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Stainless Steels for Turbine Blading.

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Synopsis.

The author discusses the history of the development of stainless iron for turbine blading. Particular reference is made to more recent corrosion troubles due to contaminated steam. Materials possessing greater resistance to corrosion are described and particular reference is made to the austenitic steels. The physical properties of the various materials at atmospheric temperatures are discussed, as are also the properties of the materials at high steam temperatures. The usual methods of determining these properties are discussed, and particular reference is made in this section to the fatigue of metals at temperatures above atmospheric. Some reference is made to the particular difficulties which might arise during the manufacture of the blading of the austenitic type of steels as compared with the well-known processes applied to the original stainless iron. Reference is made to the methods of fabrication and fitting of blading, the effect of these on the physical properties of the material, and the need for careful fitting because of the changes in size which may occur in service.

So far as the author is aware, stainless steel was first used as a blading material about 30 years ago when a few blades were inserted experimentally in a turbine in which the bulk of the blading was of 5 per cent. nickel steel; examination of these blades after periods of use and also of other blades which were inserted at somewhat later dates in other turbines, showed that they had behaved excellently. At that time the only form of stainless steel available was the one commonly used for cutlery, which contained about 12 per cent. chromium and 0·3 per cent. carbon. It was appreciably harder than blading material previously used and, whilst this might be looked upon as an advantage in giving greater strength and resistance to erosion, it caused some trouble in fabrication processes. It was more difficult to cold-roll or cold-draw into blading form and it was liable to harden intensely and become rather brittle at brazed joints, though these undesirable changes in properties could be lessened by modifications in brazing procedure or, if produced, could be removed by subsequent tempering. These difficulties were greatly minimised by the successful commercial production in 1920 of "stainless iron" by the firm with which the author is connected. Stainless iron differed in composition from the stainless steel previously available, only in having a distinctly lower carbon content—about 0·1 per cent.—but, as a result, it was much softer than its predecessor and when brazed not only hardened to a much smaller extent, but also retained a quite adequate degree of ductility. It was not long before stainless iron was adopted by many of the leading turbine manufacturers as a standard blading material and since that time it has been used for blading to a far greater extent than any other form of stainless steel and probably also than any other corrosion-resistant metal. It has, in fact, given successful results under all normal conditions of use until fairly recently when evidence has indicated that it might suffer corrosion, sometimes of a quite intense character, if the turbine in which it was fitted was fed with steam contaminated with chlorides.

Corrosion troubles due to chloride contamination of the steam fed into a turbine have varied considerably; they have been acute in some cases and very mild, in fact negligible, in others—some consideration will be given to this matter later—but their presence led to the question of replacing stainless iron with some more resistant form of stainless steel. As will be seen later, there are several types of stainless steel available which are less prone to suffer chloride attack and some of them have already given successful service over periods of years. It is proposed to describe in this paper the relevant properties of various corrosion-resistant steels or alloys which have been used or proposed for use as blading and to endeavour to assess their usefulness as blading under various service conditions.

It may be an advantage to consider first what properties an ideal blading material should possess and to see to what extent such properties are found in stainless iron.

The properties desirable in material for turbine blading would appear to be, firstly, adequate strength—coupled with sufficient toughness and ductility—at working temperatures to resist the stresses to which the blading will be subjected during use; secondly, sufficient resistance to corrosion and erosion that the blading made from it retains its original shape and smooth surface under working conditions in the turbine; thirdly, its properties, particularly its strength, toughness, ductility and resistance to corrosion, should not be adversely affected to any marked extent by prolonged heating at operating temperatures; finally, its rate of expansion when heated should preferably, not differ materially from that of the steel used for the rotor and casing of the turbine. All these properties refer to the actual use of the blading under working conditions; in addition, however, the metal of which it is made should respond well to the methods commonly used for the fabrication of blading and for fixing it firmly in position in the turbine. It should be amenable to hot and cold working processes, and be machinable without difficulty. In certain cases also, it should be capable of being welded or brazed with ease and without significant detriment to its physical and chemical properties and of responding satisfactorily to such special processes as "casting-in". The list is long and somewhat formidable and some of the desired properties can hardly be described as compatible. Stainless iron, however, possesses them in good measure. Thus when hardened and then well tempered at 700° C.—the condition in which it is ordinarily used—it has a tensile strength at atmospheric temperature of about 35 tons per sq. inch, and a yield point of about 24 tons per sq. inch—values seemingly adequate in most cases—together with ample ductility and toughness, and these properties are not appreciably affected by prolonged heating at any steam temperature in use or envisaged in the near future. It is readily cold worked and machined in this condition, but if desired, can have its tensile strength reduced by suitable annealing to about 30 tons per sq. inch, thus making it still more amenable to cold working operations. It hardens to some extent though rarely to a value above about 320 Brinell—on cooling from brazing temperatures but generally retains reasonable ductility when so treated; thus many tons of stainless iron have been supplied to a specification which calls *inter alia* for a strip, 1in. wide and ⅛in. thick, to be heated to 1,000° C., cooled freely in air and then bent through 60° without showing any sign of fracture. If considered essential, however, the induced hardness can be removed and the lowered ductility restored to its original value by tempering at 700° C. Stainless iron may also be satisfactorily fitted into nozzle boxes of cast iron or bronze by the "casting-in" method, though it may not be advisable to use it with the non-ferrous alloy owing to the possibility of electro chemical action developing between the two metals and to their differences in rate of expansion. Finally, its coefficient of expansion when heated is slightly lower than, but substantially the same as, that of mild steel and of the low alloy steels commonly used for the more massive parts—e.g. rotors and casings—of turbines; typical values are given in Table 1.

TABLE 1.

CO-EFFICIENTS OF EXPANSION.

Material.	Mean coefficient ($\times 10^{-6}$) per °C.			
	20°-200° C.	20°-300° C.	20°-400° C.	20°-500° C.
Mild steel and low carbon alloy steels, average value	11·6	12·4	13·1	13·7
Stainless iron, 12/14% Cr.	11·0	11·3	11·6	12·1
„ „ 16/18% Cr.	10·6	10·9	11·3	11·6
„ steel, 16/18% Cr. (S.80)	11·1	11·3	11·4	11·6
Austenitic steel, 18% Cr. 8% Ni	17·3	17·6	18·1	18·4
Austenitic steel, 25% Cr. 20% Ni	15·5	16·0	16·5	17·0
Austenitic steel, 11% Cr. 36% Ni	12·2	14·1	15·3	16·0
Monel Metal	14·1	14·7	15·1	15·5

If a higher tensile strength than is normally possessed by stainless iron be deemed desirable in turbine blading, it can readily be obtained, though at some loss in certain other desirable properties, by increasing carbon content to a small extent. Stainless iron contains not more than 0·15 per cent. carbon and frequently, when used for turbine blading, not more than 0·12 per cent. By raising carbon to 0·15/0·20 per cent. or to 0·20/0·25 per cent., tensile strengths of about 45 or 50 tons per square inch are easily obtainable. Such materials are of course stainless steels and not stainless irons; they are readily machinable but not so easily cold worked as the lower carbon stainless iron. When they are cooled from brazing heats they harden to a more pronounced degree than stainless iron and may easily reach a Brinell value of 450/500, in which condition they lack ductility; the induced hardness can, of course, be removed and the original ductility restored by tempering at 700° C. Although steels such as these can be cold rolled or drawn into blading sections, they are probably more suitable for blades with integral roots, which are machined from heat treated bar and are fastened mechanically into the turbine. They can be brazed successfully if care is used. Their coefficients of expansion do not differ appreciably from that of stainless iron, their corrosion resistance is of the same order as, though slightly less than, that of stainless iron of the same chromium content.

Prolonged heating at high steam temperatures has no appreciable effect on the tensile strength or ductility of these steels though it may reduce to some extent their impact value at ordinary temperatures; the steel remains quite tough however whilst it is hot.

As has already been mentioned the principal, if not the only, trouble which has occurred with stainless iron in practice has been due to corrosion which has developed under certain conditions in turbines fed with contaminated steam. Greater resistance against this form of attack can be obtained by increasing chromium content or by adding large quantities of nickel or both and certain alternative types of stainless steel have been used, or proposed for use, for blading which may be called upon to resist chloride attack during use. Improvement in some particular property of an alloy, however, frequently leads to modifications, not always desirable, of other properties and, in this particular case, none of the more corrosion-resistant steels has quite the same all round combination of desirable properties found in stainless iron. This does not of course imply that they are unsuitable for blading but that modifications in fabrication or in methods of use may be necessary. It may be convenient, therefore, to assess the usefulness of these other types of stainless steel for blading by considering how their essential properties differ from those of stainless iron. These alternative types may be conveniently grouped into four categories.

(a) Low carbon stainless irons and steels containing about 16-18 per cent. chromium.

