere of chromic chloride from which metallic chromium was deposited on the work. In addition, hard patches could be put on work by welding processes; it had been well known for many years that "Stellite" tips could be put on the tops of valves and components of that sort.

It was pleasing to note that reference was made to hardenability, because he was of the opinion that hardenability was a property which should be considered very early on when deciding which particular steel should be employed. Perhaps the author would care to give a little further information regarding the methods of testing hardenability.

On the question of salt baths, probably most people would have had some experience in the use of that type of heat treatment, but was it known that there were different varieties of salt baths available. One ought perhaps to stress the advantages which could be obtained from the use of the electrode salt bath in which the electrodes were actually immersed in a bath of molten salt. The result was not electrolysis but the passage of a powerful electric current between the electrodes. The heating effect did give rise to very rapid melting and there was an adequate mixing of the salt. In his view it provided a very satisfactory salt bath of uniform temperature, but that did not appear to be stressed sufficiently.

With regard to sub-zero treatment, that was a fairly recent treatment and he wondered whether the author would care to say anything about the type of refrigerant which he had found most satisfactory. Perhaps he could say whether carbon dioxide and trichlorethylene were generally satisfactory, or whether anything could be said about other types.

The influence on design seemed to be a matter of considerable moment. In his own view, quite a number of the failures really started at the drawing board. One often saw things produced with sharp angles which would give the heat-treatment shop man a very difficult time.

As to testing, the author had said something about the



FIG. 15

Brinell type and the Rockwell type of testing, but it would be interesting to have his opinion on one or two other types of hardness testing instruments. He had in mind the Herbert pendulum hardness tester. That was often necessary to determine the hardness of a piece of metal *in situ*. In most cases it was not possible to take the article to the laboratory; the laboratory had to be taken to the piece being tested. The Herbert hardness tester could be applied *in situ*. Then there was the scleroscope which was still used to a limited extent.

Still on the question of the testing of hardness *in situ* he wondered whether those present were familiar with a little practical dodge which he came across a short time ago for determining the hardness of a piece of steel. The set-up was as shown in Fig. 15.

The plunger was struck smartly, so producing two indentations with one blow, one on the test piece, the other on the steel in the mild steel tube. It was simple to measure *in situ* the diameter of the indentation on the test piece, the diameter of the indentation on the loose piece of steel being measured in the laboratory. From a comparison of these two diameters the hardness of the test piece could be evaluated.

With regard to the Rockwell tester, he wondered whether the author would agree that it was not perhaps the best type of hardness tester because it was prone to errors and was a little unreliable. It was perhaps most satisfactory as an inspection tool or a passing-out tool, and he preferred to pin his faith to a Vickers Pyramid hardness tester or a Firth "Hardometer".

He had one small criticism which was that ferrite was the name of a solid solution and not pure iron. However, that did not detract in any way from the value of the paper.

DR. L. C. BANNISTER said that the author was to be congratulated on fulfilling his aim, as stated in the beginning of the paper, of presenting the subject in a reasonably simple form. He had covered a great field with a very happy balance of interests.

It was quite certain, in his view, that the amount of time given to high frequency hardening was well justified by its present importance; but, like the previous speaker, he was a little surprised that no mention was made of flame hardening. He looked up one or two references which the author gave at the end of the paper—Sachs and the American Metals Handbook—and found that they both gave quite a lot of space to flame hardening. Although it was the forerunner of the high frequency method, he wondered whether the author regarded it as going out of fashion. It seemed that there were advantages in being able to see exactly where one had applied the heat when hardening the teeth of gears. The high frequency method was, no doubt, excellent for repetition work where there were a large number of similarly shaped objects all going through the cycle; but for objects which varied in shape from one unit to another, there must be some advantage in being able to see where hardening was being applied.

