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VOLUME XLII.

Recent Metallurgical Research in relation to Marine Engineering

READ

BY S. L. ARCHBUTT, F.I.C.,

On Tuesday, April 8th, at 6.30 *p.m.*

CHAIRMAN: MR. H. J. VOSE (Vice-Chairman of Council).

The CHAIRMAN conveyed a message of regret from Mr. J. Nicol (Chairman of Council) on being unavoidably absent. Introducing Mr. S. L. Archbutt to the meeting, the Chairman remarked that as a co-worker on metallurgical research with Dr. Rosenhain at the National Physical Laboratory, the lecturer was already well known by repute to marine engineers. On this subject of metallurgical research there was always much to be learnt, and they were sure that Mr. Archbutt would impart much useful information to them in his paper.

I. INTRODUCTION.

The last ten years have been very fruitful of valuable results and development from metallurgical research. So much so that to attempt to cover the field to any complete extent even in regard to metals and alloys as we use them, in a single lecture becomes impracticable. I therefore propose briefly to outline some of the most striking results and then to deal in more detail with research in one or two fields which I hope will interest you.

The last ten years have seen the rise to fame of a companion material to the fine-tempered *Stainless Steel* we have become so familiar with domestically—namely, a tractable, malleable brother, known commercially as "*Staybrite*," "*Immaculate*," "*Era C.R.*"—also "stainless in character." This is a higher-chromium steel containing nickel, which differs completely from its harder brother in structure and in the fact that it refuses to be hardened by quenching and tempering. It is admirably suited to cold working by pressing, stamping, etc. Besides their remarkable corrosion resisting properties, these stainless steels also resist oxidation and scaling at high temperatures, but still better alloy steels, more complex in constitution, have been developed by some of our steel manufacturers for resistance to high temperatures. These are known as *Heat Resisting Steels*.

Cast iron forms the major proportion by weight of the material of a turbine plant and occupies a position nearly as important in this respect in a Diesel engine plant. Valuable advances have resulted from research in this field. By control of silicon content and rate of cooling, cast iron can be caused to solidify with a *pearlite*, in place of a ferrite matrix, with resulting greatly enhanced mechanical properties. The whole question of the relationship of structure and properties to composition, melting, and foundry technique, is on a surer footing.

A range of *Heat Resisting Cast Irons* has recently been developed for higher temperature use in the region of 700° C., which show greater resistance to growth at these high temperatures than any previously used.

Definite progress has been made towards knowledge of the principles involved in producing *Alloy Cast Irons* and of the improvements in properties which can be obtained from them. As an example the effect of one or two per cent. of nickel may be mentioned, in controlling chill, increasing and equalising hardness, raising strength, and improving machinability.

By adding copper and nickel in the cupola in the form of Monel metal scrap what is known as *Monel Cast Iron* is obtained, which casts better than brass, is also stronger and has excellent corrosion resisting properties.

One of the most important features noticeable in recent years is the advance in the art and technique of *Welding* steel, and the struggle which is taking place between cast iron and welded steel construction.

Novel processes for *Surface Hardening of Steel* have been developed, to one of which I shall refer later.

In the non-ferrous field a remarkable feature has been the enormous development in the use of *Nickel and its alloys* in engineering generally. In marine engineering there is the development in use of nickel-copper for condenser and oil cooler tubes—of Monel Metal for the blading of high pressure steam turbines and for valve parts of super-heated steam and fuel oil systems.

Another feature has been the improvement in properties of *Light Alloys,* with the discovery of the mechanism of the remarkable phenomenon of *Age-Hardening* on which the properties of the well-known aluminium alloy Duralumin depends. This discovery to which I shall refer later, has been most fruitful. The phenomenon of "*Modification*" has been another valuable discovery in this field.

Research on *Corrosion,* particularly in water and salt solutions, has greatly advanced knowledge. Exhaustive research on the problem of the corrosion of the brass condenser tube in sea water has gone a long way towards providing a satisfactory solution. The study which has been devoted to investigation of the fundamental mechanism of corrosion processes in recent years has been of incalculable value in clarifying the outlook. Important advances have been made in regard to protective coatings, particularly of the electrolytic and the electrochemical type respectively. Cadmium and chromium plating may be mentioned as examples of the former type and the anodic oxidation process for aluminium and its alloys as an outstanding example of the latter.

One of the most important and interesting fields of research relates to the problem of *Materials for Use at High Temperatures,* the results of investigation of which at the N.P.L. and elsewhere has aroused the keenest interest.

Finally, in this very brief incomplete survey mention may be made of a *New Cutting Tool Material* which promises as great a further advance in machine tool practice as that which followed the introduction of high speed steel.

The particular fields I have selected for more detailed consideration this evening are research on Materials for Use at

High Temperatures—on Corrosion—on Light Alloys—on a New Method of Case Hardening Steel and on a New Cutting Tool Material.

2. MATERIALS FOR USE AT HIGH TEMPERATURES.

In the last few years demands on the strength of materials at high temperatures and on their resistance to oxidation, scaling and other forms of attack by external agents have been steadily increasing. In consequence the need for more exact knowledge of the behaviour of materials under stress and exposure at high temperature has been realised, and at the same time the necessity for developing better materials than have been available.

One of the most important requirements in this connection is ability to withstand prolonged loading, as, for example, in the walls of a steam superheater tube or drum. Some of the most interesting and important research in recent years has been directed to this requirement, stimulated by what practically amounts to a discovery that under prolonged loading at high temperatures, flow or *creep* can occur even in the strongest materials we know, so that an engineering part may ultimately fail at a stress very much below the tensile strength of the material, or even below its apparent limit of proportionality. This being so the tensile strength of the material at high temperatures as determined in the ordinary way by short time loading can no longer be relied upon by the engineer as a guide on which to base his factor of safety, and he requires some other property. The question arises as to what this property is to be. The view has been expressed that the limit of proportionality must be used—that above this stress creep will be continuous and failure eventually occur. On the other hand there is the view that within a certain temperature range, there is a definite upper limit of stress (for each temperature) above which creep will occur leading to failure, but below which creep will ultimately cease, so that after a certain degree of permanent strain has occurred the part may be expected to have a very long life. This latter view is held at the Laboratory where during the last ten years research has been in continuous progress on this problem. This *upper* limit of stress which a material will withstand without ultimate failure (or at least for a very long time) is termed the *limiting creep stress*—it may be regarded as the ultimate strength of the material at the temperature in question having regard to the effect of time, and might be called the "*time-ultimate.*" This limiting creep stress would appear to be the property which should take the place of the short time tensile strength for design purposes at elevated temperatures.

To investigate creep under load, test pieces are hung vertically between shackles and surrounded by an electrically heated furnace. The upper end of the shackles is fixed and stress applied at the lower end by means of a 10 to 1 ratio loading lever. An extensometer attached to the test piece projects beyond the furnace so that the creep can be measured either by micrometer or optically by tilting of mirrors.

A typical creep " unit " is diagrammatically illustrated in Fig. 1.

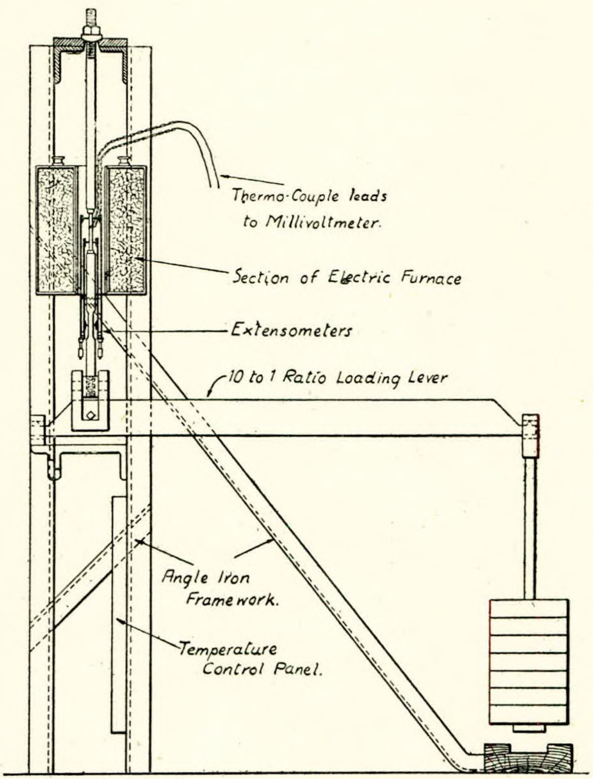
The limiting creep stress corresponding to any desired temperature is determined by applying a series of loads—decreasing in amount—to a series of test pieces (using a different test piece for each load) and determining the forms of the graphs connecting strain with duration of loading. The loads are decreased until a minimum rate of creep is reached, which is of the order of 1/100,000-in. per in., or less per day.

Typical graphs showing the relation between creep and duration of loading—in this case for an alloy steel at 400° C.—are shown in Fig. 2. The following characteristics will be observed. Under the intermediate loads creep is at first rapid —then falls off—*reaches a minimum rate*—then increases again to fracture. The falling off is due to *strain hardening*. Under the lower loads the rate of creep is approaching a minimum and there is no indication of an increase—the limiting creep stress is being closely approached at a stress of 23 tons per sq. in., which in this case is considerably above the observed limit of proportionality of the material, viz., 13 tons per sq. in. approximately, at this temperature, *i.e.*, 400° C.

The limiting creep stress in this case then lies between the tensile strength (short time loading) and the observed limit of proportionality at this temperature. The laborious nature of this work is obvious. A separate furnace, test piece, etc., is used to determine *each graph* and there are seven shown for this temperature alone—some have taken over 30 days to complete.

Extraordinary interest has been aroused in this problem of creep or flow under sustained load at high temperatures, and the behaviour of a very large number and variety of commercially available materials has been determined at the

Laboratory in the last few years. Starting with the modest total of four creep furnaces about 1921 the number has now



-Arrangement of Apparatus for Creep Tests at High Temperatures.

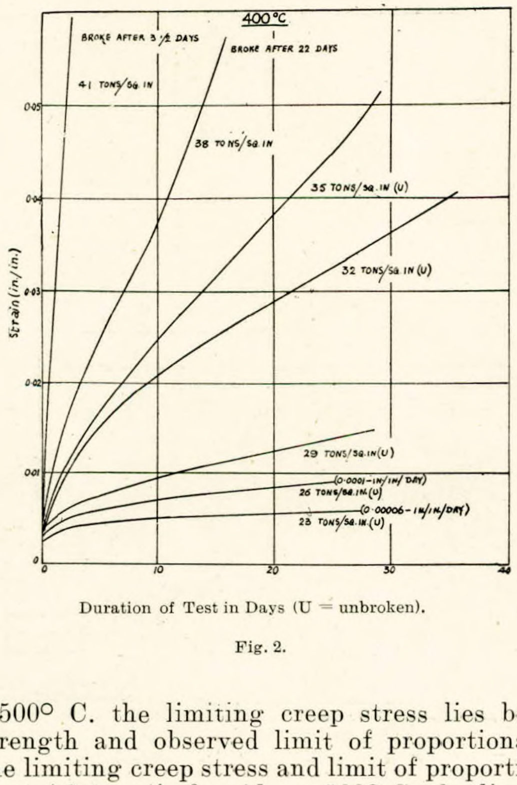
Fig. 1.

increased to 25 or more to cope with the demands for tests, and further extension is contemplated. A view of the creep stress " laboratory " is shown in Fig. 3.

Mild Steel.

Valuable light has been thrown on the behaviour of mild steel such as is used for steam plant—boilers, superheaters and steam drums. In Fig. 4 graphs are given showing the relation between temperature and tensile strength, limiting creep stress, and limit of proportionality for $0 \cdot 17\%$ carbon steel.

Strain—Duration Curves for an alloy steel at 400°C.



Duration of Test in Days (U = unbroken).

Fig. 2.

Below 500° C. the limiting creep stress lies between the tensile strength and observed limit of proportionality. At 500° C. the limiting creep stress and limit of proportionality are identical, at 4·8 tons/in.^{2}. Above 500° C. the limiting creep stress is below the observed limit of proportionality.

A limiting creep stress exceeding 5 tons/in.^{2} cannot be obtained in carbon steel by increasing the tensile strength by raising the carbon content even up to 0·51%. These results show that to meet the higher pressures and degrees of superheat required in steam plant to-day, material superior to carbon steel is urgently needed to provide a reasonable factor of safety between the properties of the material and the working stresses.

Other Materials.

Other materials the creep characteristics of which have been investigated and published include Armco iron, Ni 70 Cu 30, and Ni 80 Cr 20 alloys and a high-Ni high-Cr steel. These show the great superiority of the Ni-Cr alloy and the high alloy

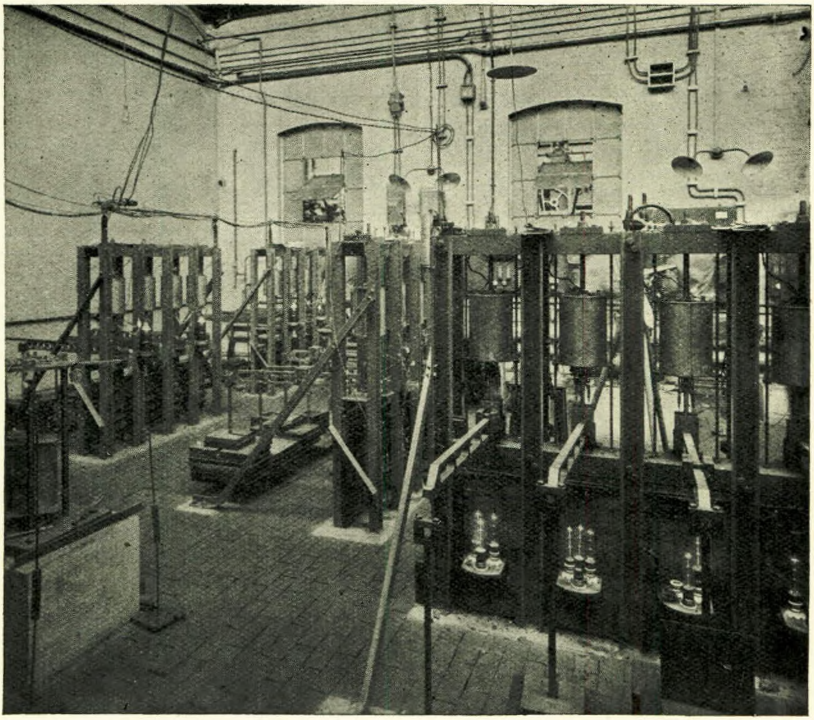


Fig. 3.—View of creep stress "laboratory," National Physical Laboratory.

steel so far as creep is concerned. This is seen in Fig. 5, which shows in the form of graphs the relation between limiting creep stress and temperature, for carbon steel, the special alloy steel and Ni 70 Cu 30, and Ni 80 Cr 20 alloys.

Development of New Materials.

As regards development of new and improved materials, so far as steel is concerned, the steel makers themselves have up to the present been mainly responsible. In respect to what may be termed high alloy steels, *i.e.*, steels containing large additions of other elements as, *e.g.*, the one already referred to which contains Ni 26·5, Cr 14, W 3·6 per cent. and only about 57 per cent. of iron, some remarkable heat resisting steels, or perhaps we ought more properly to call them iron alloys, have been produced. As regards improvement of *mild steel* by small additions of other elements—a problem of great economic importance in regard to steam plant—the position is by no means clearly defined. Systematic investigation of this problem is to be undertaken at the Laboratory. From data so far published it would appear that amongst the group of elements Ni,

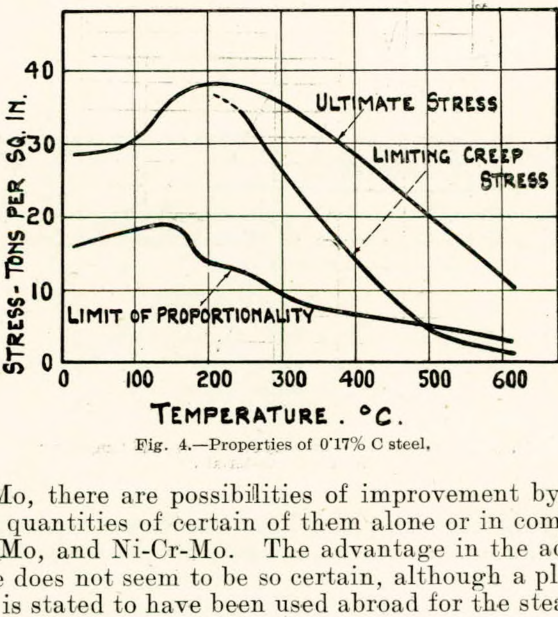


Fig. 4.—Properties of 0·17% C steel.

Cr, V, Mo, there are possibilities of improvement by addition of small quantities of certain of them alone or in combination, *e.g.*, Cr-Mo, and Ni-Cr-Mo. The advantage in the addition of Ni alone does not seem to be so certain, although a plain 1·5% Ni steel is stated to have been used abroad for the steam drums of modern high pressure plant.

Industrial Application of Alloy Steels in Steam Plant.

Through the kindness of steam plant manufacturers of world wide repute I am informed that Ni-Cr-Mo steels have been used in the form of studs and bolts for various components of high duty steam plant and that high-Ni high-Cr steel is in use for superheater tubes. For pressures over 1000 lbs. the question of using alloy steel drums is being carefully considered. For some time past on the Continent solid forged drums have been available in 3-5% Ni steel and experiments in use of alloy steel drums are already in progress. They state "unfortunately, the information available on the subject of the physical properties of alloy steels is much restricted at the present time, and in addition, the high cost of these alloy steels by reason of the high price of raw materials used in their manufacture,

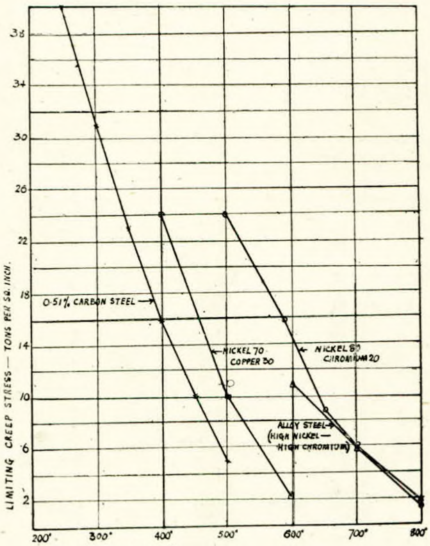


Fig. 5.—Relation between limiting creep stress and temperature for various materials.

together with the expensive heat treatment necessary, makes their adoption in steam generating plants particularly slow and difficult. Until there is definite proof that the use of these materials does give increased life on a scale which will repay the heavy initial expenditure, the advance of the use of alloy steels in steam generating plants will, without doubt, be particularly slow and difficult. Unfortunately, research and experiment of the order that is necessary in this case is, of necessity, slow, and results in heavy expenditure."

Research on New Materials at the Laboratory.

During the last four years, research on development of new materials has been in progress at the Laboratory. The main object until recently has been production of materials for use in the higher temperature range from 600°-1000° C. For this purpose Ni-Cr alloys and their derivatives early appeared pre-

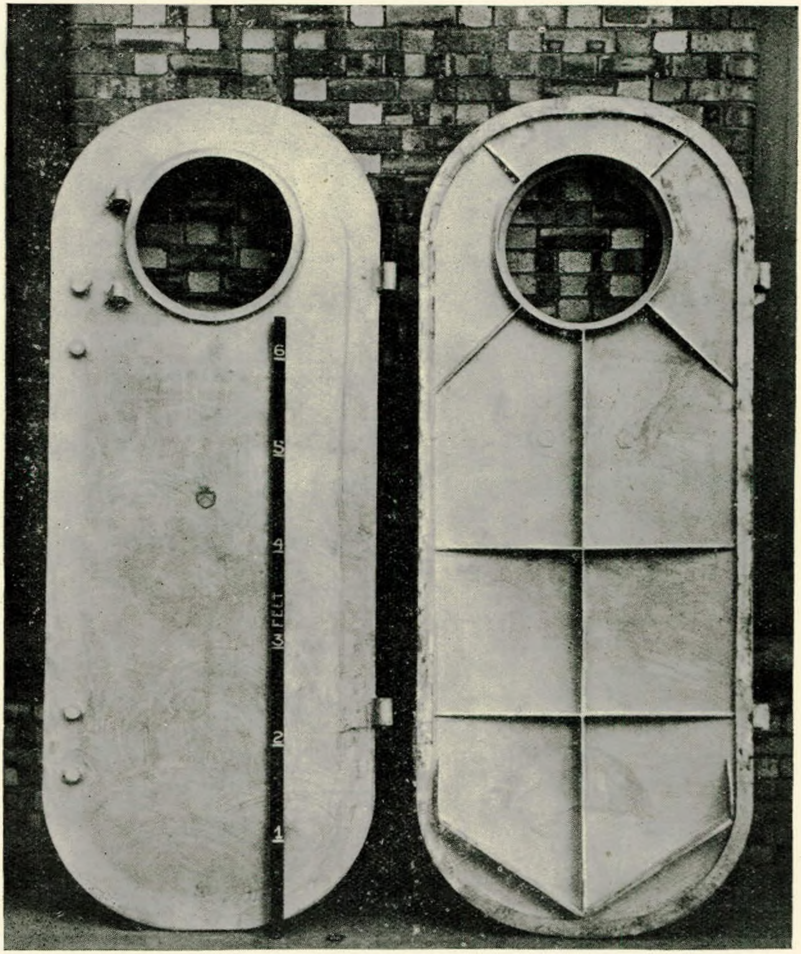


Fig. 6.—Diesel engine main column doors in Silicon-aluminium alloy (Alpax). Lightalloys Ltd.

eminently suitable. I have already referred to the high limiting creep stress found for a rolled 80/20 Ni-Cr alloy at the Laboratory. Plain Ni-Cr alloys were first studied and then attention was turned to Ni-Cr-Fe and more complex derivatives still. Pending the full publication which is in progress, of results from this work the information to be given is limited.* Preparation, casting, forging and rolling have all been carried out at the laboratory. Considerable experimental difficulties

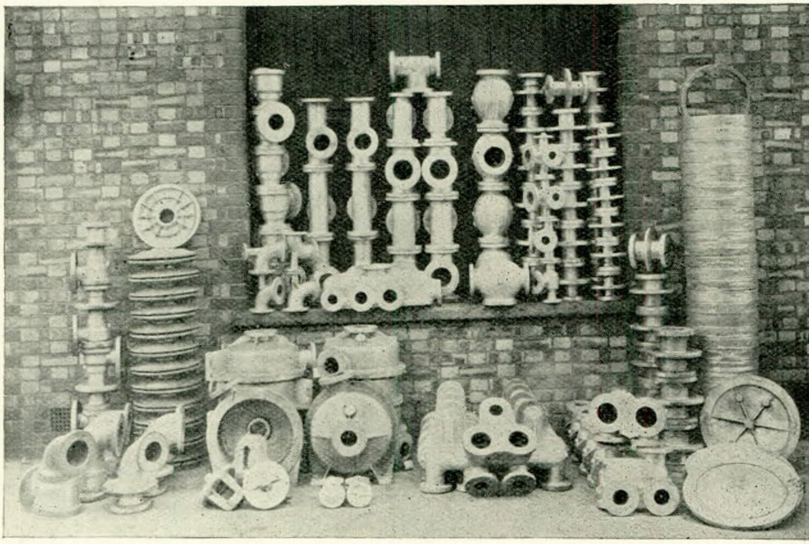


Fig. 7.—Fittings for oil (fuel and lubricating) and water systems of destroyer, in Silicon-aluminium alloy (Alpax). Lightalloys Ltd.