(b) Steels containing about 18 per cent. chromium together with sufficient nickel—generally a minimum of 8 per cent.—to make them stably austenitic; generally small amounts of other metals, e.g. titanium, columbium, silicon, molybdenum, are added to such "18/8" steels for metallurgical or other reasons.

(c) Steels containing 11 or 12 per cent. chromium together with about 36 per cent. nickel.

(d) Steels containing about 18 per cent. or more chromium together with considerably higher nickel contents than those in group (b); two such compositions are:—

  (a) 18 per cent. chromium, 25 per cent. nickel, ·25 per cent. carbon max.

  (b) 25 per cent. chromium, 20 per cent. nickel, ·20 per cent. carbon max.

Again small amounts of other metals may be present as in group (b) and for the same reasons.

Some comparison should also be made with one non-ferrous alloy, monel metal, which has been successfully used for blading; it contains essentially about 70 per cent. nickel and 30 per cent. copper.

As a first step in discussing desirable properties, consideration will be given to the question of corrosion resistance as this is one of the most important factors. Strength, ductility, toughness and other physical properties of the steels, both at atmospheric and at operating temperatures will then be discussed together with the effects of prolonged exposure at the latter temperatures. After that, the response of the various steels to fabrication methods will be described.

Resistance to Corrosion.

The corroding fluid in a steam turbine is essentially steam, either moist or superheated. If it could be guaranteed that the steam were in fact pure, the corrosion problem would not present any difficulty at temperatures up to at least 600° C. (about 1,100° F.). Experience over a number of years has shown that with this proviso the 12/14 per cent. chromium steels will resist quite satisfactorily the attack of moist or dry steam up to the maximum temperatures regularly in use whilst laboratory tests show that appreciable attack on the stainless iron commences only when much higher temperatures are reached. As is well known, steam and ordinary carbon steel react at a low red heat producing hydrogen and iron oxide. The speed of this reaction is slow up to about 500° C. but it increases at higher temperatures. If the carbon steel is replaced with stainless iron the incidence of the reaction is delayed until considerably higher temperatures are reached; in this case, no appreciable formation of hydrogen occurs below about 650° C. For example, tests carried out many years ago in the author's laboratory showed that whereas the passage of superheated steam at a pressure of 160lb./sq. in. through a mild steel tube electrically heated to 550° C. led to the production of half a litre of hydrogen in four hours, no formation of hydrogen could be detected when a stainless iron tube was substituted for the mild steel tube and the experiment continued for 223 hours. As a result of prolonged exposure to such conditions, the surface of the stainless iron takes on a greyish temper colour —due to the formation of an extremely thin, protective layer of oxide—but otherwise remains smooth and unattacked. Later tests showed that appreciable hydrogen formation was not observed until the temperature of the stainless iron tube reached about 650° C. (1,200° F.) and a still higher temperature would be required if the chromium content was raised above 12 per cent.

In spite of all precautions, however, steam fed into a turbine is not always pure, it may contain inorganic salts carried over from the boiler and of these, the most serious from the point of view of corrosion are chlorides. The liability for this to happen and the extent to which it may occur vary considerably with operating conditions—in many plants chloride contamination would appear to be negligible—but the author can well believe that it may occur more frequently and to a greater extent in marine turbines than in those used, for example, in large land power stations. The author does not propose to discuss how this carry over of chlorides from the boiler may occur or the boiler conditions which favour it—such matters are outside the scope of this paper—he will assume that chloride contamination of steam fed into a turbine may occur and consider how it may accelerate corrosion. At the outset it may be stated that the corrosive effect produced may be very serious.

It is well known that prolonged contact of moist particles of certain soluble salts, particularly chlorides, with corrosion-resistant alloys may cause the latter to be pitted. Action of moist salt particles in this manner is actually more severe than that of either the dry salt or a solution of the latter in water; it may be doubted in fact whether the perfectly dry salt would exert any appreciable corrosive action on stainless steels. It may be expected therefore, that the actual effects produced on turbine blading by particles of salt deposited thereon will depend on the moisture conditions existing in the particular part of the turbine in which the blading is situated. Consider the matter from the point of view of a large turbine, fed with highly superheated steam and working continuously. The first few rows of blades, being in contact with this highly superheated, perfectly dry steam, will remain dry together with any salt particles which may lodge on their surfaces. It may, perhaps, be questioned whether the dry particles would adhere to the equally dry blades but, even if they did, it is unlikely that they would have any marked corrosive action.

Further along the turbine, condensed moisture will appear and will moisten the salt particles which may be deposited on blade surfaces there. It is probably at this stage that the hot, moist salt particles have their greatest corrosive effect whilst the turbine is running.

At still later stages in the turbine, at the low pressure end where the steam temperature is much lower, the amount of condensed moisture present is probably sufficient to wash off the blading any particles of salt which may have been carried so far through the turbine. At this stage, where one would be dealing with a dilute solution of salt rather than moist salt particles, corrosion troubles due to chlorides are hardly likely to arise unless working conditions are very abnormal.

All turbines, however, do not run continuously under steady load. They may have shut down periods or they may work under fluctuating loads which may be met by temporarily cutting out certain stages in the high pressure cylinder. In either case, condensation may occur in the rows of blading which previously were surrounded by dry steam, but through which live steam is no longer passing; if this occurs, the dry salt particles which had previously been deposited on the blading will become moist and will have an opportunity to initiate pitting in the blading. The pitting action will be considerably intensified should air gain admittance into the turbine, the corrosive effect of salt particles in the presence of both moisture and air being more severe than if air is absent.

TABLE 2.

Spray Tests with 3·5% Sodium Chloride Solution Atmospheric Temperature. Duration 241 Days.

Mark.	Class.	Composition.			Loss in weight.		Appearance.
		C %	Cr. %	Ni. %	Grams.	%	
A	Stainless iron	·09	13·5	·30	0·089	0·28	Pitted all over.
B	do. higher chromium	·09	17·1	·20	0·015	0·041	Numerous fine pits.
C	Austenitic 18/8 steels	·12	18·0	8·2	0·004	0·010	2 or 3 minute pits
D		·13	20·1	9·9	0·003	0·008	do.
E	Austenitic high nickel steels	·13	17·1	25·4	0·006	0·016	a few minute pits
F		·13	11·5	35·4	0·025	0·061	pitted all over but less deep than A.
G		·32	11·4	35·3	0·027	0·068	

Although adequate resistance to the action of pure steam is obtained with all kinds of stainless steel in commercial use, experience has shown that the 12/14 per cent. chromium steels are liable to become pitted should there be appreciable chloride contamination of the steam to which they are exposed. If the picture sketched in the preceding paragraphs is reasonably correct, however, it follows that such pitting, unless conditions are abnormal, is more likely to occur in the blading in the early and intermediate stages of the turbine than in those at the low pressure end, and the actual amount of it will vary considerably with working conditions. It is a fact that stainless iron containing 12/14 per cent. chromium has given satisfactory service for many years in by far the greater part of the blading of turbines in land power plant working with steam up to at least 900° F. It has also been satisfactory in many marine turbines but has corroded in others. It seems possible that certain examples of severe corrosion of stainless iron blading in marine turbines which have been brought to the author's notice during the war period have resulted mainly from the admission of air into the turbines during shut down periods when condensation had occurred; there had been chloride contamination and the salt particles previously deposited on the blades were thus enabled to exert a rapid pitting action.

If it is deemed advisable to use a more resistant material than stainless iron for the blading in those stages of a turbine most likely to be affected, the question arises as to which steel should be selected. As a first step in answering this question, salt water spray tests were carried out on stainless iron together with a number of steels belonging to the various groups mentioned on page 2 as having been used or proposed for use as blading materials. The test samples, which were in the form of polished cylinders about 2·5 centimetres long and 1·5 centimetres diameter (average surface area 16·6 cm.^{2}) were exposed to an intermittent spray of a 3½ per cent. solution of sodium chloride. Spraying was carried out for eight hours a day for five days in the week; during the intervening nights and weekends, the samples remained undisturbed in the spraying chamber and it is probable that salt crystals formed on them during at least the week-end periods. The test was continued for 5,550 hours (241 days) during which the spray was in action for 1,328 hours; afterwards the samples were carefully cleaned to remove adherent rust and their losses in weight then determined. The corrosion which had occurred was mainly in the form of pitting and the losses in weight given in Table 2 are a good indication of the extent of this pitting as judged by a careful visual examination of the samples.

Although the corrosive conditions in these tests are not identical with those postulated on pp. 2 and 3 as likely to occur in a turbine fed with contaminated steam, they are of similar type to the latter and it is thought the results obtained above place the respective materials in the same order of resistance as would be obtained under actual working conditions.

These results have several points of interest. It is obvious that chromium content is the dominating factor and also that, for a given chromium content, an austenitic steel is more resistant than one which is ferritic or martensitic (compare steels A and F, and B with C and E). It would also appear that an increase in nickel content beyond that necessary to give an austenitic structure is unlikely to increase resistance to chloride attack—compare steels C and E.