Again, in the water quenching which immediately followed the heating process the author stated that one important feature was to have the minimum interval of time between the end of the heating period and the beginning of the quenching period. If that were so, he wondered whether it would not be better to follow the heating with a jet of water rather than drop the article into a bath of water. It might also be difficult to apply a jet of water with high frequency heating, because there would be induced electric current in the water streams playing upon the metal being heated, and that might create difficulties. He seemed to recall seeing patents for some method of using jets which were electrical insulators, so there was evidently some difficulty when that method was applied.

He would have liked rather more attention to have been given to nitriding, although he did not say that in any critical sense.

In the paper reference was made to difficulties in connexion with the packing of articles during the carburizing treatment. The method of gas carburization was claimed to have great advantages in that the output per space of furnace was much greater than in the more old-fashioned method of packing in boxes, and so on; yet also in the paper was mentioned the difficulty of arranging for the articles not to distort owing to the weight of one upon another when they were being processed. The two ideas seemed to be a little irreconcilable, and he wondered whether it would be possible to have any further information on that point.

MR. I. S. B. WILSON (Member) referred to the fact that Dr. Garside mentioned the difficulty of understanding what was meant by hardness. In the College at which he taught this question was put to the students by making them carry out the various hardness tests-Brinell, Vickers, Rockwell and the Scleroscope. Different metallic specimens were used, and when the students came to the scleroscope it was his practice to use, in addition to the normal specimens, two pieces of rubber, one hard the other soft; the students were then asked to estimate the hardness of this material-the usual answer was "Zero". However, when the hard rubber was put under test, their amazement was great to find that the hardness figure approximated to that of nickel steel, but they were even more surprised to discover that the soft rubber was harder still! After that he told them to write up their conclusions, the question being, "what had nickel steel and rubber in common?" Later he gave the students a lecture in which it was pointed out that the scleroscope was a good instrument for measuring the resilience of a surface or mass of a material.

## Correspondence

MR. J. P. WILSON wrote that in addition to the Ernst tester there was another portable hardness tester on the market known as the Penetrascope. This instrument employed the 136 deg. diamond indenter principle. The indenter was operated by a hydraulic thrust unit of great accuracy. No outside power was needed as the unit was operated by finger control, and the load applied was instantly variable by the turn of a handwheel.

The weight of the Penetrascope was approximately 11lb. and the instrument was particularly useful for making tests on large crankshafts, dies, rolls, etc.

# Author's Reply

MR. G. H. JACKSON, in reply, thanked Dr. Garside and Dr. Bannister for having presented him with the subject matter for another paper! As both Dr. Garside and Dr. Bannister had inferred, heat treatment and all its aspects was so widespread at the present time that to do it justice in any detail would be an impossible proposition.

The first question was: "What is hardness?" That in itself was the subject of another paper. He preferred to look upon it as something which was purely relative, without diving too deeply into what formed it. Unfortunately the word "hardness" was used rather indiscriminately. A thing was either hard or soft and there seemed to be a big space between, which nobody ever mentioned. In fact, except on a few occasions the true hardness that a steel could develop was never used. It was a degree of toughness which was used. It was probably true to say that diamond was about the hardest thing known, and even indentation machines were measuring something relative to the hardness of diamond. He would not like to try at that stage to go into the theory of lattice stress which went to make up hardness.

He could not agree more with Dr. Garside with regard to metallography. Insufficient use was made of the microscope. With due respect to the teachers of metallurgy, the answers to the problems could not be taught, at least, not those problems which were found in industry. The only thing which could be taught was how to look for them and the first thing that a metallurgist had to do when looking for them was to go to the microscope. It then became a question of comparison between that which was known should happen under normal circumstances and that under the microscope, and only by constantly so referring was it possible to build up the vast amount of knowledge which was available at the present time, and which had gone to make metals more reliable and heat treatment so exact. Before one started to use an electron microscope it was necessary to know what a thing meant under the ordinary microscope. He looked upon the electron microscope as unnecessary in industry, but of extreme value in research, provided that it was used in conjunction with the microscope.