have had to be overcome owing to the high melting temperatures—of the order of 1400°-1500° C.—and the high temperatures required for forging and rolling—of the order of 1200° C. and higher. To avoid contamination by furnace gases, and oxidation, melting has been carried out in vacuo in a high frequency electric induction furnace. Quantities up to 30 lbs. are melted in crucibles in this manner. For pre-heating ingots for forging and rolling an electric resistor muffle using " silit " resistors was constructed by means of which uniform temperatures of 1200°-1300° C. were obtained. Alloys have been tested in both the cast and the wrought condition for " creep " and short time tensile strength, generally at a temperature of 800° C. Ni-Cr alloys have been forged and rolled up to 40% Cr, a considerable advance on existing practice. Limiting creep stress at the highest temperatures increases with increase of chromium. From study of the plain Ni-Cr series

*This work has since been published in the following paper before the Iron and Steel Institute, May meeting, 1930.—"Some Alloys for Use at High Temperatures." Part I., Rosenhain and Jenkins. Part II., Jenkins, Tapsell, Austin and Rees. Communicated from the National Physical Laboratory.

attention has been directed to Ni-Cr-Fe, Fe-Cr, and finally to complex alloys of Ni-Cr-Fe with additions of such elements as W, Mo, Ti, Si, C. Forged and rolled material has been produced from all except the last mentioned complex alloys. See-

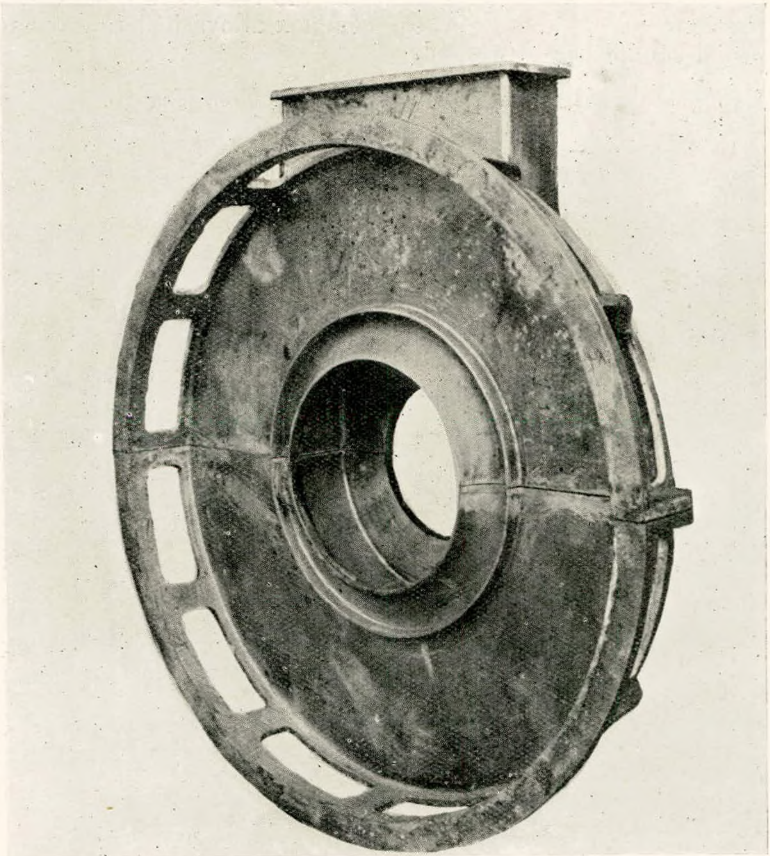


Fig. 8.—Split end bracket, 6ft. 6in. dia., 200 k.w. generator, for Admiralty vessel, in Silicon-aluminium alloy (Alpax). Lightalloys Ltd. (Laurence Scott and Electromotors Ltd.)

ing that these have been developed to resist deformation at high temperatures, the fact that they have generally been found impossible to forge and roll, follows as a natural consequence. These particular materials are also naturally very hard and strong at room temperature and in consequence difficult to machine, although they are readily ground. Thanks, however, to the modern development of tungsten-carbide tools even the hardest of them can be fairly readily machined. The best results in regard to life at 800° C. under prolonged loading have so far been obtained from alloys in the cast condition, which serves to justify the use of the complex alloys just referred to which cannot be hot worked.

High Temperature Properties of some of these New Alloys.

In order to expedite this exploratory work what are called *life-tests*, *i.e.*, period to fracture under load, have been sub-

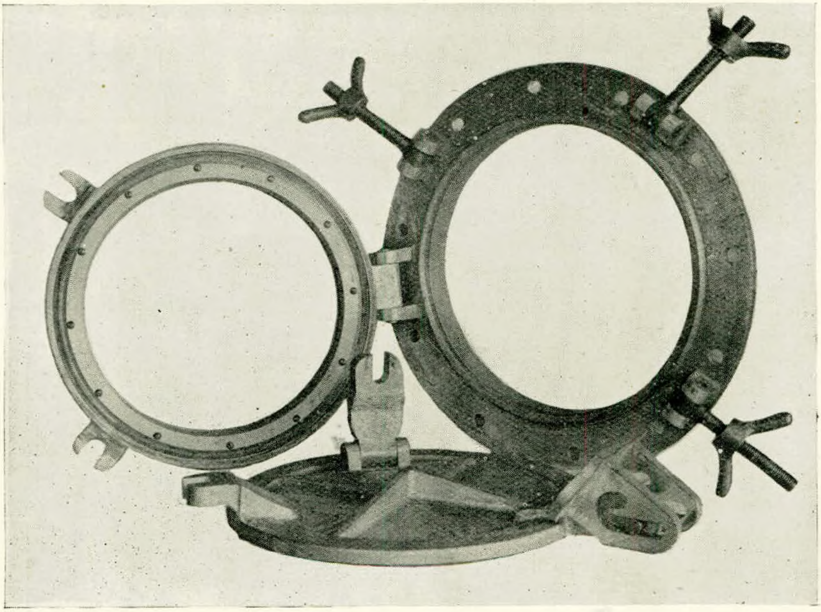


Fig. 9.—Dead light assembly in Silicon-aluminium alloy (Alpax). Lightalloys Ltd.

stituted for the lengthy determination of limiting creep stress. To give an example of the superior properties obtained from some of these chill cast alloys an alloy of Ni-Cr-Fe with additions of W, C, and Si gave at 800° C. a " short time " tensile strength of 30 tons per in.^{2} and withstood unbroken a load of 5 tons/in.^{2} for over two months (68 days). Under a stress of

8 tons/in.^{2} it had a life of 15 days. These results show marked improvement on those obtained from previously existing

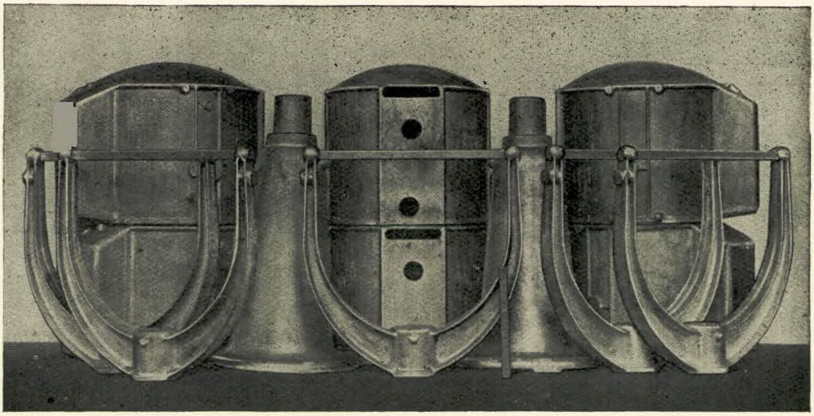


Fig. 10.—Searchlight parts in Silicon-aluminium alloy (Wilmil). William Mills Ltd.

materials the best of which according to tests so far made withstood only 5 tons/in.^{2} for length of life of 15 days at 800° C.

Indication of the superior properties at 800° C. of some of these new alloys compared with the best commercial material

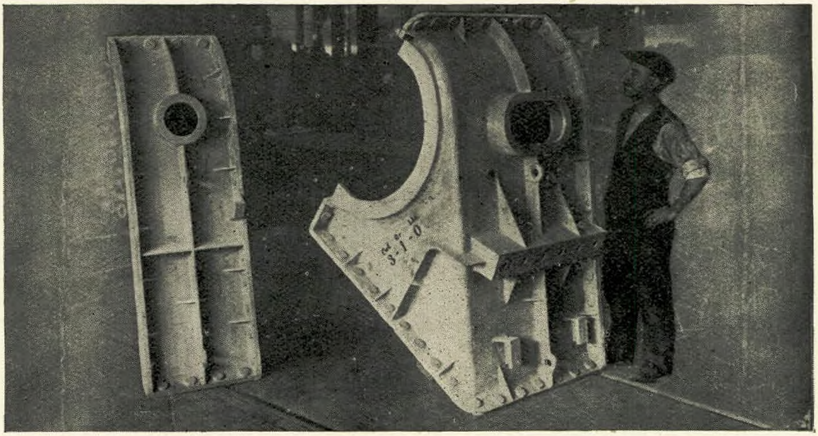


Fig. 11.—Large marine castings in aluminium alloy. A saving in weight of nearly 700 lbs. over cast iron was obtained in the larger casting.

so far tested is given by the data in the accompanying table, in which alloy M is the high-nickel high-chromium steel already referred to.

Alloy.	Condition.	Tensile strength.				Life Tests in days at 800 °C under prolonged loading.							
		15°C.		800°C.		Stress in tons/in.^{2}							
		U.T.S. tons in./^{2}	Elongn. %	U.T.S. tons/in.^{2}	Elongn. %	8	6	5	4	3·6	3·2	2·8	2·0
70/30 Ni-Cr	Chill cast	35·5	58	18·6	6	—	—	—	—	—	—	38	115
	Rolled	65·3	25	21·6	6	—	—	—	—	10	16·5	18·5	33·5
Alloy M	Forged	45·9	34	17·3	39	—	1-2	15	29	—	73	152	—
No. 183 (N.P.L.)	Chill cast	48·4	2	30·6	4	15·5	50·5	68*	—	—	—	—	—
No. 186 (N.P.L.)	Chill cast	33·3	3	20·0	9	—	8	38	50	—	—	—	—

* Unbroken.

Certain chill cast alloys most recently prepared have proved stronger still—a number have withstood a load of 10 tons/in.[2] at 800° C. for several days, *i.e.*, they appear twice as strong at 800° C. as the best commercial alloy so far tested, namely, the high-Ni high-Cr steel with 3·5 per cent. tungsten, already referred to (alloy M), which is forgeable.

Structure and Constitution.

Hand in hand with the preparation of alloys and determination of their mechanical properties, study has been made of

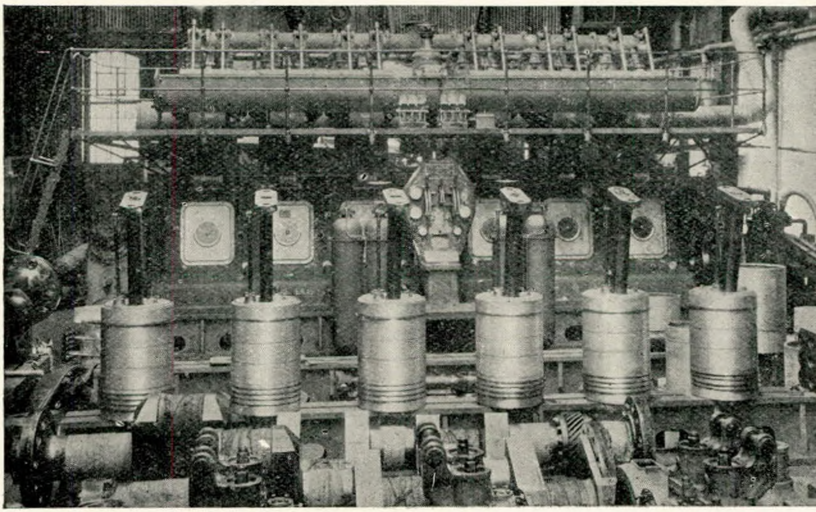


Fig. 12.—1,750 b.h.p. Six-cylinder Heavy Oil Engine with aluminium alloy (Y-alloy type) pistons 21·5 ins. dia., dismantled in foreground. Fraser and Chalmers' Engineering Works.

structure and constitution in order to determine the nature of the constituents present and the effects of composition and temperature conditions on their incidence, manner of distribution, etc. In some of the creep tests intercrystalline fractures have been encountered. It is realised that the exact mode of distribution of the constituents materially affects the behaviour under prolonged loading at high temperature. Apparatus has, therefore, been developed to enable the mechanism of flow and fracture, in actual test pieces to be studied microscopically. In this apparatus test pieces polished for microscopic examination can be subjected to strain at temperatures up to 1,300° C., in vacuo or inert gas atmosphere so as to avoid oxidation, and removed for microscopic examination at suitable intervals.

Vacuum of less than 2/1000 mm. of mercury at 1,000° C. has been maintained for periods as long as one month. Under these conditions a previously polished specimen of Armco iron remained bright and suitable for microscopic examination. Interesting results are already forthcoming—the nature of the atmosphere appears to influence the rate of creep and mode of deformation—a test specimen failed after 24 days in hydrogen at 500° C., while in vacuo, fracture did not occur in that time nor did it appear likely to do so within a very much longer period.

Oxidation and Scaling.

Oxidation and scaling affect this problem vitally also, and research on these questions is in progress at the Laboratory in conjunction with the study of creep.

3. LIGHT ALLOYS.

There is considerable scope for use of light alloys in marine engineering. In a cargo ship saving in weight offers the possibility of carrying more cargo. In a passenger ship, reduction in weight of the superstructure improves stability by lowering the centre of gravity. In a battleship, weight saving became of vital importance when tonnage was limited by the Washington Conference. In soundness, mechanical properties, and reliability, modern light alloys of aluminium compete favourably with cast iron, brass and bronze. The deterrent to their more rapid application has undoubtedly been the question of their corrosion resistance under marine conditions. Apart from the improved resistance to such conditions which modern aluminium alloys in general show by reason of greater soundness and purity, two developments in particular have had a material influence in this respect, namely the silicon-aluminium alloys and the anodic oxidation process for producing a protective coating on aluminium alloys. The satisfactory resistance of the silicon-aluminium alloys to marine corrosion is now well established, as well as the excellent protection afforded by the anodic oxidation process. Silicon-aluminium alloys will function satisfactorily without anodic treatment. The use of the wrought aluminium alloy duralumin, anodically treated, for wing and hull construction of all-metal marine aircraft is well established. In addition to excellent corrosion resistance, the remarkable casting properties of the silicon-aluminium alloys have greatly facilitated their application, so that to-day they are used in large quantities on board ship for such exposed parts as scuttles and deadlights, deck stanchions and ladder ways, and the skylight frames for engine rooms; for search-light bodies and their pedestals; pump bodies and gear casings, bearing brackets, carcase and ventilating fans of electric motors, the pipe lines, junctions, valves and filters of fuel and lubricating oil systems, etc. In some modern foreign destroyers the total weight of cast parts in silicon-aluminium alloy supplied for the oil and water systems has amounted to three tons per vessel. Examples of cast parts in silicon-aluminium alloy, for marine use, are shewn in Figs. 6-10. In Fig. 11 large marine castings in aluminium alloy are shewn in which considerable saving in weight was effected.

Where exceptional stresses or temperature conditions are likely to be met, Y-alloy (copper 4, nickel 2, magnesium 1·5% aluminium remainder) developed at the National Physical Laboratory, is suitable and widely used. Somewhat inferior in corrosion resistance to silicon-aluminium it is superior in this respect to many other aluminium alloys and is capable of anodic treatment. In the engine room there is considerable scope for use of this alloy for more highly stressed parts. It is at present widely used for internal combustion engine pistons in sizes ranging from those of the light outboard motor, up to 24in. dia. and over, for the heaviest marine Diesel engines. Fig. 12 illustrates Y-alloy type pistons 21·5-ins. dia. in a 1750 b.h.p. heavy oil engine.

Research on aluminium alloys in the last few years has resulted not so much in the development of new alloys with outstanding increase in strength over known materials but rather in discovery and development of new methods of treatment leading to improvement in properties of existing alloys. It is true, however, that some of the new processes for improvement, *e.g.*, *modification*, and *age-hardening*, have opened up promising fields in which research may be directed towards production of stronger light materials than we have at present.

The more remarkable results of research on aluminium alloys in recent years relate to the phenomena of age-hardening and "modification," to processes for removal of gases, and last, but not least, grain refinement.

(1) *Age-hardening.*

One of the most important achievements has been the discovery of the *mechanism of "age-hardening"* so called, *i.e.*, the phenomenon on which the remarkable mechanical properties of the commercial alloy Duralumin depend. This phenomenon is brought about by quenching Duralumin from just below 500° C. Immediately after quenching, the alloy is quite soft and can readily be cold worked, but a process of spontaneous hardening immediately sets in so that about two hours after quenching, the alloy is too hard for any but light cold work. Hardening continues and reaches a maximum about four days after quenching, when the alloy reaches a stable state for practical purposes. Researches at the N.P.L. and the Bureau of Standards in America on the internal constitution of aluminium alloys have indicated the conditions leading to age-hardening, and have stimulated the search for other types of alloys in which similar conditions exist. The result has been the opening of a wide field of discovery of new alloys and of improvement of existing types of alloys, not only light but also heavy non-ferrous alloys, *e.g.*, copper alloys and even iron alloys.

(2) *Modification.*

We may next consider the remarkable phenomenon of "*modification*," in which by treatment of the molten alloy with a suitable flux before pouring, certain alloys, notably those of aluminium with silicon, can be caused to solidify in the mould with an exceedingly fine structure illustrated in Fig. 13, in place of the normal relatively coarse one seen in Fig. 14.

This process of modification brings about a profound improvement in casting and mechanical properties. The remarkable casting properties and toughness of modified alloys of this type in conjunction with their excellent resistance to marine corrosion already referred to, have led to their wide application in marine engineering practice. Examples of these applications have already been given.

(3) *Gas Removal.*

More recently still we have the researches on the behaviour and effects of dissolved gases in aluminium alloys at the Laboratory and elsewhere, which have led to processes for removal of these gases resulting in vast improvement in soundness and properties of castings and ingots for rolling and forging. These processes have resulted from study of the cause of what is known as "*pin-holing*" or "*speckling*" in alu-

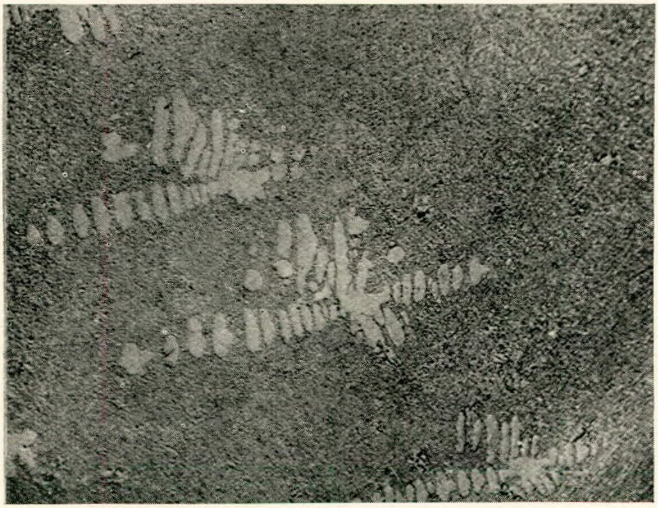


Fig. 13.—Silicon-aluminium alloy. Modified structure X150.

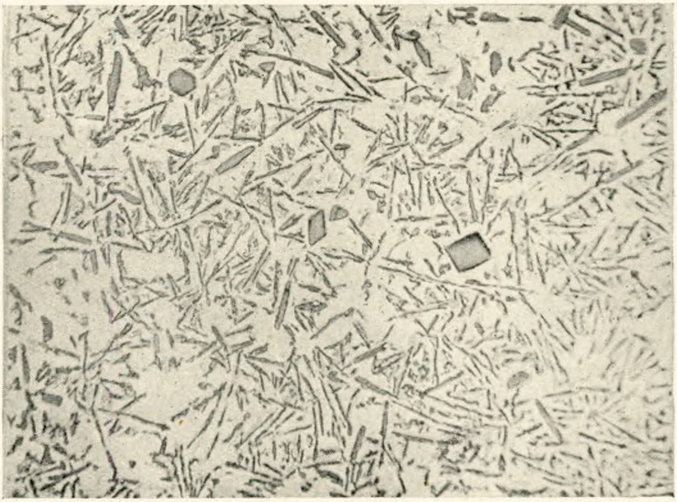


Fig. 14.—Silicon-aluminium alloy. Normal structure X150.

minium alloy castings, which consists of small cavities approximating to the size of a pin's head which are revealed on machined surfaces or sections. The cause of these was unknown. It was thought that they were related to localised shrinkage.

Research at the Laboratory showed that pin holes were caused by gases dissolved in the molten alloy which were liberated during cooling and solidification, and entrapped in the solidifying metal. The discovery was made that if a melt were sufficiently slowly solidified as *e.g.*, by shutting off the source of heat from the furnace and allowing the melt to cool down slowly and solidify in the crucible in the furnace, that the dissolved gas liberated during cooling and solidification was able largely to free itself from the solidifying metal. On carefully remelting and pouring metal so treated, castings were obtained freed from pinholes and with improved density and mechanical properties.

This discovery threw a new light on the importance and behaviour of gases in molten alloys and stimulated research in many quarters. From the known behaviour of gases towards liquids, alternative methods to double melting with intermediate slow solidification, for their removal from molten alloys soon suggested themselves. One which was at once tried at the Laboratory with very successful results consists in passing a stream of pure dry nitrogen gas through the melt before pouring. This gas is relatively insoluble in aluminium alloys. Each bubble rising through the melt provides a local atmosphere into which a soluble gas such as hydrogen can diffuse and be carried away. It is essential that the nitrogen be *dry*. Research in Germany has shown that aluminium alloys decompose water vapour and that the hydrogen liberated is absorbed by the melt.

Instead of using an inert gas like nitrogen, Tullis in this country tried the effect of passing chlorine. This also resulted in removal of dissolved gas, and at the same time appeared to have a fluxing and cleansing action. This gas, however, was found to have the disadvantageous, though extremely interesting, effect of producing a marked increase of grain size in castings.

(4) *Grain Refinement.*

The disadvantage in the use of chlorine due to the coarsening of grain, coupled with the dangerous effects of this gas when inhaled, led to trial of a volatile chlorine compound, boron trichloride*. When passed into the body of the molten alloy this volatile chloride brought about removal of dissolved gas in similar manner to chlorine gas and was very much less objectionable to use. The interesting and remarkable fact was observed that by substituting this chlorine compound for chlorine itself a pronounced *grain refinement* was obtained in addition to gas removal. Here then was a process of the greatest value. No simple method of producing grain refinement in aluminium alloy castings was previously known. A further valuable feature of the treatment is the fact that the grain refinement persists after repeated remeltings. The process was patented and some alloys so treated are known under the proprietary name of Cindal. The difficulties connected with the use of boron trichloride led to an investigation at the N.P.L.—not yet completed or published—on the use of other volatile chlorides for gas removal or grain refining. These have shown that a number of these bodies, and especially titanium tetrachloride possess valuable properties in this connection. Titanium tetrachloride can be obtained commercially in large quantities and can be used in a very simple manner. The remarkable results obtainable in this way are illustrated in Figs. 15-18 inclusive, relating to aluminium and to aluminium alloy "Y."