A further series of tests was then carried out in which the salt solution was heated to 75°/80° C. and sprayed whilst hot, conditions being otherwise the same as in the preceding tests. It was hoped by this means to obtain conditions more nearly approaching those in a hot turbine and, incidentally, to obtain results more quickly. The total period of test in this case was 25 days during which the spray was in action for 144 hours. The losses in weight are given in Table 3 and these, as well as the appearance of the several samples, placed the steels in the same order of merit as in the first test.

Finally, samples were exposed to chloride attack similar in character to but of greater severity than that which may occur in turbines, the actual conditions involving continuous contact of the samples with moist particles of sodium chloride for 27 hours in an atmosphere of air and steam at a temperature of 95°/97° C., the humidity of the atmosphere being so adjusted that the salt particles remained moist during the whole period of the test. In this case, losses in weight were not determined but the relative corrosion produced was judged by the appearance of the samples. The latter were taken from different batches of material

TABLE 3.

Spray Tests with 3·5% Sodium Chloride Solution.
Temperature 75°/80° C.
Duration 25 Days.

Mark.	Class.	Composition.			Loss in weight. Grams.	Appearance.
		C. %	Cr. %	Ni. %		
A	Stainless iron	·09	13·5	·36	0·046	pitted
B	High chromium steel	·12	17·6	1·65	0·015	do. finer and less deep.
C	Austenitic 18/8 steel	·09	19·2	11·5	0·001	2 very minute pits
D	Austenitic high nickel steels	·13	17·1	25·4	0·009	a few small pits
E		·27	10·7	35·7	0·020	pitted, less deep than A.

having compositions within the following ranges except in the case of material D of which one batch only was tested and had the stated composition :—

		Composition.		
Mark.	Class.	C. %	Cr. %	Ni. %
A	Stainless iron	·15 max.	12·5/13·5	0·5 max.
B	16/18% chromium steel ...	·15 max.	16/18	1·5/2·0
C	Austenitic 18/8 steel ...	·15 max.	18/20	9/12
D	Austenitic high nickel steel	·13	17·1	25·4
E	Austenitic high nickel steel	·25/·35	10/12	35/37

Three separate tests were carried out on steels A, B, C and E; in each test A was pitted most and C least. In two of the tests steel E was attacked less than A but definitely more than B; in the third test, E was slightly better than B. Steel D was added in one test only and gave results very slightly inferior to C but better than any of the other steels.

It is satisfactory to note that the three different conditions of testing detailed in the preceding paragraphs place the several steels in the same order of merit and hence some confidence may be placed in applying the results to corrosive conditions arising in turbines fed with contaminated steam. One may conclude that raising chromium content from 12 per cent. or so to 16/18 per cent. is at least as effective as adding 35 per cent. nickel; it is also much less costly.

Of all the steels tested, the austenitic steel containing about 18 per cent. chromium and 8 per cent. nickel has the greatest resistance to corrosive attack by moist particles of chloride and very probably its degree of resistance is ample to meet the corrosive conditions in most, if not all, turbines. If testing conditions are made more severe, they show, as might be expected, that still greater resistance to pitting by sodium chloride can be obtained by adding two or three per cent. molybdenum to the austenitic "18-8" steels—it may be noted that it is then necessary to increase the nickel content to 12 or 14 per cent. to preserve a completely austenitic structure—or by increasing chromium content to about 25 per cent., a simultaneous increase in nickel to about 20 per cent. being necessary to obtain a completely austenitic structure. Whether such greater resistance to corrosive attack in a turbine is necessary seems very doubtful, at least in the very great majority of cases.

At this point, it may be useful to refer to the one non-ferrous alloy, namely Monel metal, which appears to be used to any considerable extent for turbine blading in modern high temperature high pressure turbines. Unfortunately, samples of monel metal were not included in the tests detailed above, but other tests indicate that this material has very good resistance against the attack of wet salt, probably at least as good as that of the austenitic "18-8" steels.

Physical Properties at Ordinary Temperatures.

(a) *Stainless irons and steels containing 16-18 per cent. Chromium.*

The markedly superior resistance of these materials to chloride attack, as compared to the 12/14 per cent. chromium steels, is a very attractive feature, suggesting that they might be used extensively as turbine blading; in their ordinary form, however, these stainless irons have some other features which are not so desirable and which may limit the possibilities of their application. These undesirable features may be removed, however, by small additions of other alloys.

Stainless irons containing 16-18 per cent. chromium, and up to 0·15 per cent. carbon but with no significant amount of other alloys differ appreciably in several respects from the 12/14 per cent. chromium stainless irons. When properly softened at 700/750° C. after hot or cold working, they have tensile strengths of 28/35 tons per square inch, yield points of 18 or 20 tons per square inch, and good ductility as shown by elongation values, but they are notch brittle at temperatures up to about 150° C., their Izod impact value being generally about 5 ft. lb. They do not respond in any useful degree to heat treatment; they cannot be hardened appreciably by quenching from high temperatures and should they become coarse grained—which readily occurs when they are heated to temperatures above about 850° C.—they can only be refined by hot or cold work: heat treatment will not remove either the coarse structure or the increased brittleness which accompanies it. They have a further disadvantage in that, if held for moderately long periods at 750/950° F., they tend to become very brittle. The tendency for brittleness to develop increases with chromium content and also is at a maximum at about 880°/900° F.; other things being equal, it develops more slowly at either 850° or 950° F. than at 880°/900° F. and still more slowly at 750/800° F. No evidence has been obtained that embrittlement is produced at temperatures below 750° F. even with chromium contents well over 20 per cent.

The notch brittleness which seems inherent in these plain high chromium irons can, however, be removed very considerably by small additions of certain other elements, e.g. copper (alone or in conjunction with nickel) or nitrogen. When properly heat treated, such special irons (among which is the Brearley K brand of Messrs. Brown, Bayley's Steel Works, Ltd.) possess adequate toughness, e.g. Izod values of 40 ft. lb. or so; the addition of these other elements also raises the tensile strength somewhat so that the heat treated bars have values similar to those of the 12/14 per cent. chromium irons. They behave in a similar manner to the latter irons in cold rolling or drawing, machining and other fabrication processes. It is also very probable that these special irons are much less susceptible to the brittleness described in the previous paragraph than the plain stainless irons of similar chromium content and they may be entirely free from it. Meanwhile, until further tests show whether or not an appreciable degree of brittleness is likely to develop with prolonged heating at 880/900° F., they may be used satisfactory at temperatures up to 800° F.

Alternatively, material of higher tensile strength but possessing good ductility and toughness can be obtained by adding about 2 per cent. nickel to a high chromium iron with perhaps a somewhat higher carbon than usual. A convenient range of composition is :—

Carbon	0·18 per cent. max.
Chromium	16·0 per cent. min.
Nickel	1·0-3·0 per cent.

It will be recognised that this composition range is very similar to that of the well known B.S. Specification S.80. When hardened and tempered, such steel has a tensile strength between 45 and 55 tons per square inch, depending on its actual composition, good elongation and an Izod value of not less than 25 ft. lb. It can be brazed without difficulty as it does not harden unduly after such treatment—in any case, the effect of brazing may be removed by tempering at 600/650° C.—and although it has been successfully produced as drawn blading it is probably more suitable, on account of its higher tensile strength—like the higher carbon 12/14 per cent. chromium steels—for blading which is machined from heat treated bar. Its impact value when cold may also be reduced somewhat by prolonged exposure at 850/1,000° F. but it retains its toughness while hot. Its resistance to corrosion is equal to that of stainless iron of the same chromium content and it has been used successfully in turbines which were known to be fed with contaminated steam.

Its coefficient of expansion is the same as that of stainless iron.

(b) *Austenitic Steels of the 18 per cent. Chromium-8 per cent. Nickel type.*

The properties of these steels differ markedly in some respects from those of the irons and steels previously described. They cannot be hardened by any form of heat treatment but, like all other metals, they can be hardened by cold work; actually, they harden rather rapidly when deformed, this being one of their most noticeable characteristics. Their normal heat treatment consists in heating to 1,050/1,100° C. or thereabouts and then cooling rapidly. This removes the effects of any prior work hardening and puts the steel in its most ductile condition. When so treated, the steel is non-magnetic or practically so, has a tensile strength round about 40 tons per square inch and an indefinite and rather low yield point and is extremely tough and ductile.

These austenitic steels ordinarily have one particular characteristic which, if it is ignored, may cause trouble in practice; they are liable to undergo intergranular corrosion if they have been wrongly heat treated. Much has been written on this subject of intergranular corrosion—some of it perhaps not entirely accurate—and misconception regarding its causes and effects still exists in many quarters. It may be useful to describe in some detail how this special type of corrosion may occur, what causes it and how its occurrence is entirely prevented.