In regard to nitriding, he was glad that both these speakers had mentioned this subject and he desired to apologize for not having extended it in the paper. Nitriding as a method of heat treatment was becoming increasingly popular and was being applied to increasingly larger articles. He knew of crankshafts of massive proportions which had been nitrided and Dr. Garside made a good point when he stated that nitralloy was not the only material that would nitride. It was the subject of a patent in the early days and a lot of present-day knowledge was due to it, but there were many steels which were capable of being nitrided.

There was one very important point in connexion with nitriding which was not mentioned. It was true to say that nitriding produced quite appreciable corrosion resistance provided that the top bloom surface was not broken to any great extent. He did not consider that there was much to be gained in corrosion resistance on a fully ground surface, but those surfaces on which bloom was left had definitely a pronounced corrosion resistance. The most important thing

in nitriding was the fact that nitrided cases were in compression. The stresses present were, therefore, compressive stresses and from that point of view alone its value in articles subject to cyclic stresses could not be too highly emphasized. As was probably known, fatigue failure only occurred in tension and not in compression, and if an article were being subjected to the tension cycle over zero to plus or through a mean value, if there were compressive stresses already present in the case then it was negativing to some extent the tension strength which was being applied. The application of nitrided articles to conditions of fatigue were very good and it probably had a most promising future. The biggest disadvantage of nitriding was that it was costly. 72 hours treatment was the average period, using ammonia in medium quantities, but it was furnace utilization time which was probably the biggest drawback to nitriding.

With regard to protection in nitriding, he preferred electrodeposited tin because the amount put on was controllable. If hot tinning were used (bearing in mind that at nitriding temperature the tin itself was molten), although it made an excellent anti-nitrider, it also ran, and wherever it ran nitriding was prevented. He had not much faith in proprietary articles.

Coming to the question of high frequency, shorterizing was not deliberately omitted from the paper, but he did not consider that high frequency and shorterizing could really be considered interchangeable. High frequency was made very selective by the appropriate design of the coil and concentrator. The hardened zone could virtually be altered to anything that was desired; but it was more difficult to do with flame hardening. Secondly, high frequency was almost the production engineer's dream for "in line" hardening, using a fully automatic unit. It was perfectly true that shorterizing could have electric jigs, but the high frequency system itself permitted integral control with automatic timing valves so that the whole thing was absolutely automatic and completely independent of movement of the heating source.

There were snags in the high frequency treatment which would probably promote the use of shorterizing. High frequency induction of current into the part which was hardening was bound up not only with the electrical power available, but also with the distance or air gap between the part being heated and the heating coil. Whereas that process did provide a very nice production tool for "in line" hardening it threw back on the previous soft stages of production hardships to the extent of having to hold much closer tolerances in machining than would normally be the case.

In answering the question concerning the cost of treatment, it was rather problematical to generalize on the heat treatment because other things came into the question.

With regard to quenching, there was no difficulty so far as the high frequency hardened article was concerned.

As to the reliability of high frequency sets, his experience was that it had the same reliability as a wireless set. Electrically he found it to be extremely good. Fuses were blown occasionally because the coils burned out, but generally speaking the water-cooled valve type was very reliable. He had not found it necessary to replace oscillator valves after 4,000 hours continuous use. Chromizing on first sight was an extremely attractive proposition, particularly as it could be done with cast-iron very effectively; but the treatment temperature was 1,300 deg. C. which, when carried on for a long time, almost invariably completely wrecked the steel which was being treated.

On the question of salt baths, the electrode type of bath was preferable to the gas-heated type, but again the limiting factor was cost. For instance, a forced air circulated flame type of salt bath,  $12\frac{1}{2} \times 15$  feet, cost about £225, and the corresponding electrode furnace cost £1,375. There was, of course, a lot to be said for the electrode bath because there was not that bath wear or maintenance, whereas the gas furnace was rather high in both. So far as the hardening of high-speed steel was concerned, one was more or less forced into the use of the electrode bath, because the old gas type furnace was difficult to control from the point of view of atmosphere, decarburization and burned edges.