The discovery of a method of grain refinement for cast aluminium alloys promises to be of the greatest value, especially in improving the properties of castings, particularly of large castings, and in improving the soundness and working properties of large ingots for forging, etc.

The process is being tried on a large scale in the industry.

4. CORROSION.

Corrosion is a problem of first importance to the marine engineer because his materials are used in atmospheres charged with chlorides, the corrosive action of which on metals and alloys is well-known, and in some cases in actual contact with sea water itself, *e.g.*, in the case of condensers, pumps, etc.

Research in the last few years has greatly advanced knowledge of corrosion processes and particularly corrosion in presence of water or salt solutions. There is now general agreement that corrosion in presence of water or salt solutions

* Tullis.

is mainly an electro-chemical process. Research has demonstrated that differences in oxygen concentration (*i.e.*, in æration) and also in ionic concentration from one part to another of these media can set up electro-chemical effects in a metal immersed in them. This discovery has thrown light on that most dangerous form of corrosion, localised attack or

Fig. 15.—Vertical section of aluminium ingot cast in open sand mould without feeding. Full size.

pitting. Until recently, experimental evidence relating to fundamental factors affecting corrosion has been largely qualitative in character owing to the great difficulty in devising reliable quantitative methods. Considerable progress has now, however, been made in the quantitative study by measuring corrosion in terms of oxygen absorbed.

One of the most vital corrosion problems of the marine engineer is that of the brass condenser tube in sea water. Thanks to exhaustive research carried out in this country this problem is much less acute than it was twenty years ago. Distinct types of corrosion have been recognised and preventive measures found. So-called *de-zincification* has been shown to be really complete attack in which both copper and zinc pass into solution, and the copper is redeposited by interaction between cuprous chloride and the zinc in the tube, the net result being removal of zinc. If this takes place uniformly

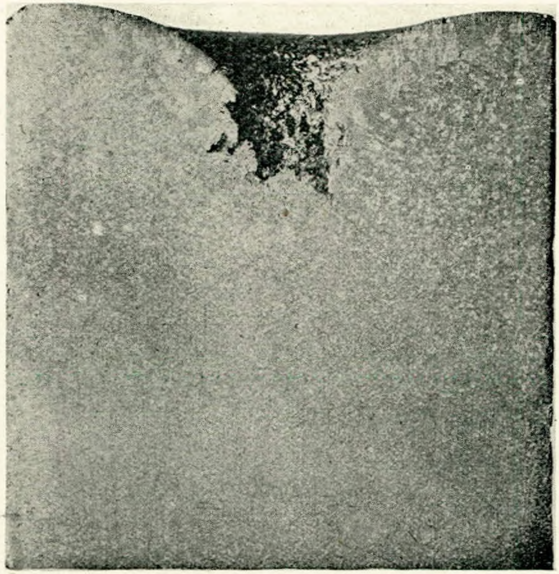


Fig. 16. Vertical section of aluminium ingot cast in open sand mould without feeding. Grain refined. Full size.

the deposited corrosion products protect more or less the underlying brass and retard the attack. If this scale is damaged, *e.g.*, by blistering through running the condenser too hot, the attack may be localised at the point of damage and is then more rapid and serious. Certain additions to the brass, notably arsenic above 0·01 per cent., prevent de-zincification. Some impurities, notably iron, facilitate it. Another form of attack, *deposit attack*, dangerous when localised, is set up by differential æration or oxygen-concentration cells, at the points of contact where foreign bodies—sand, mud, coke, etc.—may settle. The remedy is to keep the tubes clean, but to avoid any damage to the general oxide film covering the surface. Serious damage to this film by, *e.g.*, scoring, will facilitate local electro-chemical action. In the modern condenser using high water speed the most serious cause of failure is probably the localised attack known as *impingement attack*, which occurs near the water inlet end, caused by impact of free air bubbles above a certain size on to the tube wall. Below a certain size these appear harmless. The collapse on the tube wall, of vacuum bubbles caused by cavitation, can cause an exactly similar effect. Both actions, by eroding or displacing the surface film,

Fig. 17.—Vertical section of Y-alloy ingot cast in open sand mould without feeding. Full size.

expose the underlying brass to electro-chemical attack. Remedial measures can be taken by means of design and by use of grids or baffles.

An outstanding result of the exhaustive researches so far made is the recognition of the important functions of films or scales forming naturally on brass by corrosion in sea water. These films have an ennobling effect so that a difference in electric potential is set up between a clean and an oxidised brass surface in sea water and a current tends to flow in the liquid, from the clean or freshly exposed brass to the scaled brass.

The formation and behaviour of these films in moving sea water has been studied to some extent by observing the difference in electrode potential between clean brass and scaled brass respectively in sea water, measured by means of an auxiliary calomel electrode forming the cathode.* What is known as a "jet test" has been developed, in which a specimen of condenser tube is mounted in a vessel of sea water and subjected to impingement of sea water normally to its surface from a jet

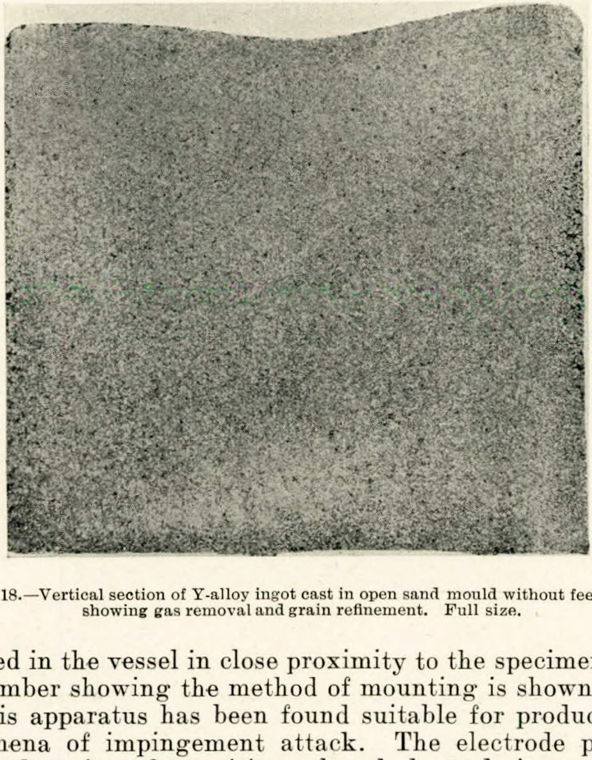


Fig. 18.—Vertical section of Y-alloy ingot cast in open sand mould without feeding showing gas removal and grain refinement. Full size.

mounted in the vessel in close proximity to the specimen. The jet chamber showing the method of mounting is shown in Fig. 9. This apparatus has been found suitable for producing the phenomena of impingement attack. The electrode potential measured against the positive calomel electrode is greatest for the clean brass and decreases as the film forms on the brass rendering it more electro-positive or cathodic. The difference between the electrode potential of the clean brass and the scaled brass measured in this way, due to film formation is termed

* May, 8th. Report to the Corrosion Research Committee, Institute of Metals, J. Inst. Met., 1928, 40, 141.

"film potential." As the film forms and the brass becomes more cathodic or positive to the sea water, the film potential increases. The increases in film potential with time for an arsenical brass and a brass containing 2 per cent. of aluminium

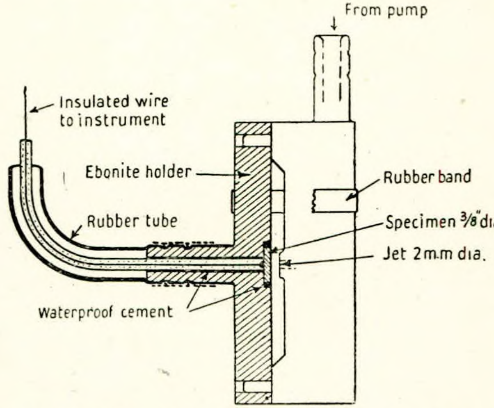


Fig. 19.—Jet Test. Method of holding specimens for Potential Measurements. (May.)

measured in this jet test apparatus using a jet of sea water moving at 15 feet per sec. free from air bubbles are shown in the graphs of Fig. 20. Film formation on the aluminium brass

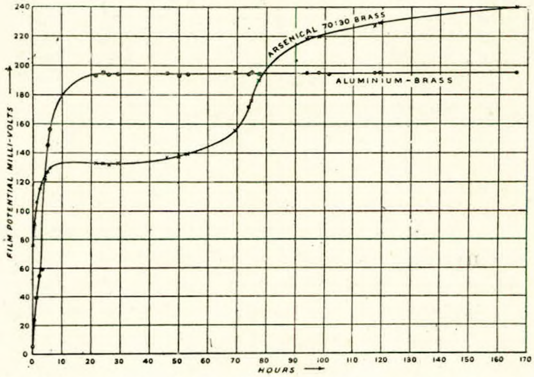


Fig. 20.—Increase in film potential with time, in jet test. (May).

appears to be complete after 24 hours, but is still proceeding on the arsenical brass. Continuations of these graphs in Fig. 21 show the effects of scratching the films with a needle point.

The film potential is decreased, but immediately begins to rise again owing to spontaneous "healing" of the film. In the aluminium brass the scratch healed in 8 hours. In the arsenical brass it was not completely healed in 24 hours. At this point about 1·4 per cent. by volume of air was admitted. The film on the aluminium brass was hardly affected, but on the arsenical brass the incompletely healed film immediately broke down and vigorous impingement attack started. On stopping the air supply the film on the arsenical brass at once began to heal again. The wide significance of these phenomena and the

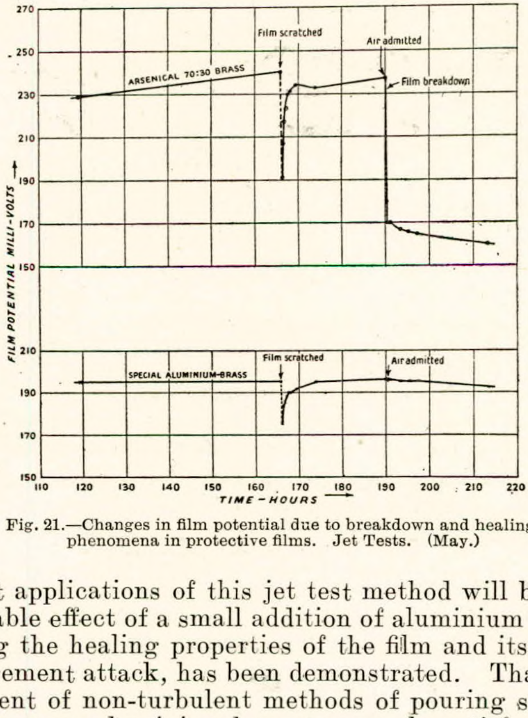


Fig. 21.—Changes in film potential due to breakdown and healing phenomena in protective films. Jet Tests. (May.)

important applications of this jet test method will be obvious. The valuable effect of a small addition of aluminium to brass in improving the healing properties of the film and its resistance to impingement attack, has been demonstrated. Thanks to the development of non-turbulent methods of pouring such as the Durville process, aluminium brass can now be satisfactorily cast in the foundry, and condenser tubes of this material are undergoing service trials. Some remarkable results have been obtained.

Amongst special alloys advocated for overcoming condenser tube troubles mention must be made of 70/30 cupro-nickel. De-zincification is of course, impossible in such tubes and they appear to have good resistance to impingement attack. As already indicated, modern research on corrosion has given us a new outlook. "It is now pretty generally understood that strictly incorrodible metals are beyond the hope of scientific or economic achievement, and that those materials which most nearly approach incorrodibility owe their superior behaviour to the protective nature of the coating or film formed by the early stages of corrosion upon the surface. In other words. instead of looking for a non-corroding metal we now look rather for one which corrodes so fast, but so well that the resulting oxide or other chemical product forms and maintains an unbroken and tenacious film on the surface."

One outstanding example of this principle is provided by the aluminium brass described above, another by the anodic oxidation process for corrosion protection as applied to aluminium and its alloys, in which a dense adherent oxide film is produced by accelerated electro-chemical corrosion.

As already stated the corrosion of condenser tubes is a much less serious problem to-day than it was some years ago, thanks to the brilliant research work carried out in this country. The recent advent through the research and activities of the British Non-Ferrous Research Association, of the aluminium brass condenser tube with its remarkable protective film forming properties bids fair to reduce the problem still further.

5. NITROGEN CASE-HARDENING.

Several novel methods of producing a hard surface layer on steel to resist wear and abrasion have been developed in recent years. One of the most interesting is nitrogen case hardening, or "nitriding" as it is termed. The process consists in heating the parts in an atmosphere of ammonia at the comparatively low temperature of 500° C. for a period of time depending on the thickness of case required. Under these conditions part of the ammonia is dissociated into nitrogen and hydrogen, and nitrogen is absorbed by the steel. The process is carried out in a gas tight box through which the ammonia is circulated, the whole being heated in an electric resistor furnace with good pyrometric control. At the completion of the process the box is removed from the furnace, allowed to cool quickly, and the parts removed. No further heat treatment is necessary.

The success of the process is due to researches carried out at the Krupp works in Germany by Dr. Adolph Fry, which led to the discovery that by addition of certain alloying elements to carbon steel notably aluminium, chromium, and molybdenum, the penetration of nitrogen could be controlled and restricted to the surface layers of the steel. In plain carbon steels the nitrogen completely penetrates the material and renders the whole part brittle. A series of steels having a range of carbon contents and containing approximately aluminium 1·25, chromium 1·5 and molybdenum 0·2 per cent. was developed by Dr. Fry. These special low alloy steels are marketed under the name of "Nitralloy." The process is patented.

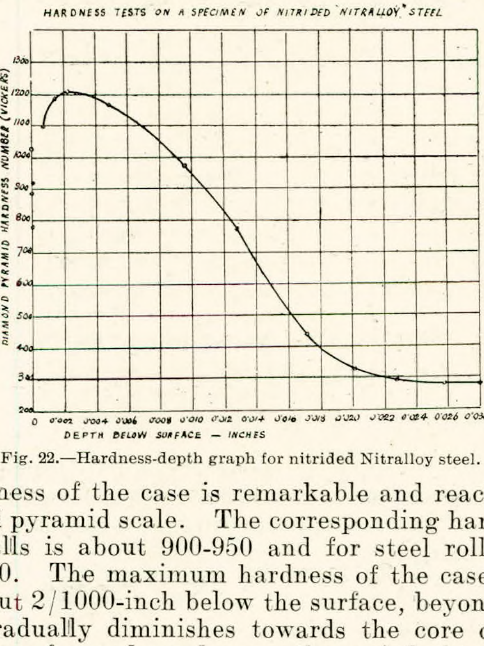


Fig. 22.—Hardness-depth graph for nitrided Nitralloy steel.

The hardness of the case is remarkable and reaches 1200 on the diamond pyramid scale. The corresponding hardness value for steel balls is about 900-950 and for steel rollers used in bearings 940. The maximum hardness of the case is actually reached about 2/1000-inch below the surface, beyond which the hardness gradually diminishes towards the core of the part. The thickness of case depends upon the period of treatment and varies from approximately 8/1000-inch after 20 hours treatment to a maximum of approximately 31/1000-inch after about four days.

The relation between hardness and depth of case for Nitralloy steels is illustrated in Fig. 22 for maximum penetration. Fig. 23 illustrates the effect of composition of the alloy steel on this relation.

Apart from the extreme hardness of case, which exceeds that of any other steel-treating process, nitriding has the great advantage over carbon case hardening that the whole of the heat treatment of the steel required to give it the particular properties desired in the core is carried out before nitriding, and in consequence the surface hardness is attained with practically no distortion. It is recommended that parts be heat treated, finish machined to close on exact dimensions, annealed at 500°-550° C. to remove internal stress, finish machined to *exact size* and then nitrided. In many cases parts are immediately ready for service after nitriding, the surfaces being perfectly clean.

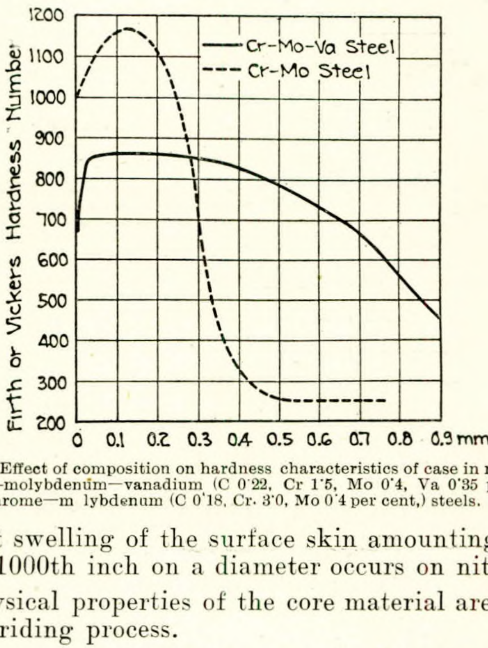


Fig. 23.—Effect of composition on hardness characteristics of case in nitrided steels. Chrome—molybdenum—vanadium (C 0·22, Cr 1·5, Mo 0·4, Va 0·35 per cent.) and chrome—m lybdenum (C 0·18, Cr· 3·0, Mo 0·4 per cent,) steels. (Fry).

A slight swelling of the surface skin amounting to approximately 1/1000th inch on a diameter occurs on nitriding.

The physical properties of the core material are not affected by the nitriding process.

Heating up to 500° C. does not affect the hardness of the case at room temperature. The relative effects of tempering on nitrided Nitralloy steel and a case-hardened carbon steel are illustrated in Fig. 24.

Apart from the more obvious uses of nitralloy parts an interesting application is for liners of internal combustion engine cylinders. Besides imparting a longer life to cylinders these liners appear to obviate wear of pistons and rings and have permitted piston speeds to be raised by as much as 400ft. per minute without ill effect.

As regards applications of special interest to marine engineers mention may be made of various pump parts, piston rods, plungers, cross-heads, rod guides, valve seatings, spindles and sleeves. Such excellent results have been obtained with nitrided steel for these parts that I understand its use has been standardised by a number of pump manufacturers.

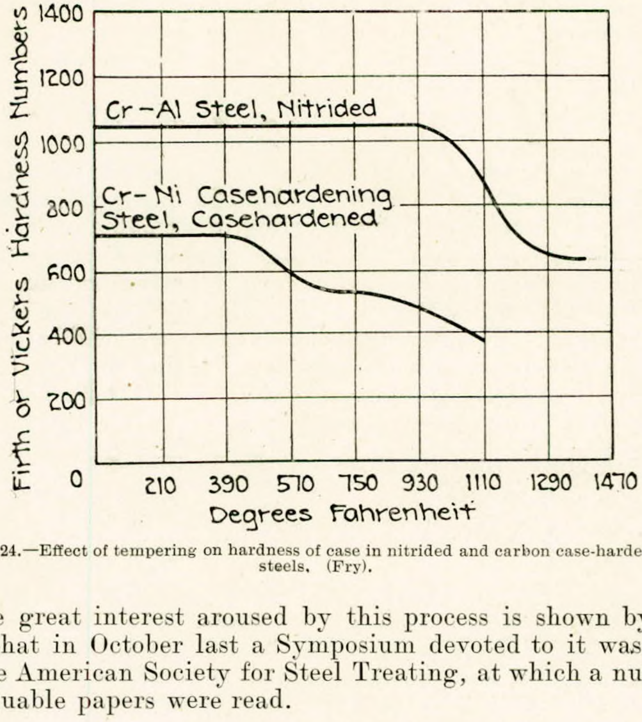


Fig. 24.—Effect of tempering on hardness of case in nitrided and carbon case-hardened steels. (Fry).

The great interest aroused by this process is shown by the fact that in October last a Symposium devoted to it was held by the American Society for Steel Treating, at which a number of valuable papers were read.

6. NEW CUTTING TOOL MATERIAL.

In this last section of my lecture I propose to deal briefly with a new cutting tool material developed in the last few years which, when full advantage has been taken of its capabilities, bids fair to amount to a further advance as great as that made when high speed cutting steels were first introduced. The material consists essentially of tungsten carbide, a product of the electric furnace produced by fusing oxide of tungsten with calcium carbide. The extreme hardness of tungsten carbide has been known for some time past—it is harder than corundum (native oxide of aluminium) which until the advent of tungsten carbide was second only in hardness to the diamond. The extreme hardness of alloys composed chiefly of tungsten and carbon has also been known for some time past and attempts have been made to develop such alloys. The great brittleness of these early materials led to failure. The success which has now been achieved is due to the development of a new method of manufacture as the result of research work at the Krupp laboratories in Germany and joint development work with the research staff of the General Electric Co. of America. It has been found that if finely powdered tungsten carbide is mixed with a sufficient quantity of cobalt, nickel or iron, compressed and then heated to a very high temperature in a neutral atmosphere, the mixture sinters and a solid mass is obtained quite comparable to that which results from solidification of a molten alloy. The method is similar therefore to that employed in preparing metallic tungsten in the massive form for wire drawing. The American product is known as "Carboloy" and the German as "Widia." This new material has aroused keen interest in America, where its capabilities as a cutting tool are being thoroughly explored and where also, study of the constitution of the material has been made.

Widia has been analysed and found to consist of

Tungsten	87·4 %
Carbon	5·68%
Cobalt	6·10%

Its hardness is remarkable; that of the American material is stated to be 2,000 on the Brinell scale (whatever that may mean). The tensile strength estimated from the resistance to bending of a small beam is stated to be of the order of 110 tons per sq. in. There is sufficient toughness with this great hardness to enable it to function as a cutting tool under correct conditions.

The material is of course only used to form the cutting edge of the tool in the form of a suitable sized piece brazed on to a steel shank by means of copper, as illustrated in Fig. 25. The tungsten carbide alloy tip can be ground by using what are known as vitrified carborundum wheels. The material is so hard that it can be used for dressing an ordinary grinding wheel.

Spectacular achievements claimed for this material include machining glass, boring smooth holes in concrete better than a diamond die and machining hard insulating materials such as bakelite.

The hard chilled surface skin on cast iron presents no difficulty, which promises valuable economic advantages in reduction of machining allowances on iron castings.

The material appears to retain its strength and hardness at high temperatures.

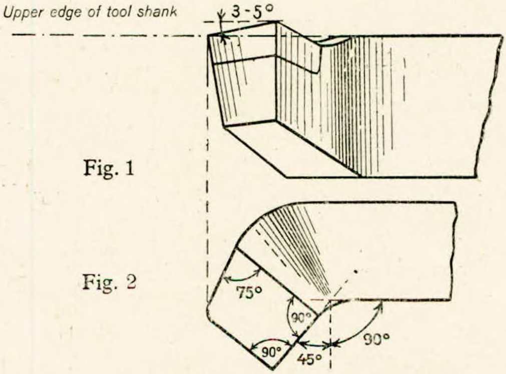


Fig. 25.—A new cutting material. Tungsten carbide (Widia) tipped tools. Fig. 1 showing side rake to facilitate cutting. Fig. 2, bent form of tool for roughing. A. C. Wickman Ltd., Coventry.

The American Society of Mechanical Engineers has issued a report, "The Present Status of Tungsten Carbide as a Cutting Material," which makes it clear that there are proved and highly important advantages to be gained by the adoption of this new cutting tool material.

The development of these tungsten carbide alloys has stimulated research on high speed cutting steels in this country, and as a result some new cutting steels have been developed with considerably enhanced properties.