When the ordinary chromium—nickel austenitic steels—i.e. those which have not been specially made in such a way as to overcome the trouble—are held at a dull red heat for even short periods, they undergo a structural change and are then liable to suffer intergranular attack if subjected to certain forms of corrosive action. The structural change consists in the precipitation of chromium carbide—which contains at least 12 times as much chromium as carbon—along the boundaries between the grains of austenite of which the steel consists entirely when properly heat treated. The chromium required to form this carbide comes from the adjacent surface layers of the grains and, as a result, the chromium content of these surface layers is seriously reduced; hence these layers become appreciably less resistant to corrosion. This becomes very serious if, as may easily happen, the precipitated carbide and the depleted surface layers of the adjoining grains form a practically continuous network through the mass of the steel. The corrosion of these depleted layers destroys the cohesion between adjacent grains, producing the equivalent of intergranular cracks and may eventually transform a solid lump of steel into a mass of loosely adherent grains. The picture thus sketched looks rather serious; actually, there is not the slightest reason why it should ever occur in turbine blading because it can be eliminated entirely.

The trouble being due primarily to the precipitation of a carbide rich in chromium, the possibility of its occurrence will automatically be removed if the precipitation of the carbide can be prevented. The method generally adopted—though not the only one available, it may be noted—is to add to the steel metals such as titanium and columbium which have a very strong affinity for carbon; these metals combine preferentially with the small amounts of carbon which the steel contains and thus prevent the formation of chromium carbide and of the chromium-depleted grain boundary layers which are produced automatically when chromium carbide is precipitated. To be effective, sufficient of these special alloys must of course be added to the steel to combine with all the carbon it contains; in the case of titanium, the theoretical minimum is four times the carbon content and in the case of columbium eight times but in practice these minima are generally increased to 5 and 10 times respectively. Such steels are often known as "disintegration-proof" steels, "stabilised" steels or "weld-decay-free"* steels and they do not suffer from intergranular attack even if they have been purposely or accidentally heated for quite long periods at a dull red heat. They are the type which should be used for turbine blading and not the plain chromium-nickel austenitic steels.

The test almost invariably used in this country to determine whether a steel is "disintegration-proof" or not consists in heating a suitable piece of the steel for some stated time—generally 30 minutes, though 60 minutes is sometimes called for—at 650° C.†, allowing it to cool and then immersing it for 72 hours in a boiling 10 per cent. solution of sulphuric acid containing in addition 10 per cent. of copper sulphate; after this, the sample is bent through 90°. A satisfactory steel is not attacked by the acid mixture and bends perfectly satisfactorily; on the other hand, the acid reagent rapidly attacks a susceptible steel and even slight intergranular attack causes distinct cracks to appear on the tension surface of the bent test piece, whilst a bad sample may break in two. The test is therefore a severe one.

Intergranular corrosion results, of course, from two causes acting in sequence; first the wrong heat treatment which induces precipitation of chromium carbide, and thus causes the steel to become susceptible and, secondly, the corrosive attack which causes the susceptible material to be corroded away. If the subsequent corrosive attack is of a very mild nature, it may not be able to attack even the chromium-depleted bands of a susceptible steel. in such a case no untoward result would occur. Actually, experience has indicated that pure water or steam, up to the highest temperatures in use in power plant, is unlikely to cause attack to occur in even badly susceptible material. An interesting example of this occurred at the experimental high temperature steam plant at Detroit U.S.A. where steam was superheated to 1,000/1,100° F. (540/595° C.) and fed into a turbine. The superheater tubes and main steam pipe in this plant were not made of the "special" disintegration-proof type but of ordinary "18-8" steel and although they were correctly heat treated when built into the plant, they gradually became susceptible while in service owing to the prolonged heating at temperatures approaching 600° C. The author had the privilege of examining a length of the steam pipe after it had been in service for about 12 months; it was then in a very susceptible condition, copious precipitation of intergranular carbide having occurred, and it disintegrated badly when tested with the acid copper sulphate solution. In spite of this however, a careful examination of the inside of the tube failed to reveal the slightest evidence of intergranular attack having occurred during its period of service. The plant remained in operation for a period of about 5 years, and according to the detailed report on its operation‡ no evidence of intergranular attack was observed in any of the tubes.

It should be noted that the tubes were exposed mainly to dry superheated steam and that special precautions were taken in this installation to ensure that the boiler feed water was particularly pure; probably similar immunity would occur in other plants operated under the same conditions. There is evidence, however, which indicates that a different result would have been obtained had the steam been less pure, particularly if moisture had also been present. Tests have shown that sea water or a solution of sodium chloride will produce intergranular attack in susceptible material though at a very much slower rate than the acid copper sulphate reagent used for testing purposes. The crack shown in Fig. 1 occurred in shrouding strip, in a marine turbine, which had been made of ordinary (i.e *not* "disintegration-proof") austenitic steel of the "18-8" type; the strip had been wrongly heat treated during fabrication and was put into service in a very susceptible condition. There is little doubt that chloride contamination of the steam was the dominant factor which caused intergranular attack to occur and thus led to the failure of the strip. Had the "disintegration-proof" type of steel been used, the corrosion and cracking would not have occurred, and this example is mentioned to show the necessity for using the special "disintegration-proof" types of austenitic steels when turbine blading is in question. These disintegration-proof austenitic steels retain their strength and toughness after prolonged heating at all temperatures commonly used in steam practice.

FIG. 1.—*Intergranular corrosion cracks in wrongly treated "18-8" austenitic steel shrouding strip. This steel was not of the disintegration-proof type, and should not have been used for blading.*

Reference has been made to the relatively low yield point of austenitic steel. It is also ill-defined, the stress strain diagram showing a gradual change in curvature rather than a sharp bend; this is illustrated in the curves in Fig. 2 where typical stress-strain diagrams of stainless iron and of austenitic steel are reproduced. If a value indicative of the stress at which an austenitic steel yields plastically is desired in reception tests, it is far more satisfactory to determine the proof stress corresponding to some definite amount of plastic extension, e.g. 0·1 per cent. or 0·5 per cent.; such values have at least

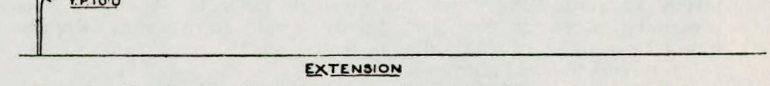

FIG. 2.—*Load extension diagrams of stainless iron (12/14% Cr.) and austenitic steel of the "18-8" type.*

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*This expression arose because one of the earliest and most troublesome manifestations of intergranular attack in austenitic steels was in connection with welds. There must perforce be a narrow band on each side of a welded joint in these steels where the steel reaches a dull red heat during welding and hence becomes susceptible to intergranular attack; the frequent failure of such bands during the early use of austenitic steels for welded equipment, particularly in the chemical industry, led to the use of the term "weld-decay" as a picturesque description of what actually appeared to happen at such joints after the plant had been in service for a shorter or longer period. When steels which did not behave in this way after welding were subsequently introduced they were naturally called "weld-decay-free" steels.

†This temperature is chosen because experience has shown that susceptibility to intergranular attack is produced very readily at 600°/700° C., much more readily in fact than at higher or lower temperatures.

‡"High Temperature Steam Experience at Detroit". Thompson and Van Duzen. "Combustion", November, 1933.

the merit of being reproducible. Some current specifications for austenitic steels of the disintegration-proof type—e.g. Air Ministry specification D.T.D. 176—call for a minimum proof stress (0·1 per cent.) of 15 tons per square inch and frequently the value obtained in bars or forgings is not much higher than this. The yield point as ordinarily determined corresponds approximately to the 0·5 per cent. proof stress and the latter is generally 4 or 5 tons per square inch higher than the 0·1 per cent. proof stress, a feature which is understandable from the shape of the stress strain diagram. Hence yield point values of about 20 tons per square inch may be recorded but the value for a given sample may be higher or lower than this, depending on the personal views of the inspector or operator as to what constitutes a yield point.

Whether a yield point of this order is adequate for turbine blading depends on working stresses and temperatures; probably in most cases it is. If it is considered desirable to have higher values it is possible to obtain them by either of two different methods, each of which however is subject to certain limitations. In the first place, the blading bar may be cold worked to some extent but, obviously, the possibility of doing this and the extent to which it may be carried out will depend on the shape and size of the blading and the method of producing it. As these austenitic steels work harden rapidly, the amount of cold deformation would need to be controlled within fairly close limits—an operation readily attained with simple sections such as wire, rod or strip, but presenting more difficulty when an irregular section such as blading is in question—otherwise the material may be hardened locally to an undesirable extent. In addition, the extra hardness of such work hardened material would be wholly or partially removed by operations such as welding, brazing or silver soldering which frequently form part of the ordinary methods of assembling blading and fixing it in position. Where cold rolled or cold drawn blading is in question, a higher yield point may also be obtained by adopting a somewhat lower softening temperature than usual after cold rolling or drawing; again, however, the method needs careful control otherwise variable results may be obtained.