That rather led up to the question of sub-zero treatment which came to this country during the war from the United States. Phenomenal things were claimed in regard to increase in life for high-speed steels, and so forth, but after investigation in Britain the conclusion was arrived at, that if high-speed steel were properly hardened and secondarily hardened under closely controlled condition, there was no point whatever in using sub-zero treatment, because if there were no austenite to transform, then sub-zero treatment could not do anything.

So far as refrigerators were concerned he, quite frankly, would not recommend their use, because at the temperatures required they caused trouble when used constantly. By far the simplest method was to use a 25lb. block of carbon dioxide in a bucket of trichlorethylene which gave a temperature of -70 deg. C.

On the question of design, he heartily endorsed those remarks of Dr. Garside's about the drawing office, particularly so far as castings were concerned. He had seen castings come from the drawing office which could not be moulded or cored. When a new project was envisaged he had always pleaded with the engineers to call in a metallurgist and the foundryman. That would save time and money afterwards.

Mr. Wilson's description of his hardness tests was very intriguing. A very interesting portable hardness tester had recently come on to the market called the Nerst—a Swiss device. He had given it a really good test, and it would appear to have an application in marine engineering. It depended upon the rate of a spring which operated a plunger which forced a column of liquid around the scale (Brinell) and the instrument was pressed on to the surface which was to be tested by both thumbs until it came to a positive stop. The instrument gave an instantaneous recording.

The Rockwell hardness tester was, in his view, subject to errors and should never be quoted in any circumstances in scientific work.

As to the question of packing on carburizing, gas carburization was rather in the same field as high frequency hardening. It was a process which had been known for quite a long time, but efforts were only now being made to apply it to production. Until recently one of the biggest objections to gas carburizing was sooting. The gas produced sooty layers which could completely impede the carburization. The cases which he had seen of gas carburization in production had been used with special jigging to overcome the question of distortion. Packing during carburizing was perhaps not quite so dangerous as he inferred in the paper.

# INSTITUTE ACTIVITIES

MINUTES OF PROCEEDINGS OF THE ORDINARY MEETING HELD AT THE INSTITUTE ON 12TH DECEMBER, 1950

An ordinary meeting was held at the Institute on Tuesday, 42th December 1950, at 5.30 p.m. Mr. G. Ormiston (Chairman of Council) was in the Chair. A paper entitled "Safety at Sea 1850-1950" by Mr. Denis O'Neill was read and discussed. 101 members and visitors were present and seven speakers took part in the discussion.

Mr. W. Sampson (Member of Council) proposed the vote of thanks to the author which was accorded with acclamation. The meeting terminated at 7.30 p.m.

#### CORRESPONDENCE

"Theoretical and Practical Training of the Marine Engineer"

> Elder Dempster Lines, Ltd., India Buildings, Water Street, Liverpool, 2. 16th October 1950

B. C. Curling, Esq., Secretary, The Institute of Marine Engineers, 85/88, The Minories, London, E.C.3. Dear Sir,

I note in the September TRANSACTIONS of the Institute of Marine Engineers, during the discussion on theoretical and practical training of the marine engineer, you are alleged to have said that the Cunard White Star Company were the only company who allowed University students to go to sea during their course.

I would like to point out that this is not correct. We have been taking four Liverpool University students, during their long vacation, for a round voyage to West Africa in our passenger ships, with the exception of the war years, for the last 20 years to my knowledge. We commenced again last year and, unfortunately, we had not the passenger accommodation available this year for the voyages which would fit in with their holiday, and the Christmas vacation was just too short to allow this to be done, but if all goes well we hope to offer these facilities again next year.

Yours faithfully,

(Signed) A. M. Bennett, Assistant Manager.