My lecture is now ended. I have endeavoured to give you a brief survey, admittedly incomplete, of the more striking achievements of recent metallurgical research, and then to describe in more detail research and development which have already resulted, and which it is anticipated will result still further, in providing the marine engineer with materials which are stronger and more resistant at high temperatures to meet increasing demands of steam plant and engines; with materials of improved corrosion resistance; with lighter materials; with bearing surfaces of greater hardness and resistance to wear and erosion; and finally in providing cutting materials of enhanced properties which not only promise important economic advantages in machine shop practice, but what is perhaps more important, bring within possibility of service, new materials the use of which would otherwise be difficult if not impracticable.

Fig. 1 *is reproduced from Engineering Research Special Report No.* 1, *D.S.I.R. by permission of the Controller, H.M. Stationery Office. Figs.* 19, 20 *and* 21, *are reproduced from the 8th Report to the Corrosion Research Committee, Institute of Metals, J. Inst. Met.* 1928, 40, 141, *by permission of the Publication Committee Institute of Metals.*

I am deeply grateful and indebted to many colleagues and friends in research and industry for the ready and generous help and advice they have unstintingly given me during the preparation of the lecture.

DISCUSSION.

The CHAIRMAN said that the Institute owed a debt of gratitude to the author for such a comprehensive and informative paper. In declaring the meeting open for discussion, he was pleased to see that Mr. Kenneth Fraser was present. He, the Chairman, was not sure whether he might be doing Mr. Fraser a dis-service in advertising his name in connection with condenser tubes at sea, because when an engineer at sea has to stop to put in new condenser tubes he might think in somewhat disrespectful terms of all condenser tube makers! Nevertheless he thought it would be very appropriate if he invited Mr. Fraser to open the discussion.

Mr. KENNETH FRASER (Companion) said that if Mr. Archbutt had dealt as thoroughly with the other sections of the paper as he had done with that on the corrosion of condenser tubes, the paper was very valuable and interesting to all marine engineers. He was glad that the author had devoted so much attention to aluminium-brass, not only because it was fairly new, but because its characteristics were so very outstanding compared to the ordinary brasses and to cupro-nickel. One must not, however, overlook the fact that there was a very considerable economy in cost as between aluminium brass and its near neighbour 70/30 cupro-nickel. The difference in price was upwards of £120 per ton—a consideration which marine engineers could not afford to overlook.

He was very glad that Mr. Archbutt had referred to the way in which this alloy was brought before the public. As he had mentioned, it was brought out by the British Non-Ferrous Metals Research Association, of which Dr. Hutton was the Director, and a very great debt of gratitude was due to that Association and Dr. Hutton for introducing this very remarkable alloy. The research into the resistance to corrosion of this alloy was very interesting. The jet tests to which the author had referred showed that after considerable time very little effect was made on aluminium brass by these tests. This test, which had been explained by the author in scientific terms, was actually a corrosion-erosion action, and it should be borne in mind that for some time past impingement or corrosion-erosion attack had formed 95% of the troubles to which a condenser tube was liable. After testing aluminium brass over very long periods not only by impingement tests, but also by other tests, tubes of this alloy had been put into service and that was the only excuse for his being present that evening. He had brought for inspection, pieces of tube which had been in service for various periods; one piece had been in service for 23 months. Up to the present not only had there been no failure, but there had not been in any tube which had been inspected any deterioration, nor had any deterioration been reported.

These tubes which had been taken out of service were in exactly the same condition as when they left the Works, except that they had covered themselves with a film of scale. Some of the specimens he would show had been chemically cleaned. These were taken from the earlier cases examined from which the scale had been completely removed. These tubes had been completely cleaned in order that the whole of the inside surfaces of the tubes could be carefully examined. The other samples he would show had had the scale removed from only one half of the specimen, the other half having the scale undisturbed in any way. The extraordinary feature was that they had a scale of identical qualities and properties no matter where they had been used. There were specimens from land stations like Newcastle (where condenser tube trouble was notoriously bad) and others from ships which had sailed the tropical seas.

He would like to ask Mr. Archbutt whether he had formed any opinion as to the saving that may be effected through the increased thermal conductivity which he thought tubes of this alloy in service must possess due to the extremely thin film of scale. He had seen condenser tubes which had been very heavily coated with scale, whereas tubes of aluminium brass which had been in service were covered with only a very thin and almost impalpable film of scale.

Mr. S. F. DOREY, M.Sc. (Member), said that he thought it would be agreed that Mr. Archbutt had given them a very enjoyable lecture, one which would give food for thought for some considerable time. He thought that nowadays one heard so much of engineering developments in Germany and of research work in America that it was a pleasure to hear of developments taking place in this country. As things were at present engineers could not do without the metallurgist, and he thought that this co-operation was very welcome.

The author had mentioned stainless steel. He understood that stainless steel had been tried for condenser tubes. He would like to know whether "Staybrite" was any better. With regard to polishing, it was very difficult to remove any small internal flaws. These flaws could not be cleaned, and when corrosion did start it went on very rapidly. He would like to know how the cost of "Staybrite" tubes compared with that of cupro-nickel.

One heard much about heat-resisting cast irons for Diesel cylinder liners, but not as regards their suitability for high steam pressures. He would like to know whether any experiments had been carried out in this connection. Some metallurgists did not recommend the use of cast iron for temperatures over 425° F.; they suggested "Perlit" iron and other irons, but there did not appear to be any information available as regards the behaviour of these irons in contact with steam at high pressure and temperature. As regards the property on which the factor of safety should be based, and the suggestion that the limit of proportionality should be used, the proportional limit was of course a short time test. It might give an indication as to what stress could be used with safety, but at high temperatures it could be very mis-leading. In the case of ordinary mild steel there appeared to be no definite proportional limit above 400° C, in fact the load extension diagram was not a straight line and in many cases there was also no sign of a yield point. It was necessary to consider plasticity as well as elasticity in such cases and use a suitable factor of safety based on the creep limit. Where a definite yield was indicated it would be preferable to use it instead of a proportional limit when its value, as found by a short time test, was lower than the creep limit. Personally he said, he was not in favour of a proportional limit as a guide in any case, since its measurement depended entirely on the degree of accuracy used in its determination, the higher the degree of accuracy the lower the proportional limit.

Another point on which more information was required was the modulus of elasticity, coefficient of expansion and coefficient of conductivity at high temperatures. Their calculations could not be correct if they did not know the values of these factors. Could Mr. Archbutt state whether the value of Poisson's ratio altered with rise of temperature?

The author had made much reference to alloy steels for high pressure boiler drums, but he might with advantage have given more information as regards alloy steels for tubes. If a material was of a certain strength at high temperatures it did not necessarily follow that it would be useful at very high steam temperatures and pressures, as it might not possess suitable mechanical properties at ordinary room temperatures. He considered that the section dealing with nitrogen case-hardening was very interesting. He thought they might expect some very big developments in that direction. He asked the author whether any experiments had been carried out as regards the conductivity and expansion of the material when so treated. The author had not mentioned whether this method of treatment had been used for Diesel engine liners. If this material was used for these liners, which were subject to heavy stresses, it seemed to him that with any great variation of heat flow surface cracks might develop due to high temperatures.

In conclusion he wished to thank the author very much for his interesting paper.

Mr. W. HAMILTON MARTIN (Member) said that the author had pointed out how greatly we were in need of material which would withstand prolonged loading at high temperatures such as obtained in the walls of steam superheater tubes or drums and tubes exposed to the direct furnace heat in water-tube boilers operating under similar severe conditions. Investigations of creep and fatigue under loads were said to be very much influenced by the condition of the surrounding atmosphere. The oxygen seemed to pierce the outer layers and have a very decided effect upon the life of the test pieces. It would seem that to obtain results comparable as far as possible to actual practice, such test bars would have to be subjected to a flow of furnace gases at similar temperatures. This could probably be arranged by allowing the heated products of combustion of a gas ring to pass round the specimen.

He asked whether the author knew of tests carried out in which products of combustion were allowed freely to attack the surfaces of the test specimens, and what was his opinion as to their possible practical value.

The author had mentioned that the great drawback of these high-temperature resisting steels for use in steam plants so far had been their very high costs. Apart from cost, he believed that most of these metals had proved very hard, brittle, and difficult to work, and that they had shown early fatigue tendencies. With reference to this it might be of interest to record that recently a heat-resisting metal had been brought out on the Continent (he was sure Mr. Dorey would forgive him for crossing the water again) which would become generally available before long for the purpose aforementioned; it could be worked as easily as mild steel, it could be welded, it was of a specially corrosive-resistant nature, showed exceptionally great strength at elevated temperatures and had a correspondingly high yield point of which the limiting creep stress values were markedly small, having also good fatigue-resisting properties, and last but not least, was one of the first of such heat-resisting steels to be inexpensive. The more general application of this steel would enable installations for high operating temperatures to be designed with confidence, offering entire service dependability.

It was a very noticeable fact that thin wall tubes possessed very little tendency to ageing. This would seem to point to the desirability of not making such tubes too heavy, and reminded one of a remark by Mr. Stromeyer some time back, when he pointed out that the general tendency was to make boiler shells too heavy, and that time might perhaps prove that a lighter shell might be the safer and more desirable one. The material he had mentioned had now been in actual continuous service for some considerable period for the superheater coils of a boiler operating at very high pressure and temperature, to which it had stood up very well indeed.

Mr. Dorey had asked as to the behaviour of such heat-resisting steels at ordinary temperatures. Tubes of this material could be bell-mouthed, expanded, flattened and collapsed endwise to greater extents than was possible and usually done when testing ordinary boiler tubing, without showing any signs of failure whatsoever. At from 900° to 1100° F. the yield point of this new material lay more than 100% above that of Siemens-Martin mild steel, while its tensile strength was approximately 100% higher. At ordinary temperatures, the yield point differed little from that of the other steels, while its ultimate tensile strength at normal temperatures was about the same as that of mild steel. At 1100° F. the yield point lay at $7\frac{1}{4}$ tons as compared with three tons for mild steel. At this temperature its limiting creep stress was also very small.

The author had shown what uphill patient labour was required before such new materials, after becoming available, could be fully proved as adequate to meet the exacting services demanded of them. The question of fatigue in metals would no doubt prove to be one of increasing interest in connection with such new materials, and a great deal of valuable time and energy would have to be devoted to these researches so that materials might be forthcoming to enable engineers to design equipments producing power at increased efficiencies and reduced cost per unit. Such eminent authorities as Professors Lea and Haigh were well known to be giving these matters their wholehearted attention, as also were some private firms as well as the National Physical Laboratory, and their collective efforts were bound to prove to be for the good of our industries.

The Institute was to be congratulated on the acquisition of this valuable paper, and he would conclude by expressing his appreciation to the author.

Mr. T. H. BURNHAM, B.Sc. (Member) (Messrs. Hadfields, Ltd.), remarked that just as every art was founded on first principles so every engineering construction was founded on metals. The importance of keeping up to date on this subject needed no emphasis, and they were fortunate in having Mr. Archbutt with them that evening to present such an interesting survey of the recent progress in metallurgical research. In view of the extensive and important post-war developments they all appreciated the author's difficulty in deciding not what to include in his paper, but what to omit. He (the speaker) was rather disappointed, however, to find that the author had not mentioned, in connection with turbine blading, the newer types of nickel-chromium steel which were rapidly coming into use for this purpose. If he might be permitted to make a personal reference he would mention that the firm of Hadfields, Ltd., had already had the honour of supplying high-nickel-chromium steel blading for turbines of 2,000,000 total h.p. The inlet temperature was in some cases 850° F. and in one instance 1000° F. In addition, this steel would withstand the conditions appertaining to marine turbines without deterioraton, and experience to date showed that after seven years running the blading was in extremely satisfactory condition. This metal has a high resistance to erosion, as was mentioned recently in a paper by Mr. S. S. Cook, B.A., F.R.S., before the Royal Society, so that the blading keeps its profile and the efficiency of the turbine is maintained.

Referring to mechanical properties at high temperatures on which it was necessary to have information, from a practical point of view one might distinguish two cases—one where no deformation was permissible, the other where a slight deformation would not interfere with the functioning of a mechanism.

In the first case one would have to take full creep stress curves, and for design purposes it would be best to choose whichever was the lower of the creep stress and proportional limit as the basis of calculations.

The author had given some very interesting information on heat-resisting steels. He (the speaker) preferred to divide them into two classes (1) true heat-resisting steels for use at a red or even yellow heat (2) another class, to which he would refer later. The first class had come into extensive application already. He had looked up some of the larger applications and would instance such parts as grates of retort stokers, links of chain-grate stokers, dampers, angles and brackets used for supporting the refractory brickwork in powdered-fuel-fired boilers, exhaust valves of Diesel engines and many others. Retention of strength was generally required to be accompanied by resistance to scaling and with regard to resistance to oxidation and heat wastage the speaker thought it was necessary to employ metals which had been thoroughly tried out, because some whilst showing a good initial resistance, might in course of time not stand up so well. A testing period of 5,000 hours was something of the order he would suggest.

The second class of steels he would term applicable to intermediate temperature ranges, such, for example, as bolts and nuts in superheated steam piping. Mr. Archbutt had referred to some of the requirements for this class of steel, but another point to be kept in mind was whether any deterioration occurred in the properties of the metal after continued service. This second class of steel might find a useful application in superheater tubes. In this connection he would mention a steel made by Messrs. Hadfields which gave four times the creep strength of ordinary carbon steel at 900° F., was quite ductile and could be expanded and worked as readily as ordinary steels. As to what would be the full extent of its use they had to leave to engineers to find by service, but it might be useful to know that such a steel was available, and could be produced at a commercial price. It was also finding a useful field for valve bodies for high temperature steam.

He thought that Mr. Archbutt had brought out a very important practical point regarding the influence of the atmosphere on creep data. Figures obtained in a laboratory might not be the same as would appertain to metals exposed to exhaust gases and under other practical conditions. The effect referred to might be on a parallel with the well-known influence of the ambient fluid on a fatigue test.

The speaker was not an expert on non-ferrous metallurgy, but he thought that the author and the National Physical Laboratory were to be congratulated on the solution of many important fundamental problems as outlined in the paper. The subject of age-hardening had always been of interest to the speaker, and particularly the methods used in connection with the age-hardening of iron alloys. He was only aware of the work of Sykes in America, and would like to ask the author whether he could give references to work in this country on the subject.

The author had referred to the role of protective coatings in the corrosion of non-ferrous metals, and he thought that probably something of the same nature occurred in corrosion-resisting iron alloys. It was interesting to note that a steel manufactured by Messrs. Hadfields had been subjected to corrosion by partial and total immersion in sea water in all parts of the world for many years. It was, of course, stronger than bronze and very tough, and the suggestion had been made that this steel might with advantage be used for propellers and a higher efficiency obtained from finer lines.

As the author had mentioned new cutting alloys, the speaker would have liked him to refer more fully to the newer classes of tool steels. Heat and corrosion-resisting ferrous alloys had in the past presented some difficulty in machining, and tool manufacturers in this country had set themselves out to develop better cutting tools. Tungsten carbide alloys had enabled much higher speeds to be used, and, he thought, might produce a revolution in the design of machine tools, but they were not so useful for work involving high compressive stresses on the tool, or for intermittent cutting or for machining material containing hard and soft spots. The new tool steels were a really distinct advance in comparison with pre-war high-speed steel. As an example, Messrs. Hadfields were using them commercially for machining manganese steel. In their own works they had difficulty in testing the new steel out to destruction.

He wished to thank Mr. Archbutt for his extremely interesting and valuable paper.

Engr. Rear-Admiral MARK RUNDLE, D.S.O. (Visitor), expressed his indebtedness to Mr. Archbutt for his valuable summary of metallurgical progress to date bearing on marine engineering, with regard to which the application of theoretical knowledge had usually had to wait on material. He had served in one of the first Belleville boiler ships in the Navy in which, whilst they obtained the pressures and temperatures for which the boilers were designed, the materials used in the construction of the boilers and fittings were not always satisfactory. For example, the high pressure steam cut the valves and valve seatings, the portable valve seats leaked, and there was difficulty in maintaining steam tightness at the pipe joints.

With regard to condenser tubes, one might fairly say that they had always been something of an anxiety to sea-going engineers. He would like to make a few remarks about the aluminium brass condenser tube, as he had to some extent been associated with its introduction. He thanked Mr. Kenneth Fraser for his compliment to Dr. Hutton and the British Non-Ferrous Metals Research Association on the work they had done in the development of this tube. So far, aluminium brass tubes had performed well on service, and there was reason to hope that they might continue to do so. The value of the tube appeared to be that its resistance to corrosion depended upon the formation of a strongly protective film of corrosion product. Moreover, this film healed itself if accidentally damaged or abraded.

Another important metallurgical development was in connection with lead sheathing for cables, which were largely used in ships. In recent years this sheathing had in some cases developed cracks, commencing inside the sheath. As the result of research, carried out at the Research Department, Woolwich, and under the auspices of the British Non-Ferrous Metals Research Association, it is considered that this cracking was caused by vibration. Investigation to find a material which would stand this vibration better than lead had resulted in the introduction of an alloy consisting of lead with a small quantity of cadmium, together with either tin or antimony, in its composition. This alloy had a considerably higher fatigue limit and tensile strength, and was about two-thirds the weight of lead. These improved properties were receiving attention. The Admiralty had specified this alloy for all cable sheathing in H.M. ships, and the Post Office had also made some use of it.

The CHAIRMAN said that with reference to creep stresses he had always felt that if one were a designer of a boiler in a boiler shop and read very carefully the reports on creep stresses, one would do no more designing for a time until the effect produced had worn off somewhat. He referred to the very high factor of safety they took when dealing with these questions. As to the ageing under creep stresses, that would perhaps be a very difficult thing to determine. They had boilers working which were about fifty years of age. He thought it would be very difficult to calculate the life of a present-day boiler, if they limited the factor of safety on their experience of creep stresses.

He had been pleased to note Mr. Archbutt's remarks on intercrystalline fracture under creep stresses. His statements agreed with the theory put forward twenty-four years ago that a feature of fatigue stresses was the intercrystalline fracture of the material.

In connection with the use of oxidation for protection, he could not help thinking that the engineers had to depend upon co-operation with the metallurgist. They had come to that stage where they could not do without his help. If they had consulted Sir William Bragg, the eminent physicist, he would probably have given them a theory that all these materials were made of electrical energy. They were families denoted by the numbers of the propagators. We might have "raw beef" or "roast beef" (heat-treated beef) but it was all electricity! The difficulty was co-operation between the physicist and the metallurgist. If they could co-operate more they would understand these things better. They would be able to make big boxes in the foundry, connected to two poles, one discharging electrons and the other protons, and they would be able to get whatever metals they wanted!

Referring to the nickel process, it would be interesting to know whether the substance used was analysed after the process to ascertain what had passed out from the aged tubes, and whether the nitrogen was analysed afterwards to know how many electrons and how many protons were present.

Mr. H. J. YOUNG (Member) (by correspondence): Mr. Archbutt's admirable paper is difficult to criticise, for the reason that by covering so wide a field it fails here and there to disclose the author's experience and, perhaps, such parts would have been better omitted. For instance, the question of alloy cast irons is dealt with in a few words, nickel or nickel alloy irons being mentioned and definite properties assigned to them in a manner which would be highly controversial if the author's paper were dealing with that subject alone. As it stands, however, one can merely point out that engineers and foundrymen should not take all that the author says as gospel. The truth is that valuable research has been and is going on, but up to the present there have not been attained under service conditions such results as justify us in saying anything as definite as are the author's statements.

In his remarks regarding corrosion-testing the author says a " Jet Test " has been developed, but he (the writer) believes he is correct in stating that when he was assistant to Professor A. K. Huntington some twenty or more years ago, Professor Huntington had a somewhat similar apparatus in constant use. It is agreed there is nothing in this statement derogatory to the Jet Test.

The author states that Widia Alloy finds no difficulty in dealing with the chilled surface skin on cast iron, but he (the writer) in his travels around many foundries and engineering works of this country has been told that the reverse experience is true and that these tungsten carbide alloys have been rather unsuccessful in dealing commercially with the outside skin of castings. It is to be noticed that the writer uses the qualifying word " commercially " because it is one thing to discover properties on an experimental scale and another to overcome the many " snags " which occur when applying the knowledge gained to commercial production.

It is refreshing to see that the author includes light alloys in a marine engineering paper, though their practical value on any considerable scale is not convincing. Probably much of a marine engine could—on paper—be made of light alloy, but whether it would be advisable or reasonable to so make it is another matter altogether. The writer remembers the time when the aluminium bicycle was going to revolutionise cycling, and to the man-in-the-street it seemed certain that a bicycle weighing a few pounds only was the last word in such a machine. The materials of construction of marine engineering need to stand up to difficulties, and to satisfy conditions which impose severe limitations upon one's choice, limitations such as the laboratory and the testing machine seldom take into account. One might almost express the matter by saying that the difficulty with light alloys is that they possess the characteristics of light alloys.

In making the above remarks the writer is merely advocating caution. We are on the brink of many advancements, and Mr. Archbutt's paper is valuable to all of us so long as we recognise that with some of these things it is the brink to which the author refers.

ORAL REPLY OF AUTHOR.

The author, in reply, said how much he had appreciated the way in which his lecture had been received, and the excellent discussion which had followed. It was somewhat difficult to reply forthwith to a number of the questions which had been raised, but he would amplify his reply in writing.

Mr. Kenneth Fraser had discussed the aluminium-brass condenser tube; he (the author) was sure that they were all very pleased that Mr. Fraser had brought the samples for inspection. He had been interested to hear of the economical advantages of the tubing, which was a very valuable characteristic, as it had to compete with other tubes on a commercial basis. He thought Mr. Fraser was quite right in pointing out that the fact that it did not scale to anything like the extent to which ordinary brass did, was of great value in regard to its thermal behaviour in a condenser.

Engineer-Commander Dorey had asked for evidence of the practical value of "Staybrite." With regard to alloy steels for tubes

Mr. Burnham and Mr. Hamilton Martin had given information in their remarks. As to the behaviour of heat-resisting cast irons under high pressure steam, he could not give any information from practical experience. He suggested that Mr. Pearce, Director of the British Cast Iron Research Association, might be able to give this information. He thanked Mr. Dorey for his reasoned opinion regarding the relative value of limiting creep stress and limit of proportionality. With regard to nitriding, that was another question where practical experience was required, which he regretted he could not give off-hand. The American symposium which he had mentioned in the paper might contain some information on the points raised.

Mr. Hamilton Martin had referred to the workability of alloy steels and the difficulty of working some of the new alloys. Certainly some of the new alloys which they were producing had proved impossible to work, but there were others that would. He was much obliged to Mr. Martin for describing the new Continental material and its interesting properties.

Mr. Burnham had pointed out some defects and omissions in the paper, for which he was much obliged. The information Mr. Burnham had given about special nickel chrome steels for turbine blading was very interesting.

With regard to the age-hardening of alloys, the work he referred to was the work on iron tungsten. He thanked Admiral Rundle very much for being present. He was able to confirm the remarkable results obtained from the aluminium brass condenser tubing. Admiral Rundle had been very correct in pointing out that engineering progressed as fast as materials would allow. It was up to the metallurgist to improve the engineer's materials for him. The introduction of alloy cable sheathing was a very important achievement, and as Dr. Hutton had pointed out, on board ship where there was considerably more vibration than in land applications, lead alloy cable sheathing was particularly valuable.