The second method is to modify the composition of the steel so that its structure is no longer wholly austenitic but consists of a mixture of the two metallographical constituents austenite and ferrite, the latter constituting perhaps 25 per cent. of the mixture. It is quite easy to produce such a duplex structure by raising the chromium content of the steel to well over 20 per cent. or by adding 2 or 3 per cent. of alloys such as aluminum, silicon, molybdenum or titanium which favour the production of ferrite; in neither case must there be any increase in the amount of nickel as this metal acts strongly in the opposite direction. The yield points of steels having such a structure are appreciably higher than those of the completely austenitic steels, values of 25 tons per square inch being easily obtained. Unfortunately such steels have at least two marked disadvantages. In the first place, they are troublesome to hot work; the austenite and ferrite do not flow in the same way when they are deformed hot with the result that cracks and tears are very liable to form in the ferrite which, incidentally, is weaker than the austenite at forging heats. The average yield of sound material is appreciably lower than with completely austenitic steels, which means that their final cost is higher than the latter. In addition—and more important —these duplex steels, unlike the completely austenitic steels, are very liable to embrittle badly when held for long periods at l or moderately high steam temperatures; thus one such steel which was proposed for use as blading—a complex alloy of the titanium-treated "18-8" type but containing in addition about 1½ per cent. of aluminium, a very strong "ferrite former"—had its Izod impact value of about 50 ft. lb. in the normally softened condition, reduced to 10-12 ft. lb. by heating for 12 hours at 450° C. (842° F.) and the value was lowered still further by more prolonged heating. Incidentally, the fairly rapid rate of embrittlement at this temperature suggests that the steel in question would also embrittle at appreciably lower temperatures in periods well within the life of a modern turbine. It would seem dangerous to use such steels for turbine blading working at temperatures which cause embrittlement though they may have some advantages at lower temperatures, e.g. below about 600° F. If so used however, care must be taken that the blades are properly heat treated when fitted into the turbine and that processes incidental to blade fitting do not have a detrimental effect on the steel.

As regards coefficient of expansion, typical values for a completely austenitic "18-8" steel are given in Table 1. A duplex steel containing about 25 per cent. ferrite would have values slightly lower than those of the fully austenitic steel.

(c) *High Nickel Austenitic Steels.*

The properties of these steels are broadly similar to those of the "18-8" austenitic steels though there are some differences in detail. Like the "18-8" steels they can be hardened by cold work but not by any form of heat treatment. The rate at which they harden when deformed decreases as the ratio of nickel content to chromium content increases, but even with the highest nickel steels in use, the rate is still greater than that of stainless iron under similar conditions. The temperature required to soften these steels to a reasonable extent also falls as the Ni:Cr ratio increases and may be as low as 850/900° C. The differences may perhaps be illustrated by considering steels of the following approximate compositions:—

Mark.	*Carbon.*	*Chromium.*	*Nickel.*
A	·1/·2	25	20
B	·25/·35	11	36

The Ni:Cr ratio of steel A is higher than that of "18-8" steel but not greatly and the physical properties and heat treatment of steels of this class closely resemble those of the "18-8" steels. They can be adequately softened at 1,000°/1,050° C., and have then a tensile strength of 40/45 tons per square inch, and are very tough and ductile. Their proof stress and yield point values are of the same order as those of the "18-8" steels though probably somewhat higher than the latter. They are subject to intergranular corrosion in the same way as the "18-8" steels though possibly to a less extent; for complete immunity, they should be treated with titanium or columbium like the "18-8" steels.

Steels of type B can be reasonably softened at temperatures of 850°/900° C. Full softening is not thereby obtained—nor, incidentally, is this generally necessary or even desirable—because at such temperatures very little of the carbon which the steel contains is taken into solution; most of it exists as particles of carbide, probably chromium carbide. The actual shape and distribution of these carbide particles is of course important. Ideally they should be more or less rounded and should be evenly distributed through the ground mass of the austenite; in this condition, obtained by proper processing, they raise the yield point and tensile strength of the steel to some extent and although they also reduce ductility and toughness somewhat, these properties are still quite adequate. For example, blading bar so treated would have approximately the properties indicated below:—

Yield Point.	*Tensile Strength.*	*Elongation per cent.*	*Izod Impact.*
25	42	30	60

whereas softening at 1,000/1,100° C. would raise the elongation to 38 or 40 per cent. and the Izod value to 80 or 90 ft. lb., whilst dropping yield point and tensile strength to about 18 and 40 tons per square inch respectively.

From another point of view—that of freedom from intergranular corrosion—there is probably a considerable advantage in softening at 850°/900° C. When properly treated in this manner, the steel does not suffer from intergranular attack because the carbide which it contains has been precipitated in an innocuous manner. The individual particles of carbide may each be sheathed in a thin membrane of steel which contains less chromium than the rest but these membranes are not connected together and thus do not form a continuous path along which preferential attack could proceed through the mass of the steel; they might lead to pitting under severe corrosive conditions but would not cause intergranular breakdown. On the other hand, softening at 1,000/1,100° C. would take some of these carbide particles into solution and if the steel were subsequently reheated at a dull red heat, precipitation of some of this dissolved carbide could be expected at the grain boundaries, making the steel susceptible to intergranular attack. That such attack can occur is seen in Fig. 3 which represents the appearance of a test strip of a wrongly treated sample of the steel; the test strip had been exposed to steam at 400° C. (750° F.) for 168 hours and was then bent, with the result shown.

As regards rate of expansion when heated, the "25/20" steels behave very similarly to the "18-8" steels. The values for steels of the other group—10/12 per cent. Cr., 36 per cent. Ni.—are liable to vary to some extent with relatively small differences in composition, a feature perhaps not surprising as their nickel content is of the same order as that of the "Invar"

FIG. 3.—*Intergranular corrosion cracks in wrongly treated austenitic steel containing 0·35% Carbon, 11·5% Chromium, 35·5% Nickel, after exposure to steam at 400° C. for 168 hours. The cracks became visible on bending the strip.*

steels. Typical values for both types of steel are given in Table 1.

(d) *Monel Metal.*

Reference has already been made to the fact that this appears to be the one non-ferrous alloy which has been used to a considerable extent as blading in modern high temperature, high pressure turbines. This alloy normally contains about 70 per cent. nickel and 30 per cent. copper and its mechanical properties are roughly of the same order as those of the stainless irons and steels already described.

Mechanical properties of blading bar at ordinary temperatures depend on the method of preparation of the bar. Typical properties are given below for hot rolled rod, cold drawn rod and cold drawn rod subsequently tempered at 750° C., the latter treatment being intended to simulate the condition of cold drawn blading which has subsequently been silver soldered.

	Y.P.	M.S.	E%	Impact.
Hot rolled ...	15/18	34/38	35 min.	100 ft. lb.
Cold drawn ...	35/40	40/45	18% min.	75 do.
do., T. 5 mins. at 750° C.	17·5 min.	30/40	25% min.	90 do.

Monel metal has a coefficient of expansion about midway between those of stainless iron and austenitic steel, see Table 1.

Properties at High Steam Temperatures.

Engineering design for steam plant at temperatures up to about 800° F. (430° C.) is commonly based, in this country and probably in others, on tensile properties at atmospheric temperature or on yield point or limit of proportionality measurements at working temperature. This is not to be taken as indicating that creep does not occur in steels at 800° F. or thereabouts but that it is negligible in amount under those stresses, based on some agreed fraction of tensile properties, which engineering practice has approved. At still higher working temperatures, however, the maximum stresses at which creep is still negligible fall quite markedly and become the dominant factor on which design should be based. Apart altogether from the fact that in so doing the basis of design thereby changes from elastic to plastic properties—a condition of creep is of course the negation of elasticity—the selection of suitable working stresses presents other difficulties. The tensile strength of a material at atmospheric temperature has at least the merit of being a value which can be determined without great difficulty and which, within quite wide limits, is independent of the precise method of carrying out the test and whilst the same cannot be said of yield point determinations at temperatures higher than about 500° F., reasonably consistent values of proof stress (at e.g. 0·1 per cent. or 0·2 per cent. extension) or limit of proportionality can be obtained if a standard rate of loading and an agreed accuracy of measurement are adopted, though precisely what significance should be attached to such values obtained at temperatures at which "creep" admittedly occurs is another matter. By contrast, the determination of the "creep strength" of a steel or other metal at some particular temperature is not easy; it demands rather elaborate equipment, is generally very time-consuming and the values obtained are by no means independent of the methods used in obtaining them. This results largely from the fact that the rate at which a material extends or creeps under a steady stress at a particular temperature is not a constant quantity but changes as the period during which the steel is under stress increases. It is not intended to describe in detail the phenomenon of creep in metals—it would be outside the scope of this paper—but some short account of what occurs may perhaps increase the usefulness of the creep strength values to be quoted presently.