> H.M.S. Illustrious, c/o G.P.O., London. 7th November 1950

The Editor, TRANSACTIONS of the Institute of Marine Engineers, 85/88, Minories, London, E.C.3. Dear Sir,

It would seem that most of the speakers in the discussion

on the Training of Marine Engineers were either not clear in their minds as to what they want a marine engineer to be or have the wrong conception of what he should be. Mr. Reid appears to have been the only speaker who really appreciated the difference between an *engineering* apprenticeship and a *trade* apprenticeship. For the marine engineer to achieve the status which we all want him to have he must be trained as an engineer and not merely as a fitter and turner.

I believe that Mr. Logan's comparison between the Royal Naval Engineer Officer and the Merchant Service Engineer reveals that he (Mr. Logan) has the wrong notion of what an engineer should be. This is confirmed by his review of the careers of his chief engineers. He (and several other speakers) seemed to be proud of the number who had obtained the National Certificate and even of the four who failed it. I do not consider the record he gives is a matter for pride. A National Certificate is only an interim examination and no man can reasonably be described as an engineer until he has obtained at least a Higher National Certificate or its equivalent. Then he must have experience at sea before he can be regarded as a marine engineer.

Several speakers wanted "electricity" taught to marine engineers. They obviously have no idea of the complication and specialization of electrical engineerng. The basic training, including basic electricity, should be the same for all engineers and specialization should take place after that basic training. Electrical engineering is a profession of its own and until the merchant service realizes this and makes use of proper electrical engineers it will never be able to take full advantage of the modern electrical developments.

I believe that the Merchant Service is many years out of date in having nothing between an officer and an unskilled man and in not having properly qualified electrical maintenance engineers.

> Yours faithfully, (Signed) J. C. Turnbull, Com'r(L), R.N. (Associate).

> > 3, Fallowfield Road, Liverpool, 15. 29th October 1950

The Editor,

TRANSACTIONS of the Institute of Marine Engineers, 85/88, Minories,

London, E.C.3.

Dear Sir,

It was with great interest that I read the discussion on the "Theoretical and Practical Training of the Marine Engineer" in the September TRANSACTIONS. However, I was very surprised to read a certain statement

However, I was very surprised to read a certain statement made by Mr. A. W. Jones, to the effect that King's College, Newcastle-upon-Tyne, was the only college in this country where a University degree was awarded in the particular science of marine engineering.

At the present time, I, myself, am now in my final year of study of a four-year course in marine engineering at the University of Liverpool, leading to a B.Eng. degree in this subject.

With regard to vacation courses at sea, I would like to mention that this can now be arranged with certain shipping companies in Liverpool.

During my summer vacation in 1949 I spent some time sailing as an assistant engineer with the Glen Line, by kind permission of Messrs. Alfred Holt and Co., Liverpool. Before doing so, however, I was graded by a Ministry of Transport examiner, made possible by the fact that I had already completed a five-year apprenticeship on marine engines with Messrs. Vickers-Armstrong Ltd., Barrow-in-Furness.

I would have spent my last summer vacation at sea, only I was prevented from doing so by circumstances beyond my control. However, a few of my fellow students did go to sea, some with Messrs. Alfred Holt and Co. and one with Coast Lines, Ltd. Students who are not qualified to sail as assistant engineers are taken on as supernumeries.

Messrs. Alfred Holt and Co. have been most kind and helpful in taking on students, not only from Liverpool University, but from other colleges as well. Two I know of are Manchester College of Technology and Trinity College, Dublin, a student from each of these two colleges being with me in the summer of 1949 in the Glen Line ship in which I sailed. The main difficulties of vacation courses at sea are that a student has only three months to complete a voyage, and that many shipping companies have no provision for carrying supernumerary engineers. Concerning the latter point, there is not much difficulty in getting a berth provided the student is qualified to sail as an assistant engineer, forming a part of the normal crew. The decision to take on student engineers rests, of course, with the superintendent engineers of the various shipping companies, and it is to these that we appeal to give us an opportunity to gain that experience which is so invaluable in our training.