Mr. Young had taken up the cudgels in contributing his remarks. As regards cast iron, he may not have struck a very good balance between the various classes of cast iron. With regard to the jet test, he might perhaps have said that an improved jet test had been developed. With regard to light alloys, he felt that Mr. Young was a little behind the times and did not realise the high duty which light alloys nowadays were successfully performing. Their use was extending very rapidly. The Aluminium Company of America was putting down a plant with an output of ten tons per day of forged heat-treated aluminium alloy parts.

He would like to thank the Chairman for his remarks. With regard to intercrystalline fracture and fatigue one must be a little careful. Intercrystalline fracture was not typical of a true fatigue failure. Prolonged loading of the kind referred to in the lecture must not be confused with fatigue testing under reversals of stress. Under the latter conditions fractures normally had a smooth surface and were trans-crystalline. In prolonged loading under direct stress on the other hand an intercrystal fracture at high temperatures was not to be regarded as abnormal, but the reverse.

The Chairman said that he was sure they would all endorse him when he proposed a very hearty vote of thanks to Mr. Archbutt for giving them such a valuable paper on recent metallurgical research. His lecture would be read practically all over the world.

The proposal was carried with enthusiasm.

A vote of thanks was also accorded to the Chairman on the motion of Mr. W. McLaren, and the meeting then terminated.

FURTHER REPLY OF THE AUTHOR IN WRITING.

The author in further reply to the discussion at the meeting wrote :—

With regard to the question of thermal conductivity in relation to aluminium brass raised by Mr. Kenneth Fraser, apart from the effect of pronounced corrosion and scaling which might be expected to have a serious effect, I can say that tests have been made at the laboratory using town water and condenser tubes of several different materials which have shown that quite a thin film, amounting only to a tarnish, can cause a serious diminution in heat transfer in a short time, *e.g.*, in two days. In this respect certain classes of tubes were found much superior to plain brass. These tests have not included aluminium brass, and I have no knowledge of any tests having been made outside the laboratory. If it is the case that aluminium brass tubes have not been tested in this way it would be of considerable interest to make comparative tests on them.

Regarding Engineer-Commander Dorey's questions, neither stainless steel nor the austenitic rust-resisting steels of the Staybrite type have been tried out extensively for condenser tubes. Such trials as have been made, I hear on good authority, have not indicated that either of these steels would be a success. From remarks made by Engineer-Captain Hope-Harrison in a recent paper to the Institution of Naval Architects in London, it will be seen that the Admiralty have tried "Staybrite" tubes and that some of them failed in service. They do not appear to be up to the standard of cupro-nickel. Regarding cost I would refer Commander Dorey to some of the chief makers—Messrs. Thos. Firth and Sons, Ltd. for Staybrite, and Messrs. Allen Everitt and Sons, Ltd., or the Yorkshire Copper Works, Ltd., for cupro-nickel. I believe the cost of Staybrite tubes is at least double that of cupro-nickel.

I was only able to make very scant reference to cast iron in my lecture, and Commander Dorey asks for more information. In recent years splendid work has been done and progress made in metallurgy and development of cast iron through the activities of the British Cast Iron Research Association, and I would recommend Commander Dorey to Mr. Pearce, the Director of that Association for more detailed information of the present position. I myself very gratefully acknowledge help from that source. Interest in cast iron has centred in the Diesel engine rather than in the turbine for the reason, perhaps, that the technical problems of the former are regarded as the greater. Under super-heated steam conditions, cast iron does not generally show any signs of oxidation or volume change until about 350° C. - 400° C. Modern plain cast iron can be heated to 400° C. without deterioration of strength, and alloy cast iron to still higher temperature, 500° C. It would appear, therefore, that the temperature of 218° C. (425° F.) mentioned by Commander Dorey could be raised considerably. The question of resistance to high pressures concerns the casting itself rather than the metal of which it is made. Progress has, however, been made both in the direction of introducing an intrinsically strong material and of making a perfect casting from it.

It is interesting to have Commander Dorey's opinion as to the relative value of the proportional limit and limiting creep stress for guidance in regard to the strength of a material at high temperature.

As regards the effect of temperature on Poisson's ratio, I am indebted to my colleague Mr. Batson, of the Engineering Department, for the following:—Poisson's ratio for carbon steels at various temperatures can be calculated from the values of the modulus of elasticity in tension and modulus of rigidity in torsion given in Engineering Research Special Reports Nos. 1 and 2.

The calculated values show a progressive decrease in the value of Poisson's Ratio, the average values for four carbon steels being as follows:—

Temperature, ° C.	Poisson's Ratio.
16	0·27
100	0·25
150	0·25
200	0·24
300	0·20
400	0·17

As regards alloy steel tubes, I state in my lecture that high-nickel high-chromium steel is in use for superheater tubes. Mr. Hamilton Martin has referred to a continental material, presumably an alloy steel, and probably a low alloy steel, which can be worked into tube which will withstand very severe expanding, flattening, etc., tests, and has high temperature properties considerably superior to those of ordinary carbon steels. I do not know whether Mr. Hamilton Martin is familiar with the special steel (Era 131) recently introduced by Messrs. Hadfield, Ltd., and exhibited by Sir Robert Hadfield before the Royal Society and the Institution of Civil Engineers. The properties claimed for this steel are similar to those given by Mr. Hamilton Martin for the continental material. It is, I think, one of the steels to which Mr. Burnham refers in his remarks. Regarding nitrogen case-hardening, I can give no results relating to thermal conductivity or expansion of nitrided steels. Investigations on this question are in progress. As regards nitrided steel liners for marine Diesel engines, progress is difficult owing to the very high cost and the large size of these, which are greater than can be accommodated in nitriding plant at present available in this country. Nitrided steel liners are, however, being successfully used for internal combustion engines for automobiles and aircraft.

Mr. Hamilton Martin refers to oxidation and scaling tests on alloy steels. As I have briefly mentioned in my lecture, this problem is at present under investigation at the laboratory. The interesting particulars Mr. Martin gives regarding the new continental material for high temperature service I have already referred to in my further reply to Engineer Commander Dorey. It is satisfactory to know that a British firm has introduced an alloy steel for which similar properties are claimed. As I have already stated, my remarks relating to cast iron are very brief, and Mr. Young feels undue emphasis has been laid on the merits of cast iron alloyed with nickel. There is no doubt, however, that admirable results are being obtained with this material when care is taken to use a balanced composition, that is, when the silicon is modified in accordance with additions made. In this connection I might refer Mr. Young to a paper entitled "The Correlation of Mechanical Tests for Cast Iron," by Mr. J. G. Pearce (an exchange paper of the Institute of British Foundrymen with the American Foundrymen's Association, May, 1930), and ask him to compare the mechanical properties of the four ringed irons in Fig. 15, page 28, which are alloyed with nickel, with the corresponding properties of a very high quality straight cast iron.

The CHAIRMAN said that he was sure they would all support him when he proposed a very hearty vote of thanks to Mr. Archbutt for giving them such a valuable paper on recent metallurgical research. His lecture would be read practically all over the world.

The proposal was carried with enthusiasm.

A vote of thanks was also accorded to the Chairman on the motion of Mr. W. McLaren (Member), and the meeting then terminated.

ERRATA.

THE STEERING SYSTEM OF A MODERN SHIP.

See March Transactions.

Page 150. Calculation for maximum torque should read:—

$$\text{Torque (Max)} = \frac{A \times p \times R \times Sa \times E}{2240}$$

Where, A = Area of ram in sq. inches.

p = Max. working pressure in lbs. per sq. inch.

R = Normal Radius.

Sa = Rapson Slide Advantage.

E = Efficiency of gear for maximum rudder angle.

and in the case of a four-ram gear:—

$$\text{Torque (Max)} = \frac{2 \times A \times p \times R \times Sa \times E}{2240}$$

Page 151. Calculation for size of ram should read:—

$$A = \frac{244 \cdot 4 \times 2240}{2 \times 1000 \times 2 \cdot 75 \times 1 \cdot 49 \times \cdot 78}$$

$= 85 \cdot 8$ sq. inches = say $10 \cdot 5$ inches dia.

Calculation for hydraulic pressure at 20° should read:—

$$\frac{605 \times 1 \cdot 49 \times \cdot 78 \times \cdot 342}{1 \cdot 132 \times \cdot 83 \times \cdot 5736} = 450 \text{ lbs. sq. inch.}$$

Calculation for B.H.P. of motor should read:—

Say pump discharges 25,000 cubic inches per minute allowing a pump efficiency of 85%,

$$\text{B.H.P. of Motor} = \frac{25{,}000 \times 450}{12 \times 33{,}000 \times \cdot 85} = 33 \text{ say } 35 \text{ H.P.}$$

—o—

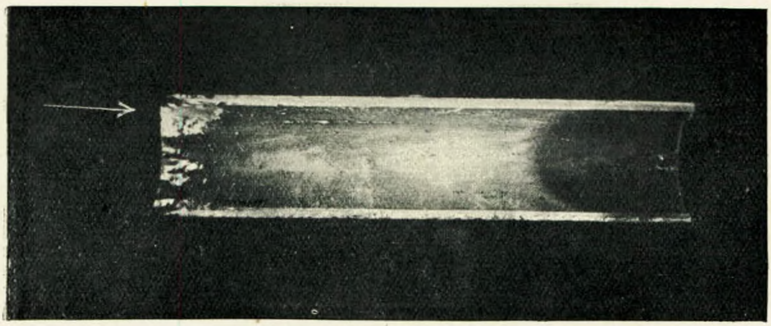
The Problem of Condenser Tube Corrosion: Some Theoretical Considerations. By D. Hanson, D.Sc., Professor of Metallurgy, University of Birmingham.

"The Nickel Bulletin," March, 1930.

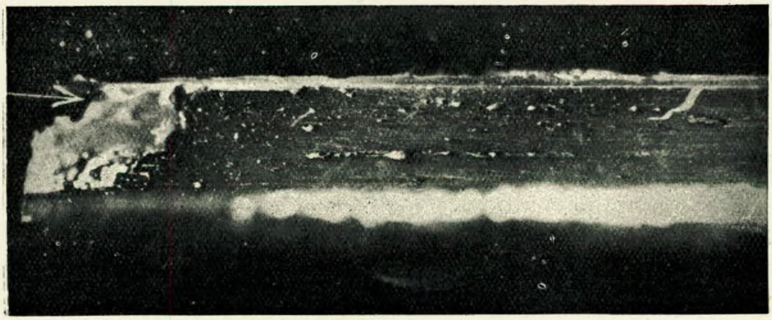
The term "corrosion" as applied to metals and alloys may broadly be considered to mean wasting away or dissolution as a result of chemical action. When we consider, on the one hand, the large number of metals and their much more numerous combinations into alloys, and, on the other hand, the even greater number of substances, both gaseous and liquid, with which they can enter into chemical combination, it is hardly surprising that the problems involved in accounting for the "corrosion of metals" are both numerous and difficult to solve. In any individual instance of corrosion, the behaviour of metal or alloy can only be accounted for in relation to the substance with which it reacts, and this "second party" is, from the point of view of theory, every bit as vital as the metal itself. Moreover, just as in studying other forms of chemical action, we take account of the nature of the reaction product, so also must we recognise that the nature and the form of corrosion products are vital factors in the problem.

The corrosion of metals by sea water is an instance in which many variables may be introduced quite apart from those in the metal itself. Sea water is a strong, complex solution of salts; it is saturated with oxygen; it usually contains air-bubbles; it may contain a variety of solids, such as sand and decaying organic matter, and in harbours and around the coast may be diluted or contaminated by mud, sewage, etc. When, in addition, it is passed through a condenser, it may also be subjected to variations in temperature, rate of flow, turbulence, and so on. It is easy to see that the nature of the action between metal and corrosive solution may vary greatly from condenser to condenser or even in different parts of the same condenser irrespective of variations in the material of the condenser tubes.

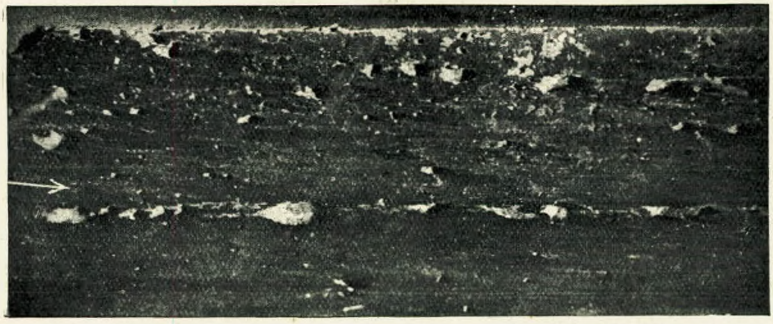
A proper knowledge of the mechanism of corrosion is necessary if we are to appreciate what is required in a condenser tube. It is now generally agreed that corrosion in water or salt solutions is essentially an electro-chemical process. According to this view, corrosion is only possible when three factors are present—an anode, a cathode and an electrolyte



X1



X3



X6—Shewing Lines of Pits.

Photographs of Inlet End of Brass Condenser Tube tested in Experimental Condenser.

(The direction of flow is indicated by the arrow.)

(From the Seventh Report to the Corrosion Research Committee of the Institute of Metals.)

capable of carrying sufficient current for the reaction to proceed with appreciable velocity. This view is by no means modern; it was originally stated by Faraday and amplified by Whitney* in 1903, although it was not in either instance subjected to very rigid tests. The majority of the exponents of this theory looked to variations in the metal, such as impurities, differences of phase, etc., as supplying the differences in potential necessary to promote electro-chemical action, and it was widely believed that a pure homogeneous metal was incorrodible, and that increased purification in metals offered a possible solution of corrosion difficulties. Walker, Cederholme and Bent† were the first to indicate the important function of oxygen in corrosion. Aston‡ observed that corrosion was caused by variations in the distribution of oxygen, and the work of Bancroft,§ Bengough and Stuart,‖ Evans**, and others has also added greatly to our knowledge of the *rôles* played by oxygen and films of corrosion products.

As a result of the labours of the above and other workers, a satisfactory working theory of electrolytic corrosion has now been built up. This may briefly be stated as follows:—

When, in a metal immersed in an electrolyte, a potential is set up sufficient to cause current to pass, metal passes into solution at the anode, while hydrogen or other secondary products are formed at the cathode, their nature depending on the character of the metal and electrolyte.

Although the reactions involved in corrosion are not necessarily complex in nature, they are usually irregularly distributed over a metallic surface, and both distribution and speed are influenced by many factors. In some cases, as in zinc or iron, the presence of impurities or heterogeneity can initiate corrosive action, but in many instances other factors are dominant; for example, in copper alloys, heterogeneity is believed to be relatively unimportant.

In most instances of electro-chemical corrosion the factors which maintain corrosive action are external to the metal itself, and of these by far the most important is the variation

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*W. R. Whitney.—"The Corrosion of I on." Jnl.Amer.Chem.Soc., 1903, xxv, pp 394-406.

†W. H. Walker, A. M. Cederholm and L. N. Bent—"The Corrosion of Iron and Steel." Jnl. Amer. Chem. Soc., 1907, xxix, pp. 1251-1264.

‡J. Aston.—"The Effect of Rust upon Corrosion of Iron and Steel." Trans. Amer. Electrochem. Soc., 1916, xxix, p.449.

§W. D. Bancroft—"Preliminary Notes on Corrosion." Proc. Amer Soc. Testing Materials, 1922, xxii (2), pp. 232-236; W. D. Bancroft.—"The Electrochemistry of Chemistry." Trans. Amer. Electrochem. Soc. 1906, ix, pp. 17-21; W D. Bancroft.—"The Electrolytic Theory of Corrosion." Jnl. Phys. Chem., 1924, xxviii pp 785-871.

‖ Jnl. Inst. Met., Vol. 28, p. 31.

** U.R. Evans.—"The Corrosion of Metals." (Ed. Arnold, London, 1924.)

in oxygen concentration in contact with the metal, areas exposed to oxygen being cathodic and unexposed portions being anodic; in the case of copper and some of its alloys, a portion of metal subjected to the action of electrolyte in rapid motion becomes anodic to that in more stagnant liquid. During the last few years U. R. Evans in particular has done much important work on corrosion due to external conditions such as those mentioned, and he has provided a satisfactory explanation of the well-known fact that corrosion is often especially severe at just those places to which oxygen has least direct access.

Electrolytes usually contain dissolved and sometimes entangled oxygen, which tends to disappear during corrosion through the formation of oxy-salts, and further supplies only reach the metal through diffusion or turbulence in the solution. Anything, therefore, which prevents renewal of oxygen supplies tends to maintain conditions favourable to electrolytic corrosion. The screening of oxygen may be due to the presence of extraneous substances or to products of corrosion, particularly when they are insoluble, or to cracks or pores in the metal.

A consideration of the nature, distribution and state of aggregation of the products of corrosion has added largely to our understanding of many hitherto unexplained phenomena. In direct chemical oxidation, the product normally consists of a layer of oxide, continuous or discontinuous, in contact with the metal. In corrosion in solutions, although some direct oxidation may occur, the first-formed products are usually soluble. The corrosion products may, however, re-act further with the metal or electrolyte to produce secondary products, which again may be insoluble. The nature of these products and the position they take up in relation to the metal has a great influence on the course of further corrosion. For example, if the product forms a continuous layer on the surface of the metal, as do certain gel-like hydroxides, it may exert an important protective action, and even inhibit further corrosion; a product that is granular in character may allow the electrolyte direct access to the metal, and have little influence on corrosion. Perhaps the most serious effects are produced when the metal is irregularly protected in such a way that oxygen has access to some portions but not to others, when corrosion may be accentuated and localised at those portions that are most protected from oxygen.

In so far as condenser tubes are concerned, the alloy that has been most extensively studied is brass, and the nature of the reaction between brass and sea water and other natural waters is now fairly well understood. The rate of oxygen supply is here very important, both in relation to general corrosion and to localised corrosion such as that known as "dezincing." As a result of electrolytic action followed by secondary reactions, insoluble copper and zinc compounds are formed which adhere more or less closely to the brass, and greatly influence the behaviour of tubes. For example, dezincing is now known to be not the direct solution of zinc from the brass, as was formerly supposed, but a redeposition of copper due to a secondary action between cupric chloride and brass, which takes place underneath the film of corrosion product where access of oxygen is difficult.

It can thus be seen that corrosion may be influenced by a very large number of factors; some of these are concerned with the metal itself, as, for example, its electrical properties, crystalline structure, homogeneity and so on; many other factors external to the metal are equally if not more important, such as the temperature; the pressure, amount and distribution of oxygen; the acidity and conductivity of the electrolyte; and the nature and distribution of the corrosion products. It is sometimes possible to exercise some measure of control over the type of corrosion that occurs, as, for instance, in the case of brass, where it has been found that a small quantity of arsenic will effectively prevent dezincing, but general corrosive action is not stopped. It seems certain that so long as the metallic surface is in contact with electrolyte, anodic and cathodic areas will be set up, and that corrosion will proceed, except in the case of the noble metals.

Having regard to its electrolytic nature, it seems clear that action can only be effectively stopped if direct contact between the electrolyte and the metal can be prevented, and considerable progress has been made within the last few years in this direction. The most hopeful results seem likely to follow the extensive studies now being made of the films of corrosion product formed in different materials under different conditions. It is frequently found that condenser tubes in service become covered with an adherent continuous layer of deposit or "scale," and many such tubes are known to have had a long life. These deposits vary greatly in character; some consist largely of lime or iron deposited from solution; others are mainly corrosion products, such as vitreous hydroxides, which usually offer good protection to the underlying metal; while, in other cases, granular or crystalline oxidation products of various kinds, less protective in character, adhere to the surface. A naturally formed protective film of corrosion product offers definite advantages over artificial coatings; the latter may easily be damaged in service, and exposure of the underlying metal may set up electrolytic potentials likely to initiate serious local attack; the same may happen with many types of films of corrosion product, but it is now becoming clear that, under certain circumstances, naturally formed films are produced that not only possess the quality of protecting the metal, but also of re-forming rapidly if they are damaged. Under conditions of service, condenser tubes are subjected not only to the action of the cooling water, but to the impingement of solid, liquid and gas which has a serious action in removing all but the strongest and most adherent of films. This impingement attack is due to two main causes; in some cases, entangled air bubbles in the water lead to an intermittent bombardment of the tube surface,* producing damage to or removal of the protective film, while the same effect can also be produced by intermittent cavitation or the collapse of vacuum bubbles.† In both instances rotating motions of the water accentuate this trouble, which is greatest at the inlet end of the tubes, and mechanical means are now being suggested to minimise it.

But while mechanical means may be partially effective, clearly the most hopeful solution of the problem is the development of alloys capable of forming a film specially resistant to impingement attack. It is not only necessary that the naturally formed film should possess the strength to resist damage under normal service conditions, but also that it should have "self-healing" properties of a high order, so that in the event of its being damaged it should readily be re-formed; in this connection, the time which the film takes to form appears to be a vital matter. A metal that will normally protect itself effectively may corrode rapidly, if the protective film is damaged, owing to accentuated electrolytic action be-

* G. D. Bengough and R. May.—" Seventh Report to the Corrosion Research Committee of the Institute of Metals." Jnl. Inst. Metals, 1924 (2), pp. 81-256; R. May.—Eighth Report to the Corrosion Research Committee of the Institute of Metals. The Corrosion of Condenser-Tubes. 'Impingement Attack': its causes and Some Methods of Prevention" with introduction by Prof. H. C. H. Carpenter). Jnl. Inst. Metals, 1928 (2), pp. 141-175.

† C. A. Parsons.—" Some Investigations into the Cause of Erosion of the Tubes of Surface Condensers." Proc. Inst. Naval Architects, 1927, lxix, pp. 1-8.

tween the freshly exposed surface and the shielded portions; a film that reforms rapidly may repair the damage before appreciable corrosion can occur, but if film formation is slow it may be prevented by rapid corrosive action.

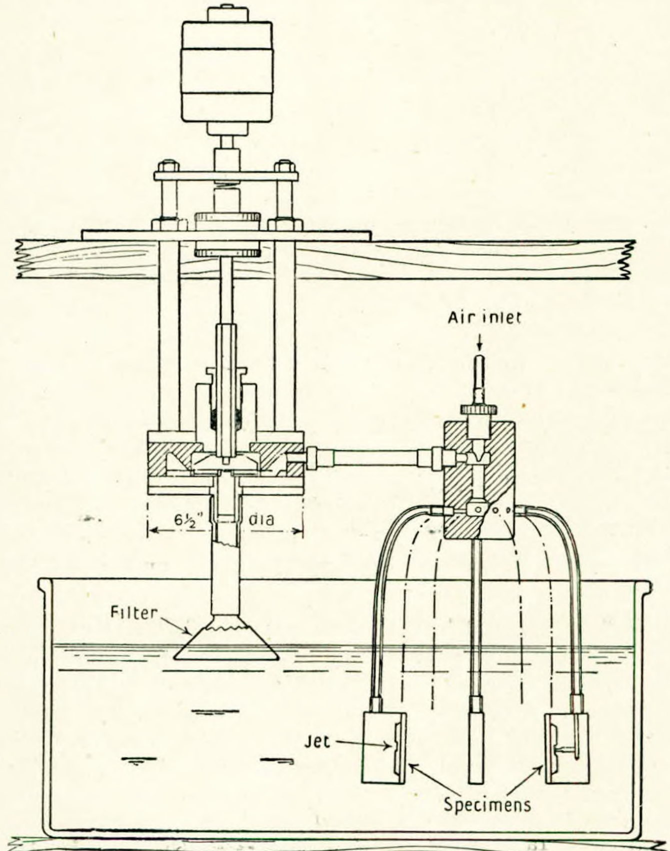


Diagram of Jet Test Apparatus.