When changes in length of individual test pieces of a given steel, each held under a constant stress at some particular temperature, e.g. 900° F., are plotted against time in tests lasting 40 or 50 days, the curves obtained show that immediately after the preliminary extension which occurs when the stress is applied to the test piece, the latter creeps at a rate which is relatively high but which soon diminishes at first quickly and then more and more slowly, until it reaches an approximately constant value which is greater, the higher the stress on the test piece. This decrease in creep rate is due to the metal work-hardening as a result of plastic flow. At high stresses, it soon becomes evident that this apparently constant creep rate is really a minimum value and that sooner or later the rate increases again, the test piece necking and eventually fracturing. At lower stresses, however, the constant rate will barely have been attained within 40 days or so, but much longer tests at such stresses show that eventually the apparently constant rate reaches a minimum value and thereafter increases again, leading ultimately to the failure of the test piece. A survey of a large number of tests carried out in one laboratory in the U.S.A. indicated that stresses which produce an approximately constant creep rate of 10^{-7} in./in./hour are not likely to cause fracture within 100,000 hours; on the other hand, stresses producing creep rates of 10^{-6} in./in./hour were found to be of the same order as, or were greater than, those estimated to produce fracture within this period. Values obtained in this country point in the same direction. Incidentally it may be noted that the stresses producing creep rates respectively of 10^{-7} and 10^{-6} in./in./hour in a steel at some given temperature between 800° and 1,100° F. are frequently in the ratio of approximately 3 : 5.

It thus becomes evident that carefully conducted tests extending over prolonged periods are required in order to determine with any degree of completeness the behaviour of a given steel under different loads at high steam temperatures. Such tests have been carried out for a few materials at the N.P.L. where the stresses which, it is judged, would produce total strains of 0·1 and 0·5 per cent. in 100,000 hours at various temperatures have been worked out for mild steels and 0·5 per cent. molybdenum steels such as are used for steam pipes and for superheater tubes and headers; they have involved a large number of tests, some of them of several thousand hours duration, and even then have necessitated a considerable amount of extrapolation.

Most published data on creep strength values however refer to stresses which have produced certain selected rates of creep at specified periods of the tests. Different investigators have adopted different testing conditions and consequently values obtained by one investigator, although comparable among themselves are not always directly comparable with those of other investigators. Much of the data regarding stainless and heat resisting steels have been obtained by one or other of the methods described below:—

(a) Determination of the stresses producing rates of creep of the order 10^{-6} or 10^{-7} in./in./hour at the end of tests lasting about 40 days or more. In such tests, the approximately constant rate of creep, mentioned above, will have been reached or approached. This method has been used extensively at the N.P.L. (where the selected rate of creep is generally 10^{-5} in./in./day, equal to 4×10^{-7} in./in./hour) and by other investigators in this country and in the United States; in the latter country it may be noted, the selected rates of creep are generally either 10^{-6} or 10^{-7} in./in./hour. Frequently, however. no indication is given in the records of such tests of the total extension of the test piece during the test, a rather important omission because, at temperatures up to about 800° F. the initial extension of the test piece before it settles down to an almost steady and fairly slow rate of creep, may be quite considerable, often larger in fact than could be tolerated in practice. At such temperatures, working stresses will be limited by the amount of initial extension rather than by the subsequent slow rate of creep.

(b) Determination of the stresses producing certain selected rates of creep in tests lasting only a few hours, i.e. within the period during which the rate of creep is diminishing. The main purpose of such tests is to obtain a reasonable idea of creep properties from tests of short duration. Their value depends on the assumption that the shape of time-extension curves in creep tests on different metals and at different temperatures is reasonably constant, an assumption which unfortunately is not entirely correct. Nevertheless, when judiciously used, the values obtained from such tests are very valuable. Two particular tests of this type, of which a considerable number have been proposed, are worthy of note.

(1) *Hatfield "Time-Yield".*

The requirements of this particular test which was originated by the late Dr. Hatfield and has since been used by other investigators, are that the test piece must not extend more than 0·5 per cent. during the first 24 hours of the test and that during the subsequent 48 hours, creep must not occur at a rate greater than 10^{-6} in./in./hour. It will be apparent from what has been said above that the "time yield" value obtained will be determined at relatively low temperatures, probably up to 800° F. or thereabouts, by the amount of initial extension and at higher temperatures by the subsequent rate of creep.

(2) The standard creep test adopted by the Deutsche Verband fur die Material-prufungen der Technik (D.V.M.) and which determines the stress corresponding to a rate of creep of 10^{-5} in./in./hour between the 25th and 35th hours of the test.

It will be observed that the permissible rate of creep in the German test is ten times that in the Hatfield time-yield test; consequently creep strength values obtained by the German test for a given steel at some particular temperature are considerably higher than those from the English test. Actually, a comparison of available data suggests that at temperatures up to 1,000° F. or so the values obtained from the "time-yield" test are of the same order as those corresponding to a creep rate of 10^{-5} in./in./day at the end of a 40 days test—the testing conditions frequently adopted at the N.P.L.—and are somewhat higher than those corresponding to a rate of 10^{-7} in./in./hr.—a standard used frequently in U.S.A.—whereas the D.V.M. results are frequently twice or thrice as high as the "time-yield" results. The D.V.M. method is rarely, if ever, used in this country and the main purpose in mentioning it in this paper is to point out that the high values obtained by its use are largely a function of the method of test and do not necessarily indicate that the steels tested have superior creep strength.

"Time-yield" values for 12/14 per cent. chromium stainless irons and steels and for the austenitic steels of the "18-8" and "25-20" types generally fall within the limits of the cross-hatched bands B & A, respectively, in Fig. 4 and they indicate that these two types of steel have comparable strengths at 800° F., but the austenitic steels are considerably stronger than the others at higher temperatures. If it was deemed necessary, still greater strength at temperatures over 900° F. could be obtained by the addition of about 3 per cent. molybdenum to the "18-8" steels; their nickel content would also have to be raised, probably to 12 or 14 per cent., in order to preserve a completely austenitic structure. The increase in strength at 900-1,000° F. thus obtainable is of the order of 30 per cent.

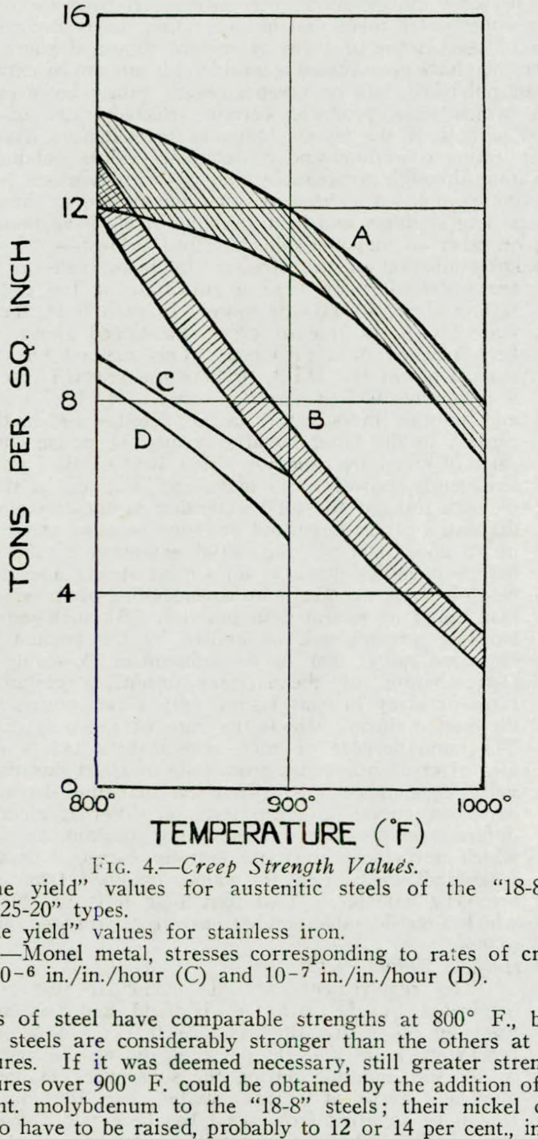

FIG. 4.—*Creep Strength Values.*

A.—"Time yield" values for austenitic steels of the "18-8" and "25-20" types.

B.—"Time yield" values for stainless iron.

C and D.—Monel metal, stresses corresponding to rates of creep of 10^{-6} in./in./hour (C) and 10^{-7} in./in./hour (D).