As many superintendent engineers are members of our Institute, I am sure the Institute could do much to interest them in taking on student engineers for vacation experience. Yours faithfully,

(Signed) T. W. Clucas (Graduate).

> St. Helen's Court, Great St. Helen's, London, E.C.3. 8th December 1950

The Editor,

TRANSACTIONS of the Institute of Marine Engineers, 85/88, Minories, London, E.C.3.

Dear Sir,

I am in full agreement with Commander Turnbull's statement in his first paragraph, that the marine engineer must be trained as an engineer and not merely as a fitter or turner; this principle was behind my comments when opening the discussion. It is, however, very apparent to me that Commander Turnbull is not altogether familiar with the qualifications required by Merchant Navy engineer officers.

Resulting from the discussion which took place, I now more fully appreciate the advantages of day study during apprenticeship, as stressed by Mr. Reid, but this fact does not change my opinion that the National Certificate standard is proving to be a sound basis of theoretical knowledge for a junior engineer to commence his sea-going career. If a man, as advocated by Commander Turnbull, is able to gain his Higher National Certificate or possibly take a University Degree, it will certainly be to the benefit of the individual and the marine engineering profession.

Yours faithfully,

(Signed) A. Logan. (Member of Council)

#### LOCAL SECTIONS

#### Sydney

The Annual Dinner of the Sydney Local Section was held at the Carlton Hotel on the 16th November 1950 and was attended by about forty-five members and thirty-five guests. The official guests included Mr. V. J. F. Brain, Senior Vice-President of the Institution of Engineers, Australia, and a Member of the Institution of Electrical Engineers; Mr. T. H. Silk, the Local Councillor of the Institution of Civil Engineers and the Local Representative of the Institution of Naval Architects; Eng'r Rear-Admiral A. B. Doyle, the recently retired Third Member of the Australian Naval Board; Capt.(E) A. E. Good, Engineer Manager, Garden Island Dockyard; Mr. H. G. Conde, Chairman, State Electricity Commission; Mr. C. R. Bickford, Chief Engineer, Maritime Services Board; Dr. R. K. Murphy, Principal, Sydney Technical College; Mr. G. R. Rickards, senior partner of Messrs. Macdonald Hamilton and Co., who manage the P. and O. and associated lines in New South Wales. The Local Vice-President (Mr. H. A. Garnett) was in the Chair and welcomed the visitors and members present.

The toast of the Institute of Marine Engineers was proposed by Mr. V. J. F. Brain in a most interesting and entertaining address, and this was replied to by Mr. C. McLachlan (Member) who, in doing so, gave some impressions of his recent visit to Great Britain.

The toast of "Our Guests" was proposed by Mr. G. T. Marriner (Member) and replied to by Messrs. T. H. Silk and G. R. Rickards. The speeches were all particularly apt and were thoroughly enjoyed by all those present.

At the conclusion of the dinner members and guests moved into small groups and remained in cheerful conversation for a considerable period afterwards. It was again a most successful function and the evening was a great success, demonstrating clearly the support which the local members are giving to the Committee of the Local Section of the Institute.

#### JUNIOR SECTION LECTURES

#### Lecture at Greenock

A joint meeting of the Institute and the Greenock Association of Engineers and Shipbuilders was held at "The Lorne", West Blackhall Street, Greenock, on Tuesday, 7th November, when Mr. J. S. Redshaw, O.B.E. gave a lecture on "Stability of Ships". The meeting was most successful and there was a large audience of engineers and naval architects, including a number of visitors.

The speaker was introduced by the Chairman, Mr. David Hutchison (President of the Greenock Association). Mr. Murdoch McAffer (Local Vice-President) represented the Council of the Institute.

Mr. Redshaw proved himself to be a most able exponent of his subject and dealt with the points raised in the discussion to the entire satisfaction of his audience. The enthusiasm of the meeting may be judged from the fact that it was 10.30 p.m. before the discussion finished.