(From the Eighth Report to the Corrosion Research Committee of the Institute of Metals.)

The development of tubes with suitable film-forming properties is now proceeding rapidly; the brasses formerly used are not satisfactory in this respect, but some of the copper-nickel alloys now on the market are able to resist impingement attack almost completely under violent conditions, and are giving excellent results in actual practice. A diagram of the jet test apparatus, used for determining the comparative corrosion-resistance properties of various condenser tubes, is illustrated above. The alloys containing more than 30% nickel seem to be especially good. No other tubes of the self-healing type have yet had sufficient practical trials to enable any final opinion to be formed, but there seems little doubt that we are only at the beginning of important developments in overcoming condenser tube corrosion.

CONDENSERS.

"Engineering," 11th April, 1930.

The following extract is from a paper on "Some Materials used for Naval Engineering Purposes" read before the Institution of Naval Architects by Engineer-Captain J. Hope Harrison, R.N.:—

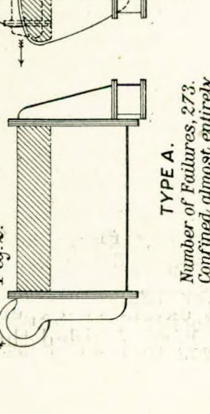
In 1920, Engineer Lieutenant-Commander G. B. Allen, R.N., read a paper before the Institute of Metals on "Service Experience with Condensers." Speaking of condenser tubes, he summed up the situation as follows:—"With every precaution taken during manufacture and with the adoption of any known preventative or protective process, it must be admitted that freedom from deterioration cannot be guaranteed; and it appears that complete immunity, or at least a guaranteed life, can only be obtained by the employment of an alloy other than a simple brass." A considerable amount of further research work has been carried out since the date of that paper, and, although the subject is undoubtedly better understood, it cannot be said that condenser troubles are now a thing of the past. Since 1918, the reports made to the Admiralty of cases of failure of condenser tubes show an average of 50 per annum, assuming that each defect reported counts as one (although several tubes may be referred to). In Figs. 2 to 7, on this page, the more common types of condensers fitted are given, and the total failures per annum with all types since 1918 are given in Table II.

By far the largest percentages of failures have occurred on foreign stations, and, making allowances for the numbers of ships on each station, the highest percentages of failures have been reported from the West Indian, China, and African stations, showing undoubtedly that sea-water temperature is an active factor. It is evident that the design of the condenser is important; Type E, Fig. 6, appears to be the best.

It should be stated that the tube surface per horse-power is approximately the same in all cases. Defects have occurred at all positions of the tubes, but principally as indicated by shading in the sketches. It should be observed that, in Type A condenser, the large number of defects reported is probably due to the use of war-time material, which, besides being of

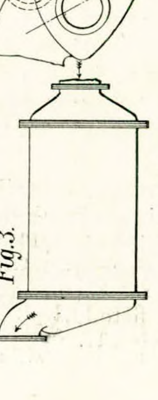
DIAGRAMMATIC VIEWS OF THE MORE COMMON TYPES OF CONDENSERS FITTED IN H. M. VESSELS

Fig. 2.



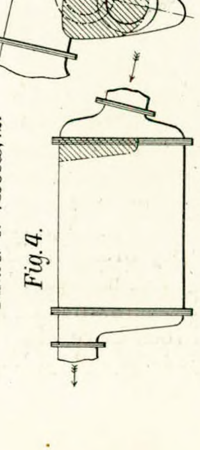
TYPE A.
Number of Failures, 273.
Confined almost entirely to portion shaded.
Number of Vessels, 3.

Fig. 3.



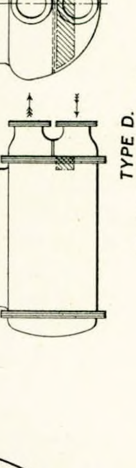
TYPE B.
Number of Failures, 85.
Number of Vessels, 12.

Fig. 4.



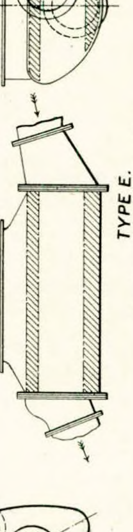
TYPE C.
Number of Failures, 338.
Tubes affected mostly in shaded portion.
Number of Vessels, 21.

Fig. 5.



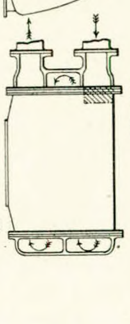
TYPE D.
Number of Failures, 75.
Tubes affected particularly in shaded portion.
Number of Vessels, 4.

Fig. 6.



TYPE E.
Number of Failures, 305.
Failures slightly more marked in portions shaded.
Number of Vessels, 203.

Fig. 7.



TYPE F.
Number of Failures, 132.
Tubes affected principally in portion shaded.
Number of Vessels. 20.

(2015.B.)

"ENGINEERING"

lower grade, did not have such rigorous inspection as is now possible and necessary. To enable members to realise the

TABLE II.—FAILURES REPORTED IN CONDENSERS.

Year.	Number of Failures Reported.	Year.	Number of Failures Reported.	Year.	Number of Failures Reported.
1918	51	1922	72	1926	45
1919	53	1923	39	1927	45
1920	48	1924	37	1928	60
1921	43	1925	38	1929	48

nature and type of defects reported, the exact figures for 1926-27 have been analysed, and are as follows:—

Total tubes in all condensers, 2,892,400. Total tube failures reported, 157.

Causes:	Per cent.
End action corrosion at inlet end	29·4
Local pitting	19·8
Obstructions	3·2
Steam impingement	10·8
External damage to tubes	2·5
Crushed ends	2·5
Splitting	6·4
General corrosion	19·7
Insufficient information reported to assess causes	5·7
	100·0

Only twelve failures were reported from warships operating in home waters. The actual ratio of failures to total tubes fitted is small, but one tube failure out of nearly 60,000 tubes fitted may put a ship out of action for a time. Practically all the failures reported have been of tubes manufactured from Admiralty brass. The specified composition is: Copper, 70%; tin, 1% minimum; zinc, remainder. A number of alloys have been manufactured into condenser tubes, and coated brass tubes have also been fitted, but, until extensive experience on service has been gained, it has now been decided that a mixture containing 70% copper and 30% nickel or Monel shall be used. Difficulty was experienced at first in obtaining tubes of other material than Admiralty mixture with the high standard of finish that had been obtained. Manufacturers have now succeeded in producing tubes of copper-nickel, the finish of which is equal to any previously obtained.

Materials that have been tried or are now under trial are: Stainless steel, Staybrite steel, Monel, aluminium brass, Melloid, chromium coated (0·0005 to 0·001 of 1 in. of chromium on Admiralty brass tubes), Corronil, synthetic Monel, copper nickel, 80—20, copper nickel, 70—30, brass, Admiralty mixture, and Silveroid. The only tubes that have stood up on service without showing signs of corrosion at all, up to the present, are aluminium brass, 70—30 copper-nickel and Silveroid. Care must be exercised in speaking of trials of condenser tubes, as cases are known of Admiralty brass tubes that have shown no signs of deterioration for over twelve years, and, with the exception of Admiralty-mixture brass, none of the above has been fitted in ships for much longer than five years. Chromium-coated brass tubes have only just completed one year's trial, and the coating has been found to be removed in places. Aluminium brass has not been in use long enough, or in sufficiently varying types of ships, to assume that it will give good service under all conditions. Solid packing, in lieu of linen gromets, has been tried with success.

Originally condenser doors were of gunmetal, but were replaced by cast iron with a view to resisting tube corrosion. Recently cast-iron end doors and water-boxes have been replaced by cast and mild steel. Cast-steel doors are necessarily thick and there is a fair margin of strength. With a view to reduction of weight, while retaining strength and a measure of resilience, doors were built up of boiler-plates and angles. Corrosion proved rapid on built-up doors on service, and as the doors were only $\frac{3}{8}$in. to 7/16th in. thick, some form of protective coating was found to be necessary. Rubber was first tried, but peeled off the outlet end. Doors were re-coated and then vulcanised. This was done by clamping two doors together and filling with steam. The rubber coat may be either hard or soft. Hard rubber is liable to crack, but resists the action of oil. The results reported to date appear to warrant the experiment being continued, and several processes of rubbering doors are now under trial in different ships of the Fleet.

TURBINE AND MOTOR SHIP RELIABILITY.

"The Motor Ship," April, 1930.

To say that reliability is the most necessary characteristic of marine propelling machinery is a truism that need not be stressed. Had Diesel engines not possessed it in a marked degree they would not have progressed so far that the motor ship tonnage now building is greatly in excess of that of steamers. When other arguments of those who are convinced of the superiority of steam plant fail, it is not unusual for the criticism to be made that motor ship machinery is not so reliable as geared turbines. Such statements have not been taken seriously, for they obviously have little basis since owners continue again and again to build motor vessels after their first experience.

This is the reason why, in these columns, such criticisms have been ignored. But we note with some surprise, in a recent issue of "Engineering," the comment:—

"As against the considerable experience of motor ships that has been reported as satisfactory, there are rumours, certainly but perhaps naturally less explicit, of occasions on which the complex and costly machinery of motor ships has given trouble."

The statement is made in an article which advocates the wider use of powdered fuel at sea. We have hitherto refrained from referring to the numerous troubles that occur with steam machinery, but in view of what must be considered as a veiled implication that motor ship machinery is less reliable than steam plant, we feel the time has arrived for a few facts to be brought forward. There is no desire to indicate that, for instance, steam turbines are unreliable.—They are not, and all machinery is subject to trouble at times. But it can be shown that of all the types of engines available for propelling ships at sea at the present time, the internal-combustion motor is as reliable as the reciprocating steam engine and boiler, and more reliable than geared turbines, either of the high or low-pressure type.

The following extracts from "Lloyd's List" during the past few weeks may be quoted:—

Malolo (17,000-ton geared turbine American liner built in 1927). Two boilers damaged, 1,500 small, 116 large boiler tubes to renew. (February 7th).

The Canadian Pacific turbine liner *Montrose* (16,000 tons), St. John for Liverpool, reported 880 miles west of Inishtrahull, has starboard engine damage and was proceeding at the rate of 10 knots on her port engine. (February 8th).

Owing to some trouble having developed with the turbines in the liner *Sultan Star* (a geared turbine vessel constructed in 1929), London for Buenos Aires, the master has decided to return to St. Vincent. The owners state from later information received that they think it will be necessary to bring the vessel back to the builders' yard for overhaul. (February 27th).

Towards the end of the trip (of the new North German Lloyd liner *Europa*) some trouble occurred with one of the turbines, so the *Europa's* full engine capacity could not be realised. (March 1st).

The Federal liner *Cornwall* (10,537 tons), New Zealand for London, is ashore at the south-east point of Curaçao. Her port turbine is out of action. (March 4th).

The *President Grant* (14,000 tons) arrived with machinery damage. Cost of repairs $9,500. (March 10th).

It is to be emphasised that these troubles are not recorded with any intention of suggesting that geared turbine-driven vessels as a whole are unreliable. But when vague statements are made which may give the uninformed the impression that Diesel ships suffer at a disadvantage in this respect, it is necessary to show how little basis there is in criticism of this nature.

The most serious troubles which have arisen with motor passenger liners have been the breakage of piston rods on the *Augustus*, the accident to the *Kungsholm* during trials, and the replacement of bedplates on the *Saturnia*. Full publicity, with explanation of the causes, was given to each of these matters, but, so far as we are aware, practically no details are ever published concerning the numerous troubles arising with steam machinery, the only exception being the case of the North German Lloyd liner *Columbus*.

When it is recalled that during the past year or two many more motor passenger liners have been constructed than geared turbine ships, it will probably be conceded that Diesel machinery is more reliable than geared turbine plant.

Fresh or Salt Water.

"The Motor Ship," April, 1930.

It is surprising, after the Diesel engine has been used for marine work for nearly 20 years, that totally contrary opinions should be held by leading engine builders concerning the media most desirable for cooling pistons and cylinders respectively. If, for instance, we take three important types, the Doxford, Burmeister and Wain and Sulzer motors, we find that in the first case fresh water is employed for pistons and cylinders; in the second type of engine lubricating oil is adopted for pistons and either sea water or fresh water for the jackets. In the Sulzer engine the builders give preference to salt water throughout, but owners often specify fresh water for the pistons. Yet, in the most recent Sulzer-engined ship, the *John van Oldenbarnevelt*, the process was reversed, and salt water is supplied to the pistons and fresh water for the jackets.

The objection raised by those who believe in salt water is that when fresh water is employed it is bound, sooner or later to become dirty, when its influence on the pistons is more detrimental than salt water can possibly be. There are, of course, special cases of ships which have to operate to a considerable extent in shallow and sandy waters, but, apart from this, conditions for all ships are somewhat similar. In view of the success of all classes of machinery using diverse systems of cooling, it may be that the importance of the problem has been exaggerated.

The Improvement of Air-Injection Systems.

"The Motor Ship," April, 1930.

At a time when all manufacturers are turning towards airless injection, the question has arisen whether we have reached the limit in air injection. Normally it is considered that the air compressor with an air-injection engine absorbs something in the neighbourhood of 5% to 6% of the total output of the motor. Hence, by eliminating the compressor, an increase in efficiency approaching 5% is usually recorded.

With a new large Diesel engine which has just made its first trial, it would appear that by employing a new design of fuel-injection nozzle the amount of injection air used has been so reduced that the total power absorbed by the air compressor does not exceed 3%. It is, moreover, claimed that with this unit a degree of flexibility quite remarkable with Diesel motors is attained, the engine running satisfactorily and continuously at a speed substantially less than one-sixth of the designed maximum revolutions.

Competition is invariably good, and it is just possible that the increasing interest taken in, and the favour found by, the compressorless engine will lead designers who believe in the air-injection type to search for higher efficiency. At any rate, the results indicated suggest a new line of thought.

LOWEST DIESEL ENGINE WEIGHTS.

"The Motor Ship," April, 1930.

Although it was stated in "The Motor Ship" a short time ago that the reputed weight of the 50,000 B.H.P. machinery of the German cruiser *Ersatz Preussen* (given as 17 lb. per B.H.P.) was probably incorrect, we notice that the figure has frequently been repeated in recent publications. It seems extremely doubtful whether such a low weight can possibly be obtained, and, as we remarked in our last issue, a German naval authority, at a meeting of the German Society of Naval Architects, stated officially that the engine would have a weight of 50 lb. per B.H.P. It certainly seems somewhat doubtful, in the present stage of metallurgical development, whether the total weight of a large marine Diesel engine, combined with gearing in the case of a high-speed unit, can be reduced much below 50 lb. per B.H.P.

HEAVY-OIL ENGINE WORKING COSTS.

"The Motor Ship," April, 1930.

The annual report on "Heavy-oil Engine Working Costs," issued by the Diesel Engine Users' Association, although dealing with stationary Diesel engine plant, is of considerable interest and value to those concerned with the operation of marine Diesel machinery. The report for 1928-29 was recently published covering 42 stations in various parts of the world. The average fuel cost is 0·307d. per unit generated, which is lower than in any of the three previous years, as given in earlier reports. The total cost, including water and stores, and lubricating oil, wages, repairs and maintenance, is 0·64d., which is also the lowest figure yet recorded.

QUADRUPLE VERSUS TWIN-SCREW MOTOR SHIPS.

"The Motor Ship," May, 1930.

Although the view is now fairly generally held that for motor vessels requiring machinery not greater than 20,000 s.h.p. a twin-screw installation is preferable to quadruple-screw plant, there appears to be something to be said for the latter system. Comparisons of efficiency are notoriously difficult, since it is almost impossible to obtain exactly similar conditions, so that the figures which were published in this journal last month giving the relations of the propulsive efficiencies of the *Chichibu Maru* and *Asama Maru* were of exceptional interest. The two vessels are similar, except that the *Chichibu Maru* has 2ft. more beam and twin screws, whereas the *Asama Maru* has four engines.

Our contributor stated that at 18·5 knots (which is about the service speed) the quadruple-screw ship had a propulsive efficiency of 54·8% and the twin-screw vessel of 53·7%. The respective powers required were 13,500 s.h.p. and 13,900 s.h.p. (corrected for the same displacement). At 19 knots, however, the quadruple-screw ship showed a still further advantage, and the difference in power was 920 B.H.P.

The advantage, viewed commercially, is not considerable. At 18·5 knots, if the engines are required to develop 400 B.H.P. more on a twin-screw ship, this will involve an extra consumption of about 2½ tons daily, or, say, 450 tons of fuel per annum, which, on the present quotations at San Francisco, would probably be not more than £750 per annum. Other circumstances could easily outweigh this difference. It has to be remembered that the twin-screw ship is 2ft. larger in beam, but apparently this is necessary in the twin-screw system with the higher centre of gravity of the engines. The machinery space appears to be nearly the same in the two vessels, and it is doubtful which arrangement gives the best passenger accommodation. Taking all in all, there does not appear much to choose between the two systems.

INCREASING SPEEDS.

"The Motor Ship," May, 1930.

A few months ago it was announced that the Netherland Steamship Co. had decided to instal larger power in their motor passenger liner *P. C. Hooft* so as to give a speed of 17 knots to 17½ knots, and the Rotterdam Lloyd has now arranged for a similar conversion for their liner the *Indrapoera*. The former owners have just taken delivery of the *Johan van Oldenbarnevelt* and the latter of the *Baloeran*, both vessels capable of maintaining an average of 17 knots to 17½ knots in regular service, and each will acquire a similar vessel before the end of the year.

The object of the replacement of the machinery in the older ships is to bring them into line with the new tonnage, and in each case there will be three passenger liners on the service to the East with a speed of 17 knots to 17½ knots, although a maximum speed considerably over this figure is possible. The new ships will thus apparently nearly be able to equal in performance the latest P. and O. liner, the *Viceroy of India*, judging from the speeds given in a paper read before the Institution of Naval Architects last month.

STEAMER FUEL CONSUMPTION.

"The Motor Ship," May, 1930.

There were two important and interesting lectures delivered before the Institution of Naval Architects last month at their Spring Meeting, dealing with the consumption of fuel of steamers. In both cases the issue seems to have been somewhat clouded, inadvertently, by the authors, in one instance by referring the fuel consumption to higher calorific value than that of the oil actually used, and in the other by estimating the consumption at a power not developed in service. It is of value, therefore, to examine the actual results obtained as recorded in the tables in the two papers.

In Dr. Meijer's lecture he gave the fuel consumption for the 29,000-ton high-pressure turbine steamer *Statendam* for one complete round voyage from Southampton to New York and back. The vessel utilises steam at 420 lb. per sq. in. and takes advantage of every modern possibility for improving efficiency. The average consumption for the whole voyage works out at 0·66 lb. per s.h.p. hour, but the figures given depend on the accuracy of the torsionmeter, which has yet to be guaranteed. In fact, it was stated that no reasonable torsionmeter reading was available on three days, owing to the heavy pitching of the ship, and on the other days the ship was " pitching heavily " in most instances, although torsion readings were taken and recorded. No speeds are given, so we are unable to check the results against any corresponding steamers or motor ships.

At any rate if, as is stated, the *Statendam* is the most economic steamer afloat, we have a result of 0·66 lb. per s.h.p. hour, against the best motor ship figure (the *Amerika*) of 0·36 lb. per s.h.p. hour for all purposes. Neither is an average figure, but if we give the best results for one class of ship we must do so for the other. Even so, we have a little doubt as to the accuracy of the measurements on the steamer, specially bearing in mind that the fuel consumption on the *Bremen* appears to be well over 0·7 lb. per s.h.p. hour.* In any case all the figures given are at the commencement of service and the average for the life of the ship will certainly be much higher.

THE TURBO-ELECTRIC SYSTEM.

"The Motor Ship," May, 1930.

Mr. Belsey dealt with the performance of the turbo-electric liner *Viceroy of India* in his paper—a valuable contribution from which we are able to obtain much information.

The conditions under which the *Viceroy of India* operates are remarkable and we have made a detailed analysis of them. Taking a complete round voyage it may be said that there are three different speeds at which, for certain reasons into which we need not enter, she has to run. The first is between 17 knots and 18 knots, the second about 15½ knots, and the third about 14½ knots. These are rough figures.

In Mr. Belsey's paper we have separated the periods when these speeds were approximately attained; they represented 18 days at about 17½ knots, 15 days at about 15½ knots and five days at about 14½ knots. The actual figures are given below, all being averages per 24 hours :—

Average Speed, Power and Consumption.

Period.	Knots.	S.h.p.	Tons per day.	Lb. s.h.p. hour
18 days ...	17·47	13,916	107·6	·723
15 days ...	15·58	8,714	78·2	·842
5 days ...	14·43	7,604	78·1	·960

It is claimed by Mr. Belsey—and probably the claim is justified—that with the conditions of service under which the *Viceroy of India* operates, no geared turbine steamer could show equal economy because the consumption at the lower

* The Motor Ship, January, 1930.

speed would be so much higher. But in order to obtain this flexibility at low consumption and moderate speed the designed power of the turbines driving the generators in the *Viceroy of India* totals 23,200 s.h.p., although the maximum power obtained at any period on the voyage was only 15,200 B.H.P., so that the installation can hardly be termed economic from the standpoint of capital cost.

On the other hand, a Diesel ship could, in the first place, show a great saving at the highest speeds required and would be proportionately more efficient at reduced output. At what may be termed approximately half power, the *Viceroy of India* shows a specific increase of 16½% in fuel consumption. The Diesel engine would certainly show to better advantage in this respect.

A DIESEL-DRIVEN "VICEROY OF INDIA."

"The Motor Ship," May, 1930.

To fulfil all the conditions of service of the *Viceroy of India* a twin-screw 16,000 s.h.p. Diesel plant would suffice. The specific fuel consumption between 14,000 s.h.p. and 17,000 s.h.p. would to all intents and purposes remain constant. At about 9,000 s.h.p. the increase would not be more than 10% and at 7,600 s.h.p. 12 to 14%. These figures are lower than the increases shown by the turbo-electric machinery.

On this basis, and utilising the accepted figures for Diesel fuel consumption, we have worked out within close limits the saving which would be effected by a Diesel ship on the round voyage as indicated, operating for 18 days at 17·47 knots, 15 days at 15·58 knots and five days at 14·43 knots. The total fuel required is 1,850 tons, against the actual amount used in the *Viceroy of India* of 3,070 tons.

According to market quotations the lowest price of boiler oil on the route is at British ports, namely, £3 7s. 6d., and of Diesel oil, £3 17s. 6d., at Aden. Assuming that each ship bunkered at the cheapest port—this is doubtful in the *Viceroy of India* on account of the large quantity—the Diesel ship would spend £7,200 on fuel (excluding charges in port) and the steamer £10,600.

The net result is that a twin-screw direct-driven Diesel ship similar to the *Viceroy of India*, but with a normal machinery output of 16,000 s.h.p., capable of meeting all the requirements specified in the *Viceroy of India*, would save £3,400 on the round trip. In view of these figures it may be suggested that the P. and O., when considering new tonnage, should at least build one motor ship in order to demonstrate whether these savings can be effected, and as the figures are based on actual performances, there does not seem to be any doubt on this score.

It is not out of place to remark that two Diesel-engined liners have just been completed, also for the Eastern run, nearly similar in size to the *Viceroy of India* with machinery of approximately the power we have mentioned. These are the *Johan van Oldenbarnevelt* and the *Baloeran*, the owners of which have ordered some 20 motor vessels since taking delivery of their first oil-engined ships. During that period they have not ordered a single steamer.

OSCILLATIONS IN EXHAUST PIPES.