Few data are yet available regarding the strength of some of the other types of stainless steels at high steam temperatures. Stainless irons containing 16-18 per cent. chromium have rather lower values than the 12-14 per cent. chromium material, possibly by about 20 per cent. Steels of the S.80 type have similar values to the 12/14 per cent. chromium steels up to 850° F., but are slightly less strong than the latter at 900° F. As regards the austenitic steels containing about 11 per cent. chromium and 36 per cent. nickel, values obtained in this country at the rather high rate of creep of 10^{-5} in./in./hour indicate that they have about the same strength as stainless iron at 500° C. (932° F.) but are somewhat stronger than the latter at 450° C. (840° F.).

The author is not aware of any published "time-yield" values on Monel metal but the values plotted on curves C and D in Fig. 4 were obtained in tests lasting 1,000 hours or so, for stresses producing creep rates respectively of 10^{-6} and 10^{-7} in./in./hour.[*] It would appear from these results that Monel metal is weaker than stainless iron at 800° F. but the difference is much less at 900° F. and possibly is negligible at 1,000° F. It is considerably weaker at all these temperatures than the austenitic steels of the "18-8" and "25-20" types.

The question will doubtless arise as to what fraction of these creep strength values should be used as a basis of design. The matter is one primarily for the designer because much depends on the accuracy with which working stresses can be calculated and on the value of the factor of safety deemed necessary to cover various contingencies but, assuming that working stresses can be calculated with satisfying accuracy, the author would suggest that working stresses should not exceed 50/60 per cent. of the "time-yield" values and be further reduced by whatever "factor of safety" is deemed desirable to cover contingencies.

Finally, there is the question of fatigue and, unfortunately, few data are yet available concerning the effects of rapidly alternating stresses over long periods of time at temperatures well above atmospheric.

As is now well known, most steels, when tested at air temperature under alternating stresses with zero mean stress, have fatigue or endurance limits equal to 45-50 per cent. of their tensile strengths. Stainless steels behave in the same fashion except that in the case of the austenitic steels, the value may be slightly lower than 45 per cent.; it seems possible that this latter effect may be connected with the relatively high rate at which these steels work harden and which results for example in the value obtained for their tensile strength being higher than would be expected from their Brinell hardness values.

Fatigue tests on mild steel at temperatures above atmospheric[†] gave the following values for its fatigue limit at the temperatures indicated under alternating stresses with zero mean stress:—

Temperature	Fatigue limit.	
Air	±12·5 tons/sq. in.	
100° C	±12·3	do.
200° C.	±12·3	do.
300° C.	±16·0	do.
400° C.	±16·8	do.
500° C.	±11·7	do.

When plotted, these results suggest that the fatigue limit would reach a maximum value at about 360° C. These fatigue tests were taken on the basis usually adopted in tests on ferrous metals, namely that of 10^{7} alternations of stress and as they were run at 2,400 cycles per minute the time taken for this number of alternations would be about three days. This point is important because there would be little time for creep to occur and actually the creep strength values for the same steel, corresponding to a rate of creep of about 10^{-5} in./in./day were:—

Temperature ...	300°	400°	500° C.
Creep strength ...	26·0	14·5	4 to 5 tons/sq. in.

Thus the fatigue limits at the two higher temperatures were greater than the creep strength values. Had the fatigue tests been continued for much longer periods, it seems probable that the pieces tested at stresses higher than the creep strength would have ultimately failed by creep. One may perhaps deduce from this that at high steam temperatures, where creep strength becomes an important factor in design, fatigue failures are unlikely to occur as a result of alternating stresses if the maximum tensile stress in the cycle does not exceed the creep strength value; if it does exceed the latter value, failure may develop either through creep or by fatigue depending on circumstances.

These tests were carried out in air. In a turbine, there is the added complication of steam, wet or dry, and again there is little data available. Tests carried out by T. S. Fuller[‡] showed that when a jet of wet steam at 170° F. was directed on the test piece, fatigue limits were reduced, a result which might be expected as the test was really one of corrosion fatigue. Thus a 3·5 per cent. nickel steel hardened and tempered to give a tensile strength of 47 tons/sq. in. had its endurance limit at 10^{7} cycles reduced from ±20·5 to ±10·3 tons/sq. in.; when previously heat treated to give a tensile strength of 53 tons/sq. in., the fatigue value was reduced from ±26 to ±10·7 tons/sq. in. A sample of stainless iron (0·1 per cent. carbon 12·5 per cent. chromium) with a tensile strength of 45·5 tons/sq. in. similarly had its endurance limit reduced from ±27·2 to ±14·7 tons/sq. in. When however, the harder nickel steel and the stainless iron were tested

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[*] Dr. Pfeil, Mond Nickel Co., Ltd. (private communication).

[†] H. J. Tapsell, Iron and Steel Institute, 1928, I, p. 275.

[‡] "Endurance Properties of some well known steels in Steam", Trans. Amer. Soc. Steel Treating, XIX (1931), p. 97.

in an atmosphere of steam at the following temperatures and pressures, air being virtually excluded, the following results were obtained.

Conditions of Test.	Endurance Limits.	
	Nickel Steel.	Stainless Iron.
Air, Room Temperature	±26·0 tons/sq. in	±27·2 tons/sq. in.
Steam 212° F. 0lb. pressure ...	±26·0 " " "	±24·1 " " "
" 300° F. 60lb. " ...	±24·1 " " "	±24·5 " " "
" 356° F. 140lb. " ...	±28·5 " " "	±24·1 " " "
" 700° F. 220lb. " ...	±23·6 " " "	±24·1 " " "

These results—the most complete of the series reported in Fuller's paper—indicate that fatigue limits are not greatly reduced at moderate steam temperatures by contact with steam under the pressure and temperature conditions noted.

Fatigue failures in turbine blading are not unknown though probably comparatively rare. Those which the author has met have generally been in root fittings and have occurred in blading made of stainless iron and of the "18-8" and "12-36" chromium-nickel types of austenitic steels. In all cases, the fatigue cracks had originated at sharp re-entrant angles or at roughly machined surfaces in the root fitting. It is well known that both these undesirable features of machined surfaces lead to stress concentration and are apt to act as starting points for fatigue cracks; it cannot be too strongly emphasized that they should not be present in root fittings or, for that matter, in any other engineering parts which may be subjected during use to alternating or vibratory stress. Fig. 5 shows a typical fatigue crack which had its origin in a roughly machined surface on the side of the root fitting. Cracks in other similar blades originated at the sharp re-entrant angles.

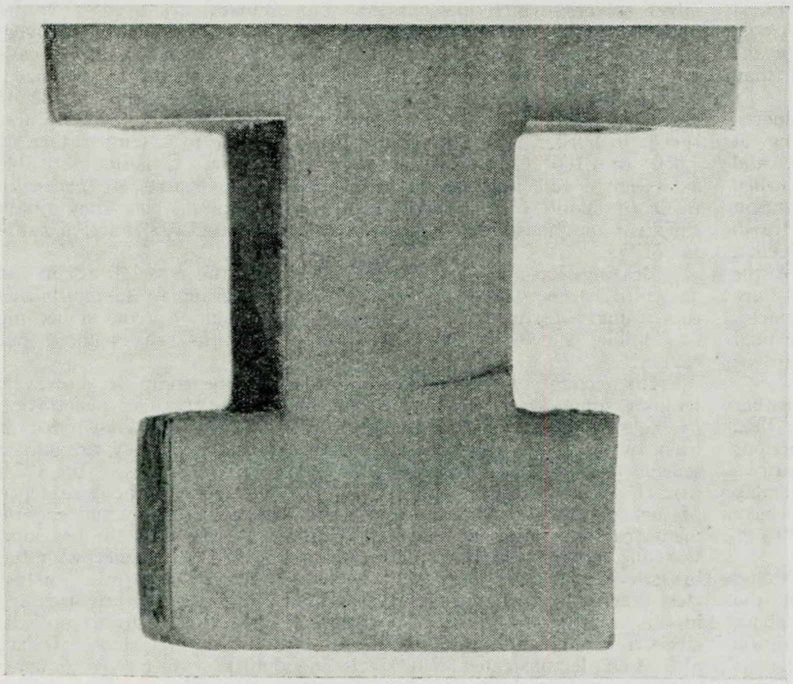

FIG. 5.—*Fatigue crack in root of austenitic steel blade; the crack had its origin in the roughly machined surface at the side of the root.*

The production of a fatigue crack indicates of course, that alternating or vibratory stresses have been produced in service. The admittedly rather meagre data on fatigue limits at temperatures above atmospheric, which have just been given, suggest however that such fatigue stresses have probably been somewhat high or, if superimposed on a static tension, have led to a rather high maximum tension in the stress cycle. Possibly it may be difficult to determine how such stresses have arisen or even to understand how they can have arisen but it is a matter which merits thorough investigation if future failures are to be avoided. Such investigations will be largely concerned with matters of design or of working conditions regarding which the author does not consider himself competent to express an opinion but he would draw attention to the necessity for accurate machining, within very close tolerances, of both the root and the groove into which it fits and also to the importance of taking into account the differences in rates of expansion between the materials used for blading and wheel or casing. In this connection it seems possible for example that a design of root fitting which has proved successful for blades made of stainless iron and the hardenable stainless steels may require some modification—at least as regards the tolerances to which it is machined or the type of "fit" in the groove—to make it equally satisfactory for austenitic steel blades or vice versa. Further reference to this matter is made in the next section.