### Lecture at Poplar

Between 130 and 140 students attended the Junior Lecture on the 15th November on the "Construction of Marine Boilers" by Lt.-Com'r(E) A. P. Monk, D.S.C., R.N.(ret) (Member).

Mr. W. Sampson (Member of Council), Chairman of the Board of Governors of the College, was in the Chair and introduced the lecturer. The Principal of the College, Mr. Laws, and members of the staff took part in the proceedings.

The lecture, which dealt with the construction of modern water-tube boilers from the fabrication of fusion welded drums to the final hydraulic testing, was well received by an enthusiastic audience. The question period after the lecture gave listeners ample opportunity to raise points of personal interest, and it was evident that all were keenly interested in the subject.

Mr. Sampson thanked Commander Monk on behalf of the College and the students present for his excellent lecture.

MEMBERSHIP ELECTIONS

#### Elected 6th November 1950

MEMBERS

Mahmud Ahmad Ansari, Lt.-Com'r(E), R.P.N. James William Chase Charles Edward Gibbon Herbert Jenkins Bryan Colin Jeremiah Alfred Stanley Mallam Albert Evelvn Miles Thomas Edward Munro Albert Edward Nixon Victor Frederick O'Connor, B.Sc., Lieut.(E), R.C.N. John Garnett Pollard William MacKenzie Ramsay Tom Emmerson Reav John Hunter Robertson Eric John Ross Leonard Antoine Sanh Joseph Henry Tyler, D.S.C. ASSOCIATE MEMBERS Victor Leonard Kilgour Robert McKechnie Nicholson William George Collins ASSOCIATES Edward Cherry Alan Lindsay Cramb Alec Henry Croft Donald Dver James Thomson Foster Iames Edmund Gander Arthur Victor Heighton Francis John Kearins Herbert James Gillespie Macneil Franklin Daniel Mathias Eric Morinan Clifford Soranson Gordon Benjamin Thrift Cyril Ernest Tong Robert Joseph Tozer John Prince Vickery Joseph Clifford West Harry Whitfield GRADUATES John Denis Dobie Ian Anderson Fraser STUDENTS Peter Ronald Bolt Brough Bramley Girling Brvan Pacev John Russell Sedgwick TRANSFER FROM ASSOCIATE MEMBER TO MEMBER Robert Cook, M.Sc. TRANSFER FROM ASSOCIATE TO MEMBER Kenvon Roderick Alexander Russell Shaw Peter Barrie TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER Anthony Riley Hinson TRANSFER FROM GRADUATE TO MEMBER Roland John Boxall Arthur William King TRANSFER FROM GRADUATE TO ASSOCIATE

Eardley Erroll Rockwell Newman TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER Geoffrey Noel Fisher

Elected 5th December 1950 MEMBERS Percy Adams Archibald Duncan Blue Sven Bertil Bovin George Barton Dawson Arnold Hall Duckworth Leslie Finkle John Haralambis, Constr. Com'r, R.H.N. James Henderson Barclay Dickins Mackinnon Om Prekash Mital John Alfred Murray James Patton, O.B.E. Jack Herbert Pigott, Eng. Lt.-Com'r, R.A.N.R.(S) Robert Arthur Stables **James** Tocher Francis William Walker Ronald Ernest Zoller, B.Sc. ASSOCIATE MEMBERS Dennis Wayman Edwards, Lieut.(E), R.N.(ret) Stig Sugwar Goranson ASSOCIATES Kenneth Abel Raymond Frederick Bartlett Derek Hughes Hugh Henry Lee Archibald Murphy Peter Milburn Oxley Francis Vernal GRADUATES Lionel Roy Prew, B.Sc. John Kenneth Roscamp Barrie Francis Slater STUDENTS Gordon Ridley Pringle John Leon Wood PROBATIONER STUDENTS William Dennis Fildes William Henry Mier Arthur Raymond Priest Dennis Sydney Revere Ian Ross Paul Victor Turner TRANSFER FROM ASSOCIATE TO MEMBER Ausaf Ahmad Joseph Gavin Landells Black George Emmerson Harry Jervis Jack Kellett Edmund Morrison Pentney Randhir Singh Rawal Michael Wyndham Sydenham Francis Ralph Tarry TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER James Nesbit Fatkin TRANSFER FROM GRADUATE TO ASSOCIATE Robert William McCreerv TRANSFER FROM STUDENT TO ASSOCIATE MEMBER Gerald Dixon van Someren, Lieut.(E), R.N.