By Dr. Oppitz. "The Motor Ship," May, 1930.

Previous attempts to explain the phenomena of oscillations in exhaust pipes and to determine in advance their magnitude have been confined to the investigation of the stationary waves which are dependent on the volume and length of the pipes and the frequency and variation of the exhaust cycle of each cylinder.

It is found when investigating these exhaust oscillations that the essential cause of the rise in pressure is the progressive compression waves which may increase up to a surging shock.

Consider a time-distance diagram in which the abscissæ represent the length of the exhaust pipe. On the ordinates the cylinders are shown in positions corresponding to those they occupy on the engine. Lines are drawn through these points parallel to the axis of abscissæ, and on these lines the main piston positions are indicated and the various operations taking place during the cycle (Fig. 1). The advancing crests of the waves form sloping lines, the angle of inclination of which depends on the wave speed.

The points of intersection of these lines with the parallel lines give the time and points in the cycle at which the wave crest arrives.

This diagram will be called the " wave diagram."

The diagram in Fig. 2 shows the exhaust oscillations of a six-cylinder double-acting two-stroke engine at the top of the sixth cylinder. This diagram is analysed with the wave diagram for the engine. It shows very clearly the variation of pressure to be expected from the wave diagram. The reflection waves from cylinder six (top) and cylinder three (bottom) are very interesting.

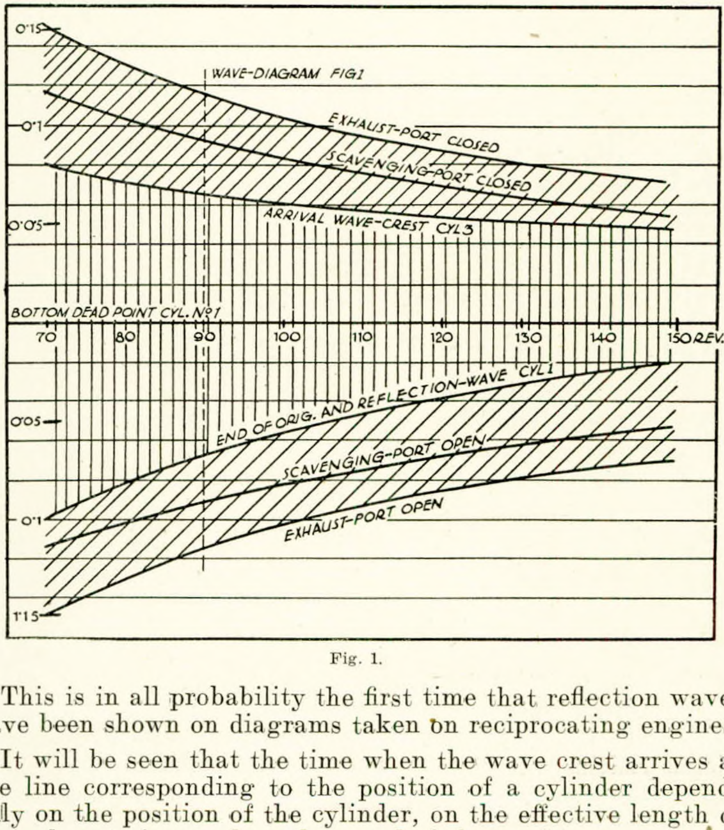


Fig. 1.

This is in all probability the first time that reflection waves have been shown on diagrams taken on reciprocating engines.

It will be seen that the time when the wave crest arrives at the line corresponding to the position of a cylinder depends only on the position of the cylinder, on the effective length of the exhaust pipes and on the speed of the engine.

Fig. 3 shows the arrival and end of the waves during the scavenging period of a four-cylinder single-acting two-stroke engine when running at various speeds. We can see that it is necessary to distinguish (for example, in the case of a turbo-blower) between a static and a dynamic line of resistance. The dynamic line of resistance depends not only on the phase but also on the amplitude, which varies according to the output of each cylinder.

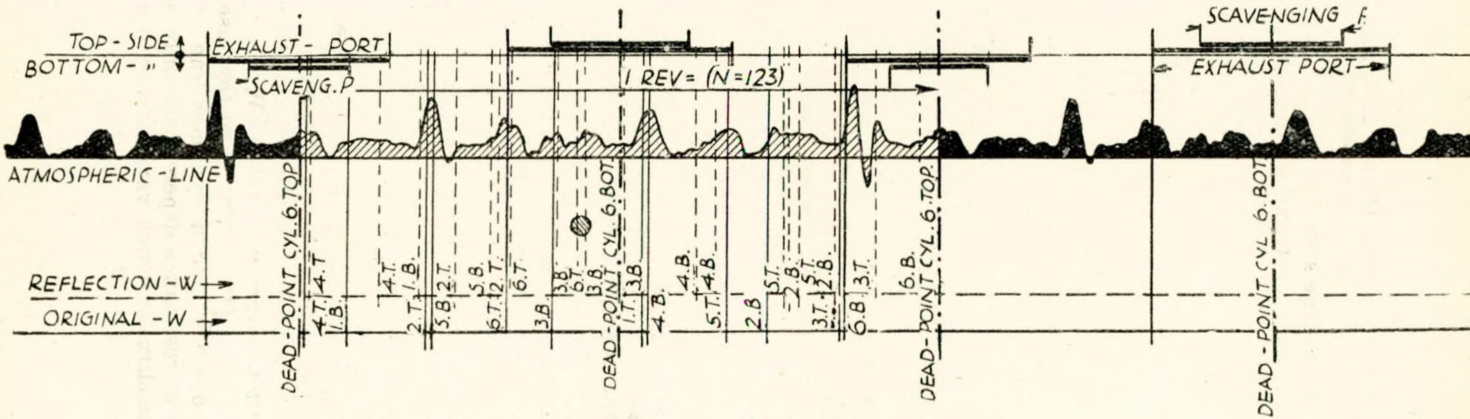


Fig. 2.—Exhaust oscillations of a six-cylinder double-acting two-stroke engine.

Dividing up the engine's exhaust pipes is neither an indication nor a guarantee of a trouble-free scavenging period for each cylinder. It is, of course, sometimes possible that it may be the simplest way to attain the desired effect.

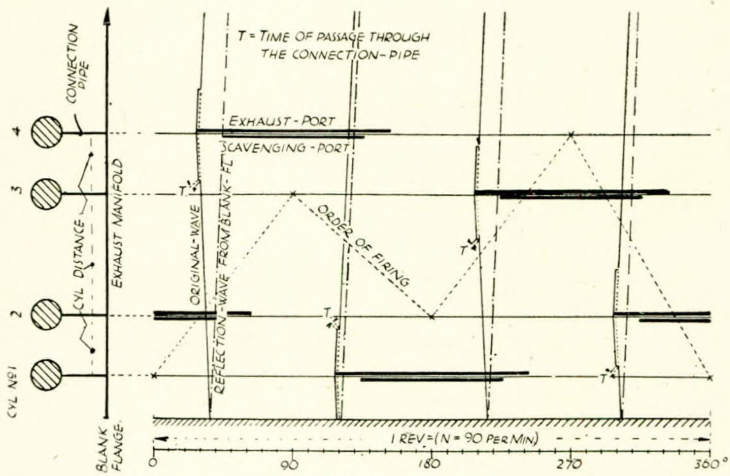


Fig. 3.

Thus we see that by means of the wave diagram it is possible to determine in advance the tendency of the pressure variation and to decide the correct length of pipe in any particular instance.

The volume of the exhaust pipes is only of secondary effect in determining the magniture of the pressure variation.

LOW-POWERED DIESEL ENGINES.

"Shipbuilding and Shipping Record," 17th April, 1930.

It is only during the past two or three years that it has been regarded as a practical proposition to design an engine of low power operating on the full diesel cycle. Previously to that for powers of about 100 H.P. per cylinder or less, it was usual to employ the semi-diesel principle, in which the compression pressure was in the region of 250 lb. per sq. in., but while this led to lower average working pressure and temperature throughout the cycle, thereby greatly simplifying the design of the cylinder and piston, it involved the provision of some external heating arrangement for starting up the engine. With a view to eliminating what is obviously a disadvantage, the

" cold starting " engine was developed by the simple expedient of increasing the compression pressure, until with the gradual improvement in the details of design it has become possible to employ compression pressures in excess of 400 lb. per sq. in. in cylinders of 12 in. diam. or even less. It is to be noted, however, that while the name diesel is used in describing these engines, the fuel is not burned at constant pressure, but with explosive effect, leading to an increase of pressure after compression is completed. Thus, in the trials of a two-cylinder Petters atomic diesel engine rated at 130 B.H.P., recently carried out under the supervision of Mr. W. A. Tookey, the well-known authority on internal-combustion engines, it was found from the indicator cards that the compression pressure was 420 lb. per sq. in., while at full load the explosion pressure reached 650 lb. per sq. in. The engine operates on the two-stroke cycle with crankcase compression, and using Diesoleum of 0·895 sp. gr. as fuel, 133·8 B.H.P. was developed at a speed of 280 r.p.m., the fuel consumption being 0·408 lb. per B.H.P. per hour, while with Tarakan oil of 0·938 sp. gr. as fuel 133 B.H.P. was obtained with a specific consumption of 0·427 lb. per B.H.P. per hour.

CONDENSER SCOOPS.

"Shipbuilding and Shipping Record," 17th April, 1930.

In the design of high-speed naval vessels such as torpedo-boat destroyers, the scoop has been employed either in lieu of or in conjunction with the centrifugal pump for supplying circulating water to the condenser. Hitherto but little scientific investigation had been undertaken with a view to improving the design of the scoop or to determine its suitability for other types of vessel, and it is of interest therefore to note that the current issue of the " Journal of the American Society of Naval Engineers " contains an interesting paper by Mr. H. F. Schmidt entitled " Theoretical and Experimental Study of Condenser Scoops," which formed the Naval Engineers' Prize Essay for 1929. The author's investigations convinced him that the existing design of scoop was not of the best form as no means were provided for converting the velocity of approach of the water to the scoop inlet into static pressure, this pressure being, of course, required to overcome the resistance through the injection and discharge piping, condenser tubes, water boxes, etc. Following his theoretical investigation into the effect of divergent nozzles and pipes based upon the well-known theory of Bernouilli, the author conducted a series of experiments in order to obtain data as to the effect of various forms of scoop at different velocities of approach of the water, and he comes to the conclusion that a well-designed divergent scoop can be given a very sharp turn into the ship, thus reducing if not entirely eliminating the penetration of frames by the injection and discharge piping, and shortening the space occupied by the condenser installation. Although the author does not consider the problem from the merchant ship point of view, it might be of value to investigate also the adoption of some form of scoop arrangement as a means of reducing the power demanded of the circulating pump.

AMERICAN SHIPBUILDING.

American "Motorship," April, 1930.

It looks as if everything is arranged so that the U.S. Lines can go ahead and place contracts for the construction of two super liners to run with the *Leviathan* on the North Atlantic. When a pair of mammoth American ships are completed, in common with all other nations who achieve high honours on the sea, we shall be very proud of them. They will make a splendid display of luxury, a beautiful gesture, and a fine tribute to America's determination to become a nation with a merchant marine. They will end prestige and permit us to claim with pride the finest and fastest ships afloat. So long as these ships surpass in speed and luxury we need not worry about how they are obtained or what they cost. Comment on that score will, no doubt, be made without restraint by, possibly, La Guardia.

Just what benefits other than those resulting from prestige we may expect to derive from the operation of such ships remains in doubt. If an amount equal to their cost were spent on the construction of first class freighters, capable of competing with modern foreign freight ships, the benefits could be more readily defined, which brings up the question of freighters. Should America fail to modernize its fleet of freighters the real backbone of our merchant marine will fall into decay, and no number of North Atlantic super liners will ever restore it. What this country needs more than anything else in the form of ships is something to ensure permanent aid in the maintenance and upbuilding of foreign trade. Our best reason for wanting a merchant marine is its unquestionable aid to foreign trade. And the reason we want foreign trade is its unquestionable stimulus to domestic activity and business.

The bid for prestige should come after the establishment of an adequate fleet of ships best suited to ply trade routes reaching to every corner of the globe.

We believe that something will be done to aid the freighters and put the American shipowner on an equal footing with his foreign competitor, thus permitting him to devise his own ways and means of improving his chances of success. If the government dole is made too enticing, if success is guaranteed, the incentive to self improvement will be killed.

As the super liner holds the centre of the stage for the present at least, let us consider the power plants in such ships. Undoubtedly at the time the *Bremen* was designed her machinery was the best available. We may depend upon Dr. Bauer for that. Ten years hence it will be about as far out of date as the *Leviathan's* machinery is at present. Granting that this country can not afford to experiment, it seems unfortunate that we can not look far enough into the future to design machinery which will not be obsolete by the time the new liners have been in operation a few years.

On ships of this type and power the Diesel has less to commend it than it has in less spectacular vessels such as freighters. For example, the *Bremen's* 120,000 s.h.p. weighs about 10,000 tons and consumes slightly more than 0·68 lb. per s.h.p. hr. On a trip from New York to Cherbourg, steaming 115 hours, she would consume 4,190 tons, which at $7·35 per ton, would cost $30,800. Dr. Bauer mentioned a Diesel installation of 120,000 s.h.p. in a paper presented last fall before the Schiffbautechnische Gesellschaft in Berlin. Such an installation consuming 0·42 lb. per s.h.p. hr. would burn 2,590 tons of fuel at $12·25 per ton (the prevailing price) costing $31,750 for the Atlantic crossing. At first glance these figures do not seem to favour the Diesel proposition. But Dr. Bauer mentions a Diesel plant weighing only 8,900 tons as compared to the *Bremen's* 10,000-ton power plant. In machinery weight alone a saving of 1,100 tons could be obtained. The difference in weight of fuel favouring the motorship is 1,600 tons for one trip across, 3,200 for the round voyage. The difference in weight of machinery plus the difference in weight of fuel required for the round trip would give the motorship an advantage of 4,300 tons at an extra cost for fuel amounting to $1,900 for the round trip. Naval architects with some 4,000 tons of extra space at their disposal can achieve startling results in a ship of this size.

This is a fascinating subject, if for no other reason, because high pressure steam and high superheat are just as much a step in the dark as high-power Diesel installations are purported to be. That such is true is borne out by rumours in Germany, which have reached this side of the Atlantic, to the effect that the Hamburg American Line is planning two motorships, one of 180,000 s.h.p. and another of 120,000 s.h.p. for North Atlantic service. Final decision as to the type of drive for these ships is said to be waiting on the trial trip of the *Ersatz Preussen*. This coupled with Dr. Bauer's example of a 120,000 s.h.p. geared Diesel plant should indicate with some degree of approximation which way the cat will jump.

For the time being, we should bear in mind that the Germans are advancing by progressive steps, thus fitting themselves for a prodigious undertaking. Whereas, we have not prepared ourselves in this country to do more than Dieselize our freighters, and build motorships of the cabin class. We have fallen behind, we must catch up with the world of shipping, and a stern-chase is a long chase.

SAFETY-VALVE BLOW-OFF PRESSURE.

"Shipbuilding and Shipping Record," 3rd April, 1930.

Some very interesting figures regarding the loss of water which occurs on board ship as a result of "feathering" at the safety valves were given by Mr. Donald MacNicoll during the course of the discussion on Mr. Mellor's paper "The Design and Performance of the Boilers of the *Viceroy of India*, which was read a short while ago before the Institution of Engineers and Shipbuilders in Scotland. Referring to the fact that the safety valves on these boilers were loaded to a pressure which was "a reasonable amount above the working pressure," Mr. MacNicoll suggested that this was a wise policy, since safety valves loaded only to the working pressure were always feathering, becoming thus a source of considerable loss of efficiency as well as allowing much waste of fresh water. Although it can scarcely be credited, he gave it as a fact that each of the 48 original German safety valves on the boilers of the *Majestic* lost over two tons of water per 24 hours, which collectively meant a loss of over 100 tons of fresh water per day. It will be appreciated what this means in fuel consumption apart from the loss of fresh water, involving the carrying of additional feed make-up and the increased risk of impurities and air in the feed system. It will perhaps be suggested that there is a risk in setting the safety valves to blow-off at, say, 25 lb. per sq. in.

above the working pressure, but this is more imaginary than real, since with the red mark on all pressure gauges placed at the working pressure, the engineers-on-watch will always endeavour to work with the pressure at this figure rather than at the higher figure at which the safety valves blow-off so that it will be only in emergencies that the higher figure will be reached, and even at this figure the stresses in the various drums, pipes, etc., should not encroach to any great extent on the factor of safety. Mr. MacNicoll also commented favourably on the idea of placing the safety valves on the superheater outlet rather than on the main steam drum.

DIESEL ENGINE FOUNDATIONS.

"The Marine Engineer and Motorship Builder," May, 1930.

In proportion to the amount of power it develops the marine Diesel engine as we know it to-day is considered by many to be a heavy type of prime mover. No doubt, as experience proves it justifiable, scantlings of various parts will be reduced and new materials proved safe, until a sound working minimum is reached. Foundations, however, so far as present-day design is concerned, must not be tampered with in this respect. Owing to the number of the earlier motorships which have been guilty of loosening and breaking rivets in their engine seats, much more care and attention is now being given to this part of the vessel's structure. Boiler shop practice, almost, is demanded in this vicinity for the drilling, fairing up and riveting of the various longitudinal and cross members. The adoption of drilling all holes is, generally, too expensive a method even for this all-important part of the motorship's hull, but, where a plate is to be riveted to an angle-bar or similar member, very good workmanship is being obtained by punching the holes in the former and then setting up and drilling the adjoining bar in place. To ensure still further stiffness some firms are now, on completion of the riveting, electric-welding all the plate landing-edges of the engine seats and also the tank top, floors and frames in the near neighbourhood, so that no relative movement of these parts can possibly take place.

Engine builders are tackling the problem a step higher up the vertical plane. They are making the engine bed-plates much broader and of heavier section than was their practice several years ago for similar engines. When this latter method of stiffening up has been adopted the shop trials on the test bed should furnish comparative information of any success thus obtained over a previous job in the damping of vibration generally. In cases where the additional stiffening has been applied to the structure of the hull the comparison will not be available until the engines have been installed and tried on board under working conditions. In neither case, however, will the ultimate result be known until the ship has been in actual service for some time. It is still a moot point among marine Diesel engineers whether or not a certain amount of flexibility is desirable in the crankshaft of an oil engine, but they are now mostly agreed that everything below that should conform, as nearly as sea and weather conditions will allow, to the rigid foundation obtainable in power station and other shore installations. In the past heavy engine-seating maintenance costs have been incurred on many motor vessels, and where the engine foundation has been inadequate the lack of stiffness has had the effect of causing bedplate and/or crankshaft trouble. Present practice, built upon experience, seems to be along correct lines, a generous depth of floor under the engines and the highest quality of workmanship usually being found in modern motorships.

For our part, we prefer a construction where dry tanks or water tanks are arranged in way of the engines. When oil is carried under a Diesel engine and slack rivets develop it is most difficult, owing to the presence of the oil, for the work ever to again be made permanently sound. Some engineers prefer the flat-bottomed, tank-top type bedplate, but there seems little to choose between the two patterns so long as the engine seating is sound in every way and the arrangements for reaching the holding-down bolts have been planned with care.

BOILER EXPLOSION REPORT.

REPORT NO. 3049. S.S. *Davaar*.

The explosion occurred at 11.25 a.m. on the 8th October, 1929, when the vessel was in the Firth of Clyde between Garroch Head and Gourock. Mr. Hugh Smellie, the chief engineer, was burnt about the face and hands, but has since recovered. Mr. Smellie holds a First Class Board of Trade Certificate of Competency as an engineer.

The boiler was situated on the port side of the stokehold. It was of the cylindrical marine type, double-ended, 11ft. in diameter and 17ft. in length. There were two furnaces at each end and two combustion chambers. The boiler was made of steel, excepting the tubes and screwed stays, which were of iron. The boiler was worked with natural draught, and the working pressure was 110 pounds per sq. in. The usual mountings were fitted and these included a water gauge of the hollow-column type at each end of the boiler. The boiler was made in 1903.

In 1923 the wasted parts of the bottom end plates in way of the shell landings were reinforced by the electric welding process. The bottom manhole doors were renewed, and the end plates, where flanged to form the manholes, were made good with welding.

In 1927 the welded parts of the bottom end plates in way of the shell landings were made good with welding.

In 1929 the end plates, where flanged to form the bottom manholes, were made good with welding, and the manhole doors were refitted. Seventy plain tubes and six stay tubes were renewed.

In addition to the above, repairs of a minor character had been made from time to time.

The port combustion chamber top plate collapsed and was forced over the ends of several of the girder stays, thus permitting steam to escape with some violence. The starboard combustion chamber top plate was buckled between the stays, but not sufficiently to cause any leakage.

The explosion was caused by the overheating of the port combustion chamber top plate, and this overheating was due to shortness of water. The vessel had a moderate list to starboard and this explains the fact that the starboard chamber was not overheated to the same degree as the port chamber.

The S.S. *Davaar* maintains a regular service for passengers, cargo and mails between Glasgow and Campbeltown, a daily run from one port to the other being made with calls at certain intermediate ports. The vessel is propelled by a compound surface condensing engine with dependent pumps. The engine develops a maximum of 1,200 I.H.P. and is driven by steam generated in two double-ended boilers. After the vessel is berthed at the end of each day the boilers are pumped up with fresh water and the fires are banked for the night. This procedure was carried out at Campbeltown on 7th October. At 4.30 a.m. on 8th October a fireman went below and prepared the fires for the day's work. He saw 11 inches of water in the gauge glasses at that time. The after water gauges only were in use, the forward water gauges being shut off from the boilers according to the usual practice in this vessel. At 6.45 a.m. the second engineer went on watch. He tested the gauge cocks on both the after mountings in the following manner. He opened the drain cock, blew through the glass, and then shut the drain cock. He then shut the water and steam cocks alternately and opened the drain to blow through the steam and water cocks alternately. He finally shut the drain cock and opened the steam and water cocks. He did not test the terminal cocks independently, but was satisfied that both gauges were in order. He then blew down each boiler until the levels were at 9ins. in each glass. Shortly after 7 a.m. the chief engineer went below and was present when the boilers were being blown down. At 7.52 a.m. the vessel left Campbeltown; the trim was 2ft. by the stern, and there was a moderate list to starboard. A brief call was made at Saddell, and after departure the chief engineer went on deck. The next call was at Carradale, and at this port the chief engineer relieved the second engineer. The water levels were observed to be maintained at 9ins. The port feed check valve had been shut half turn after leaving Campbeltown and it was opened that amount just before arriving at Carradale. The feed check valves were then at their usual setting, that is, 2 turns open port and 1½ turns open starboard. The vessel called at Pirnmill at 9.34 a.m. and was approaching Lochranza at 9.50 a.m. At this time the second engineer went below again and saw that the levels had increased. He thought that the condenser was leaking, and this impression was also shared by the chief engineer. At 10.15 a.m. the chief engineer went on deck, and at 10.20 a.m. the second engineer saw fully 11 inches in the port glass and 10 inches in the starboard glass. He decided to blow down the port boiler and he reduced the level in the glass by about 4ins. The chief engineer saw the levels again at 10.35 a.m.; he did not know that the port boiler had been blown down, and thought that the levels were much the same as when he last observed them, that is, at 9ins. in each glass. He left the stokehold soon after this and did not enter it again until shortly before the explosion occurred. The second engineer appears to have been the last to observe the levels at 11.10 a.m. and he thought that they had again increased. At 11.25 a.m. the chief engineer was in the forward stokehold and he heard a hissing noise coming from the wing chamber of the port boiler. The noise increased rapidly and the explosion occurred. The wing fires of this boiler were being fired at the time, but both firemen fortunately heard the warning hiss of steam and instinctively jumped clear. The fire doors were blown open and flame and steam escaped into the stokeholds. The chief engineer passed the front of the damaged boiler, climbed a short ladder from the firing platform to a side stringer, and went aft along the passage between the boiler and the ship's side. His intention was to shut the main stop valve which was mounted on the end plate of the boiler at the after end, but he was unable to do so because of the steam and flame escaping from the boiler at that end. He returned, passed through steam and flame at the forward end, and escaped to the deck. The second engineer who was in the engine room when the explosion occurred was able, some time after, to shut the main stop valve of the damaged boiler with a rake whilst standing at the stokehold door. The port feed check valve was shut 10 minutes after the explosion, and the main stop valve was shut five minutes later. The second engineer then succeeded in isolating the damaged boiler by closing the starboard boiler auxiliary stop valve and whistle valve. The engines were stopped by the chief engineer about this time, and the fires in the port boiler were being drawn. Steam ceased to blow about 20 minutes after the explosion and the observed water levels were then nil in the port boiler and 3ins. in the starboard boiler. The steam pressure in the starboard boiler had dropped to about 50lbs. The pressure was raised to 85 lbs., and the vessel completed the voyage to Glasgow without further incident. When the vessel arrived at Glasgow the top manhole door was taken off the port boiler, and it was observed that the water was level with the underside of the top row of tubes.