TRANSFER FROM STUDENT TO ASSOCIATE Subramaniam Thiruchelvam

# OBITUARY

JAMES PEACOCK (Member 2507) was born in Glasgow and educated at Allan Glen's Technical School. In 1882 he was apprenticed to Messrs. Lees, Anderson and Co., general and marine engineers. Five years later he entered the drawing office of Messrs. John Brown and Co., Clydebank, becoming assistant departmental manager. He transferred to the Atlas Steelworks, Sheffield, of the same firm in 1899 as works engi-



neer, and the following year joined the Orient Steam Navigation Co. He remained with that company for thirty-eight years as superintendent engineer, a span encompassing the building of fifteen ships, from the first *Orontes* in 1902 to the last of the pre-war liners, the *Orcades*, in 1937. He retired from the Orient Co. in December 1938.

He was elected a Member of the Institute in 1910, becoming a Member of Council in 1913. He was elected a Vice-President in 1915, serving again as a Member of Council from 1917 to 1919.

He died in Edinburgh on 30th October 1950 at the age of 85 years.

WILLIAM LLEWELLYN TURNER (Member 9817) was born at Sunderland in 1905 and educated at Hanna's Preparatory School. He served his apprenticeship with the Middle Duffryn Power Station, Aberdare, and then went to sea with Messrs. Sanderson and Mathews Co., Ltd. After a short period ashore, Mr. Turner went back to sea, serving with Messrs. Chellew S.S. Management Co., Ltd., Messrs. W. S. Miller and Co., Ltd., Messrs. Hall Bros. S.S. Co., Ltd., Messrs. C. T. Bowring and Co., Ltd., Messrs. Shaw Savill and Albion Co., Ltd., and the South American Saint Line Ltd. In 1947 he took up an appointment with the National Coal Board, No. 5 Area, as Technological Engineer.

He was elected an Associate in 1944 and transferred to

Member in 1948. He died on the 3rd August 1950 after a short illness.

ALLEN FREDERICK CHARLES TIMPSON (Member 2806) was born in 1896 at Sandbank, Argyllshire. His family moved to London in the year 1904 and he was educated at the Poplar School of Engineering and the Royal Technical College, Glasgow.

He served his apprenticeship with Messrs. Green and Silley Weir, Ltd., The London and Glasgow Engineering and Iron Shipbuilding Co., Ltd., and Messrs. Burmeister, and Wain.

At the time of his completion of apprenticeship war had been declared and Mr. Timpson enlisted in the Highland Light Infantry, and within a very short time was in action in France. After a period he was transferred to the Mesopotamian Forces and served with the Inland Water Transport. He was finally in charge of the Baghdad Workshop and Slipway and was promoted to the rank of Captain and awarded the M.B.E.

At the end of the war he returned to England and entered the family business of Messrs. Ferguson and Timpson, Ltd., rising to the position of Managing Director; this post he held at the time of his death.



Mr. Timpson was elected a Graduate of the Institute in 1914, transferring to Associate Membership in 1918 and Membership in 1921. He was elected a Member of Council in 1937 and became Chairman in 1939, retiring from the Council in 1940. He served subsequently on the Council 1941-4, 1945-8, 1949 to the date of his death. He served on the Papers and Transactions Committee of the Institute for twenty-four years, twenty-two of which being in the capacity of Chairman. He also served on various other committees of the Institute.

He passed away on the 20th October 1950 and, at his own request, was inurned at a private funeral.