An inspection for the purposes of this inquiry was made on the 10th October. The forward water gauge was found to be shut off from the port boiler and the after or working gauge had all cocks except the drain cock in the open position. The passages from the boiler to the plugs of the terminal cocks were quite clear. The after gauge column and the steam and water pipes were removed bodily from the boiler by breaking the joints at the terminal cocks. When this was done a gritty sediment slightly impregnated with grease fell from the bore of the water pipe, the adjacent passage in the terminal cock was found to be half choked with the same substance, and its clear area further reduced by about $\frac{1}{8}$in. of hard incrustation. The gauge columns and pipes were subsequently examined in detail, and all parts were found to be quite clear. The condenser was tested and a small leak was found coming from the packing at the end of one tube. The condenser had been thoroughly overhauled about three weeks before the explosion, and the chief engineer was satisfied that it had remained tight. The normal amount of extra feed water had been used daily, and until the morning of the explosion no doubts had been entertained as to the tightness of the condenser. The leak which was found under test was much too small to be detected by its effect on the water levels, and its influence can be disregarded for the $3\frac{1}{2}$ hours' voyage from Campbeltown to the place where the explosion occurred. The normal loss of water from the boilers for this stage of the voyage would be about three to four inches in each glass and would be mainly due to the fact that the steering engine, dynamo, capstans and winches all exhaust to the atmosphere.

The substance of these remarks can now be briefly recapitulated and examined so that the factors contributory to the explosion may be clearly understood.

The height of water in each glass when the vessel left Campbeltown was 9ins. and equivalent to a height of about 14ins. above the combustion chambers.

The water gauge which was in use on the port boiler was recording a false level at this time due to an accumulation of sediment at the water terminal cock. This was not noticed by the engineers at that time, and its effect later in the day was wrongly attributed to a leaky condenser, but no attempt was made to ascertain if the condenser was leaking. The engineers, under the impression that everything was in order, made a slight adjustment to the feed checks which had some effect in maintaining an actual level of 9 or 10 inches in the starboard boiler. There was an apparent level of a somewhat greater amount in the port boiler. This means that the normal loss of water actually occurred wholly in the port boiler and may be expressed as about 7ins. of water. The actual increase in the starboard boiler, stated to be about 1in., must be added, thus giving a total loss of 8ins. in the port boiler. This boiler was blown down and about 4ins. were taken out of the glass, the total reduction of water in this boiler therefore being in the region of 12ins. In so far as these levels were approximately stated by witnesses in customary language as $\frac{3}{4}$ glass, $\frac{1}{2}$ glass, as the case may be, so the conversions to inches made in this report are approximate to the same degree. It has been shown, however, that a dangerous reduction of water had taken place in the port boiler.

The fact that the level in the glass fell when the boiler level was reduced by blowing down appeared to indicate that the water gauge was in proper working order, but actually the water connection to the gauge was partially choked, the obstruction being of such a nature that there was filtration of water through its mass when a sufficient difference in head existed between the water in the column and the water in the boiler. The pipes leading to the column were unlagged and the effect of condensation in the stream connection would assist in maintaining a deceptive level.

It was stated in evidence that both water gauges showed a normal pulsing of the water level. This could not have been of any magnitude as the gauges were in the centre vertical plane of the boiler and the motion of the vessel was slight. Fluctuation due to easy rolling would therefore be negligible and pitching would have but the slightest effect. This would add to the difficulty of the engineers in detecting a false reading from a true one by merely looking at the glasses, and it could only be done in this way by most careful observation.

An automatic shut-off valve was incorporated in the water end of the gauge glass mounting. The tail of this valve and the centre hole of the grid supporting it were found to be a little worn. Further wear would eventually permit this valve to cant when lifted and thus possibly cause an obstruction in the gauge. It was therefore removed and the remaining water gauges were treated in a similar way. The boiler was repaired satisfactorily and subsequently tested by water pressure to 180 lbs. per sq. in.

Observations of the Engineer Surveyor-in-Chief.

It is clear from the report that the water gauges of the boiler on board this vessel had not received the careful attention necessary for safe working of the boilers. The practice of shutting off the forward water gauges cannot be too strongly deprecated, and the obstruction in the water connection of the after water gauge on the boiler from which the explosion occurred indicates that there had been laxity in not testing the gauge frequently by the double shut-off method which should be used particularly where, as in this case, the water gauges are of the hollow-column type.

INSTITUTE NOTES.

Student Graduate Examination, 1930.

At the Annual Examination held on April 7th—10th, 1930, the following eleven candidates passed in all subjects and thereby qualified for the Institute's Diploma, and for election as Student Graduates :—

NEWCASTLE:	J. Anderson, G. Guthrie, A. F. Kelley, W. J. McDonald, A. Moffett, J. L. Oliver.
LEYTON:	A. E. H. Clewer.
LIVERPOOL:	R. H. Clarke, A. D. McCready.
PORTSMOUTH:	E. J. Moyse.
GRIMSBY:	E. C. Plastow.

Prizes of books, instruments or cash have been awarded to the following candidates for distinction as noted :—

Candidate.	*Distinction in*
A. F. Kelley	Mechanics, Heat and Heat Engines (bracketed highest), Practical Engineering (bracketed highest).
E. J. Moyse	Heat and Heat Engines (bracketed highest).
L. E. Fletcher	Machine Construction and Drawing.
A. D. McCready	Practical Engineering (bracketed highest).
E. C. Plastow	Practical Engineering (bracketed highest).
A. E. H. Clewer	Mathematics.
C. W. A Hayes	English and Composition.
J. L. Oliver	Electrical Engineering.
J. Anderson	For high average merit in all subjects.

Election of Members.

List of those elected at Council Meeting held on June 2nd, 1930:—

Members.

John Barr, 23, Portland Street, Norwich.
Thomas Braidwood, 7, Woodland Drive, Wallasey, Cheshire.
James Buyers, 20, Hammerfield Avenue, Aberdeen.
John Edward Cooper, 6, Keppel Terrace, Stoke, Devonport.
Henry Reginald Flower, La Guaira & Caracas Railway Co., Ltd., Caracas, Venezuela, S. America.
Charles Robert Archibald Grant, Lt. (E), R.N., BM/VCHD, London, W.C.1.

John Louis Hagan, 7, Iolanthe Terrace, South Shields.

Leslie George Youldon Harman, 70, Chaldon Road, Caterham, Surrey.

Alexander Kemp, 298, Holburn Street, Aberdeen.

David Winthorpe Low, 17, Walmer Crescent, Ibrox, Glasgow.

Donald McFadyen McPhail, 13, Port Street, Glasgow, C.3.

John Dewar Paul, 8, Hartfield Gardens, Dumbarton.

John Albert Pollock, Remuera, 9, Cambridge Street, Drummoyne, Sydney, N.S.W.

George Rodham Unthank, *c/o* Messrs. R. & H. Green & Silley Weir, Ltd., 130/132, Leadenhall Street, E.C.3.

David Douglas Williamson, 56, Gower Street, W.C.1.

James Webster, Selborne Plantations, Padang Tungku, Pahang, F.M.S.

Donald Walker Urquhart, 74, Forsyth Street, Greenock.

Associate-Members.

Leonard Harry Bird, The City Engineer's Office, Dunedin, N.Z.

Ronald Nicholas Forrest Smit, Bonnie Brae, Seymour Road, Waterloo Green, Wynberg, Cape Town, South Africa.

Christianus Lieshout, 108, Woodcote Valley Road, Purley, Surrey.

Student-Graduates.

John Anderson, 13, Grey Street, Blyth, Northumberland.

Royston Herbert Clark, 30, Hamlet Road, Wallasey, Cheshire.

Arthur Edward Hubert Clewer, 13, Moyers Road, Leyton, E.10.

George Guthrie, Sunniside, Baxter Avenue, Milmain, Newcastle-on-Tyne.

Arthur Frederick Kelley, 22, West Avenue, Gosforth, Newcastle-on-Tyne.

Allan David McCready, 65, Trevor Road, Orrell Park, Liverpool.

Wilfred James McDonald, 65, Sackville Road, Heaton, Newcastle-on-Tyne.

Alfred Moffett, 238, Alexandra Road, Gateshead-on-Tyne.

Edwin Charles Plastow, 89, Convamore Road, Grimsby.

Associate.

Marshall Brook Pollock, Wybourne Grange, Tunbridge Wells, Kent.

Graduates.

George Murray Baxter, 47, Couper Street, Leith.
Cyril Francis, 197, Hither Green Lane, Lewisham, S.E.13.
Albert Benjamin Richard Sexstone, 7, Marsala Road, Lewisham, S.E.13.

Transferred from Associate-Member to Member.

Geoffrey Charles Aylward Kirkman, Thanet, York Avenue, New Milton, Hants.
Wilfred Simons, 19, Wolverton Road, Newport Pagnell, Bucks.

Transferred from Graduate to Member.

William Phillips, 398, Kingsbridge Drive, Rutherglen, Glasgow.

LIBRARY.

The Council gratefully acknowledge a donation of £3 3s. to the Library Fund from Mr. J. C. G. Williamson, Vice-President, Buenos Aires.

BOOKS ADDED TO THE LIBRARY.

Purchased.

The National Physical Laboratory. Report for the year 1929. Published by H.M. Stationery Office for the Department of Scientific and Industrial Research. Price 11/- net.

Presented by the Authors.

"Between Two Oceans," by M. T. Zarotschenzeff. Published for the author by the Cold Storage and Produce Review, Empire House, St. Martin's-le-Grand, E.C.1. Price 5/-.

World Engineering Congress, Tokyo. October-November, 1929. Seven papers by R. W. Allen, C.B.E. (Printed for private circulation only).

Presented by Mr. G. J. Wells, Vice-President.

"Refrigeration, Cold Storage and Ice-Making," by A. J. Wallis-Tayler. Published by Crosby, Lockwood and Son, 1902.

Presented by Mr. C. W. Barnes, Member.

"An Outline of the Metallurgy of Iron and Steel," by A. Humboldt Sexton and J. S. G. Primrose. Published by the Scientific Publishing Company, Manchester. Price 12/6 net.

"An Introduction to Engineering Drawing," by J. Duncan. 1922. Published by Macmillan and Co., Ltd.

"Experimental Applied Mechanics for Technical Students," by James L. Maxim. 1910. Published by Longmans, Green and Co.

Presented by the Author and Publisher.

"The Time-Journey of Dr. Barton," an Engineering and Sociological Forecast based on Present Possibilities, by John Hodgson. Published by the Author, John Hodgson, Eggington, Beds. Price 3/10 net, post free.

No commentary which we could compress into the space available in these pages could adequately cover the range of mental vision which is spanned by the author in the ninety pages of this amazing book. Mr. Hodgson will be remembered as the author of the valuable paper on "The Measurement of Pressure" which was read at the Institute and published in the Transactions during Session 1924. He is a well known engineer, and is recognised as one of the leading authorities on the metering of compressed air, gas, and steam, in which connection he has rendered expert service on the Heat Engine and Boiler Trials Committee in collaboration with the Institute's representatives. The writer of this review was intimately associated with the author for several memorable years, during which the ideas woven into this fascinating narrative were expounded and discussed privately. The present finished product of the author's brilliant intellectual and imaginative faculties has already created much interest.

The book, which Mr. H. G. Wells, the eminent author applauds as "an excellent synthesis of current creative ideas," must be read to be judged in its proper perspective, and at a price which even a student can afford it is a wonderful intellectual and ethical stimulant. The tale is supposed to be told by a Dr. Barton, a mathematical physicist and engineer, who in the Spring of 1927 succeeds in perfecting a machine by means of which he achieves a "time jump" of two thousand years into A.D. 3927, and in transmitting back an account of his first three days' observations and impressions.

The following abstracts from the book itself will intimate better than any paraphrase something of the nature and scope of the vision with which this "Engineer looking at the Future" rewards his readers:—

"While your age could see only individual groups struggling for survival, the wider view that we are able to take shows us that harmonious co-ordination was what was being actually achieved."

* * * *

"The manuscript describes some evidences of the immense engineering and scientific activity which Dr. Barton saw. We learn of the creation of almost unlimited new territories by means of floating and travelling islands; of the amazing achievements of rocket transport; of the intensive use of the world's fresh water supplies in great irrigation schemes; of the conquest of heat, cold, insects and disease; of the tapping, in order to make possible and to sustain all these new activities, of almost unlimited sources of power: the internal heat of the earth, the coolness of the abyssal ocean depths, the Brahmaputra discharge at Payi, the evaporation from the million square miles of the Mediterranean basin. . . ."

* * * *

". . . . those who feel that the world of 3927 of which Dr. Barton tells, with its absence of poverty, war, waste and disease; its elimination of human stocks which are below a minimum level of mentality and bodily stamina; its hatred of regimentation; its encouragement of, and delight in, individuality; its joy in human relationships; is undesirable because the achievement of these ends necessarily involves planning, forethought, and world-wide regulation, have only to reflect upon the complex planning, forethought, and regulation on which our by no means despicable civilisation of 1929 is based, and without which it could not possibly exist."

Almost any one of the chapters alone would furnish material for a lengthy debate. The author's penetrating insight into and uncanny acquaintance with the most elusive facts of our social and economic system are such that "Dr. Barton" cannot fail to become a classical "Bradshaw" to travellers along the numerous but correlated routes to the future Utopia. In confirmation of this opinion and as a proof of the practical nature of the Author's idealism, it may be mentioned that already, since the book was first circulated privately in 1927, a number of his ideas have materialised or are being brought to fruition. The book contains twenty unique illustrations (one in colour) by such eminent artists and architects as Sir

Edwin Lutyens, R.A., Professor Richardson, F.R.I.B.A., and Albert Daenens, who have enthusiastically co-operated with the author. The reviewer, whilst trying to reflect the merits of this remarkable book, anticipates that it will meet with a keenly controversial reception, and he most earnestly recommends it to all engineers disposed to spare a thought for posterity.

B.C.C.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examination for certificates of competency as Sea-going Engineers under the provisions of the Merchant Shipping Acts.

For week ended 3rd May, 1930:—

NAME.	GRADE.	PORT OF EXAMINATION.
Armstrong, John L.	2.C.	Belfast
Twigg, George	2.C.M.	Cardiff
Barbour, David	2.C.	Glasgow
Macdonald, Angus	1.C.	,,
Barbour, Charles	2.C.	,,
Bruce, David A.	1.C.	,,
Hepburn, James S	1.C.	Leith
Cruickshank, Hector M. ...	2.C.	,,
Davie, David A. B.	2.C	,,
McKnight, John R	2.C.M.	,,
Collin, Ronald B.	2.C.	Liverpool
Goodall, Stanley J.	2.C.	,,
Seubert, Reginald W.	2.C.	,,
Nutter, Henry	2.C.M.E.	,,
Hudson, Gilbert A.	1.C.E.	,,
Dalgarno, Cecil M.	1.C.	London
Pool, Lionel W.	2.C.	,,
Thompson, William L.	1.C.	Newcastle
Newrick, Albert	2.C.	,,
Reay, Tom E.	2.C.	,,
Wood, Norman H.	2.C.	,,
Kirkman, Geoffrey C. A. ...	1.C.	Southampton
Osmond, Francis R.	2.C.	,,

For week ended 10th May, 1930:—

McPhail, Donald M.	1.C.	Glasgow
Anderson, John	2.C.	,,
Forsyth, George	2.C.	,,
Bennett, William G.	1.C.M.E.	,,
Lowe, James	1.C.M.E.	,,
Himsworth, Harold F.	1.C.M.E.	Hull
Rollerson, William H.	1.C.E.	,,
Pearson, Harold M.	1.C.	,,

For week ended 10th May, 1930—*continued.*

NAME.	GRADE.	PORT OF EXAMINATION.
Keggin, William	1.C.	Liverpool
Roberts, William G.	1.C.	,,
Adams, Frank	2.C.	,,
Berry, Thomas	2.C.	,,
Davies, Francis W. J. W. ...	2.C.	,,
Nicolle, Philip K.	2.C.	,,
Postlethwaite, John	2.C.	,,
Robb, Douglas	2.C.	,,
Love, William G.	1.C.M.	,,
Jones, David	2.C.M.E.	,,
Quinn, James	1.C.	London
Catchpole, Arthur	1.C.	,,
Hodges, Ernest G.	2.C.	,,
Rogers, Benjamin	1.C.M.	,,
Shute, Berthron D.	2.C.M.	,,
Golder, Quintin	C.M.E.	,,
Grant, George	1.C.	Newcastle
Wright, William	2.C.	,,
Brownlee, Alexander	1.C.	Sunderland
Bell, Thomas	2.C.	,,
Jackson, George W.	2.C.	,,
Johnson, Alexander	2.C.	,,
Oliver, Thomas V.	2.C.	,,
Allinson, Reginald I.	1.C.M.E.	,,
Atkinson, William A.	1.C.M.E.	,,
Emerson, Roland H.	1.C.M.E	,,

For week ended 17th May, 1930:—

Jenkins, Gerald W.	1.C.	Cardiff
Jackson, Charles	1.C.	,,
Roberts, Samuel H.	2.C.	,,
Benwood, Allan	1.C.	Glasgow
Calder, William A.	1.C.	,,
McInnes, Joseph E.	1.C.	,,
Petrie, James	1.C.	,,
Ramsay, John F.	1.C.	,,
Ingram, Harry	1.C.M.	,,
Braidwood, Walter S.	2.C.	,,
Watt, Alexander	2.C.	,,
Bisset, James	1.C.	Leith
Davidson, David C.	1.C.	,,
Noble, Stewart	1.C.	,,
Russell, Matthew	1.C.	,,
Gardiner, Thomas D.	2.C.M.	,,
Johnstone, Arthur T.	2.C.	,,
Coxe, Charles J. D.	1.C.	Liverpool
Salt, James A. T.	1.C.	,,
Short, George F. J.	1.C.	,,
Sims, John	1.C.	,,
Wynn, Francis K.	1.C.	,,
Yeadon, Albert E.	1.C.	,,
Browne, Richard	2.C.	,,
Corkill, George H.	2.C.	,,
Davies, Evan T.	2.C.	,,
Roberts, William G.	2.C.	,,
Nettleton, Albert J.	1.C.M.	,,
Bass, James A.	1.C.	Southampton
Coates, William G. R.	1.C.	Newcastle
Warburton, Robert N.	1.C.	,,

For week ended 17th May, 1930—*continued*.

NAME.	GRADE.	PORT OF EXAMINATION.
Dawson, Arthur	2.C.	Newcastle
Gibbeson, John	2.C.	,,
Harrison, Walter V.	2.C.	,,
Bridges, Robert H.	1.C.M.E.	,,
Nixon, Albert E.	1.C.M.E.	,,
Harvey, Richard A.	1.C.	London
Lillywhite, Sidney A.	1.C.	,,
Williams, Walter H.	1.C.	,,
Simons, Wilfred	1.C.M.	,,
Martin, Harry S.	1.C.M.E.	,,
Roy, Owen J.	1.C.M.E.	,,
Wood, Edward S.	1.C.M.E.	,,

For week ended 24th May, 1930 :—

Morrison, William J. M. ...	2.C.	Glasgow
Wylie, John H.	2.C.	,,
Young, Ashley T. M.	2.C.	,,
Ablett, William	1.C.	,,
Duncan, John	1.C.	,,
Gateley, Joseph P.	1.C.	,,
Jack, Hugh McL.	1.C.	,,
Johnston, Alexander	1.C.	,,
Lawrie, Leonard L.	1.C.	,,
Forbes, James B.	1.C.M.E.	,,
Milligan, William	1.C.	Liverpool
Beaumont, Thomas J.	2.C.	,,
Crossley, Edward	2.C.	,,
Grace, Eric F.	2.C.	,,
Howieson, Nicol M.	1.C.	London
Neville, Ernest C.	1.C.	,,
Tomlinson, Wilfred	1.C.	,,
Bickford, John H. P.	2.C.	,,
Russell, Leslie G.	2.C.	,,
Smit, Ronald N. F.	2.C.M.	,,
Chapman, George A.	1.C.	Newcastle
Smith, Thomas A.	2.C.	,,
Heatley, George	2.C.	,,
Adamson, Robert S.	1.C.M.E.	,,
Purse, Robert	1.C.	Sunderland
Turner, Gerard V.	2.C.	,,
Wardle, Frederick	2.C.	,,
Goodram, Frederick	2.C.M.E.	,,

For week ended 31st May, 1930 :—

Allen, William F.	2.C.	Belfast
Faulkner, Samuel	2.C.	,,
Chamberlain, Reginald H. ...	1.C.	Cardiff
Jones, John I.	1.C.	,,
Rowles, William	1.C.	,,
Kitchin, Stanley	1.C.	,,
Guinee, Richard C.	2.C.	,,
Nicholson, John S.	2.C.	,,
Thomson, Alexander	1.C.	Glasgow
Ferguson, James M.	2.C.	,,
Taylor, Alexander	2.C.	,,
Wilson, William	2.C.	,,

For week ended 31st May, 1930—*continued.*

NAME.	GRADE.	PORT OF EXAMINATION.
Kidd, James R.	2.C.M.	Glasgow
McDonald, Ian F.	1.C.	Leith
Linton, Robert	2.C.	,,
Mathieson, William T.	2.C.M.	,,
Dixon, Robert W.	1.C.	Liverpool
Harvey, Frank	1.C.	,,
Foulkes, George H.	2.C.	,,
Williams, Percy	2.C.	,,
Williams, William J.	2.C.	,,
Anderson, John W. N.	1.C.M.	,,
Disley, Peter	2.C.M.	,,
Robinson, John C.	2.C.M.	,,
Clough, Edmund	1.C.M.E.	,,
Hooper, William H.	2.C.	London
Houston, Matthew C.	2.C.	,,
Monk, Cyril L.	2.C	,,
Harlow, Vincent L.	2.C.M.	,,
Hobson, Samuel	2.C.	Newcastle
Grandison, James	2.C.M.	,,
Mellish, Arthur W. R.	2.C.M.	,,
Black, Robert	1.C.M.E.	,,
Bryan, Stewart G.	1.C.M.E.	Southampton