Fabrication and Fitting of Blading.

Turning now to the question of the production of the blading and the methods of fixing it in position, the most satisfactory from the steelmaker's point of view would be to machine the blades from heat treated bars of the selected steel and to fasten them in position by purely mechanical means. The steelmaker could then supply the selected steel, heat treated to be in its best structural condition, with the comforting knowledge that the blading actually inserted in the turbine would not have had its properties adversely affected by the treatment it had received at the turbine maker's hands.

Blades of this type are generally integral with their roots and the machining of such blading from bars—even those of "rhubarb" sections which approximate to the overall size of the machined blade—is a rather costly and wasteful procedure. Wastage of material can be reduced by suitable forging, a method applied more particularly to blades of considerable size such as may be needed for the last few rows of large turbines. The necessity for machining all over still remains however and in this respect it may be noted that the austenitic steels as a whole are more difficult to machine than the stainless irons or hardenable stainless steels. The difference in machinability seems to be due primarily to the much greater rate at which the austenitic steels harden when they are cold worked. When machining these steels, it is of the utmost importance that tools should be sharp, held rigidly—i.e. without play or chatter—and should cut all the time they are up to the work; they should never be allowed to rub the steel surface instead of cutting it as the "rubbed" surfaces may be hardened to such an extent as to make further cutting difficult, if not impracticable.

As regards the production of hot rolled blading sections, the 12/14 per cent. chromium irons lead the way in ease of production but steels in all the groups which have been described are producible commercially in this manner although there may be difficulty with steels of very high nickel content which are apt to crack at sharp edges during hot rolling operations.

Accuracy of machining is a major factor in determining whether a mechanical root fitting behaves satisfactorily and in this connection it is important to note that the "fit" of a root fixture will alter with rise in temperature because most of the materials used for blading have coefficients of expansion which differ to a greater or less extent from the steels commonly used for rotors or casings. The latter steels expand somewhat faster than the stainless irons and the hardenable stainless steels but appreciably slower than the austenitic steels or Monel metal. As a result, the root of a blade made of stainless iron or the hardenable stainless steels will become less tight at high steam temperatures whereas roots in austenitic steels or Monel metal will become tighter and will tend to be deformed themselves or to expand the groove into which they are fitted or both. The extent to which these effects may occur is shown in Table 4 which gives the amounts (inches per inch) by which the expansion of the blading materials listed exceed that of a typical rotor steel at 750° F. and 900° F. and also the calculated stresses thereby set up on the assumption that the average moduli of elasticity at these two temperatures are 10,500 and 10,000 tons/sq. in. It should be noted that the values for the hardenable stainless steels will not differ appreciably from those of stainless iron.

Blading Material.	Difference in expansion (inches per inch).		Calculated Stress induced (tons/sq. in.).	
	750° F.	900° F.	750° F.	900° F.
Stainless Iron ...	−0·00057	−0·00077	—	—
Monel Metal ...	+0·00078	+0·00085	8·2	8·5
11% Cr. 36% Ni	+0·00087	+0·00106	9·15	10·6
25% Cr. 20% Ni.	+0·00129	+0·00156	13·6	15·6
18% Cr. 8% Ni.	+0·00184	+0·00220	19·3	22·0

At 900° F. some deformation will occur either in the blade root or the groove or both with blading of Monel metal and of all of the austenitic steels; the blade will remain tight while it is hot but will become less tight on cooling down. On the other hand, as noted above, stainless iron blades become less tight while they are hot. Whether these results of differential expansion will have any detrimental effect on the behaviour of the turbine blade during its working life would appear to depend on several factors but particularly on the design of the root fitting and the character of the machined "fit". It is important, however, that they should be borne in mind.

Much blading, particularly of the reaction type, is produced by cold rolling or drawing, methods by which the requisite smooth surface and cross section, within narrow limits of size, of a finished blade are obtained without the necessity for subsequent machining. Steel for such blading should be soft so that it can be cold worked with reasonable ease and in order that cold rolling or drawing may not be too long a process, it is sometimes desired—though much less frequently nowadays than ten or twenty years ago—that the hot rolled bar supplied for these operations shall approximate in size and shape to the finished article.

The relative ease of cold rolling or drawing these various stainless steels depends on their initial hardness and the rate at which they harden when cold worked. The stainless irons and the hardenable stainless steels are similar in the latter respect and hence, in their case, initial hardness is the determining factor; the stainless irons are the easiest to handle and the hardenable steels in the order of their hardness. Some firms who produce cold rolled or drawn blading sections dislike using material which cannot be softened below a tensile strength of about 35 tons per sq. inch, a figure which almost rules out anything harder than stainless iron. At the same time, cold rolled or drawn blading in both the S.80 type of steel and in the 12/14 per cent. chromium steels containing higher carbon than stainless iron has been successfully produced.

If irons and steels of these groups are hardened and tempered before cold rolling or drawing, the usual interstage softening at 700° C. (or 650° for the S.80 steels) reinstates the hardened and tempered condition and removes the effects of cold work. The rolled or drawn blading is sometimes finally softened in this manner; in other cases the final tempering is carried out when the blading is drawn or rolled nearly to size; it is then descaled and afterwards given a light pass to obtain the desired section and also to improve the finished surface. If the hot rolled bars of these irons or steels are supplied in the annealed condition, instead of hardened and tempered, in order to provide a softer raw material for cold working, the final heat treatment of the drawn blading should then consist of hardening and tempering.

The austenitic steels, though soft initially, work harden rather rapidly and hence generally require more interstage softenings than the stainless irons. They are producible in rolled or drawn sections without undue difficulty however; for example, many tons of drawn blading of impulse section with a long thin trailing edge, probably one of the most difficult sections to obtain by cold drawing, have been produced in "Weldanka" steel, a stabilised steel of the "18-8" type made by Brown Bayley's Steel Works, Ltd.

Brazing or hard soldering is frequently used when assembling and fitting blading in position. The solder may be either the ordinary copper-zinc alloy which requires a temperature of about 1,050° C. or a more complex mixture, containing silver in addition to copper and zinc, which may melt at as low a temperature as 700/800° C. The method may be employed to fasten together a group of blades and distance pieces to form a segment which can be more readily fitted into machined grooves in rotor or casing than the individual blades, or it may be used in attaching lacing wires or shrouding strip or the hard steel strips which are frequently fitted to the backs of the leading edges of blading in the l.p. stages to prevent erosion by condensed moisture. In the first case, the blades and distance pieces, suitably assembled together, are frequently immersed to the required depth—possibly an inch or an inch and a half—in a molten bath of the brazing alloy which is covered with a layer of flux and maintained at the requisite temperature; after a suitable time, they are withdrawn and cooled freely in the air. As a result, the blading is heated locally to the full temperature of the bath and from the end so heated to the unimmersed ends of the blades, there is a temperature gradient to a value not much above atmospheric. The effect of this heating, followed by air cooling, on the structure and properties of the steel will depend on the bath temperature and the type of steel but those parts of blades of the hardenable stainless steels and irons which reach temperatures above 800° C. will be hardened to an extent depending on their composition, mainly their carbon content, and the actual temperature attained. Thus the 12/14 per cent. chromium stainless irons, heated to 950° C. or over, may harden to about 300 Brinell whereas the higher carbon steels under the same conditions may reach a value of 450/500. The S.80 type of steel, containing not more than about 0·15 per cent. carbon, would probably reach a maximum value about 350. This induced hardness may be removed by tempering at 700° C. (650° C. for S.80 material) and such tempering is almost essential for the harder 12/14 per cent. chromium steels. The softer stainless irons (12/14 per cent. chromium) and S.80 steels—unless the latter are abnormally high in carbon—retain a considerable amount of ductility even when hardened and hence tempering may not be essential in their case. The effect on the 16/18 per cent. chromium stainless irons depends on their composition and properties. Those which contain no toughening element and are therefore notch brittle when cold and whose use the author does not recommend, would not harden to any marked extent but they would become noticeably less ductile and even subsequent tempering at 700° C. would not necessarily restore the original ductility. The special forms of these stainless irons which contain a toughening agent harden to some extent on cooling from 1,000/1,050° C. but the induced hardness is removed and the original ductility restored by tempering at 700° C. On the other hand, if a complex copper-silver-zinc brazing alloy melting at 700° C. or not much higher is used, the maximum temperature reached by the blading need not exceed 800° C. with the result that no appreciable hardening would be produced and subsequent tempering would not be necessary.

When lacing wires or shrouding strips are brazed to blading, using a blow pipe, the effects are broadly similar though some difference may be noted. For example, temperature control is much less certain and hence there is risk of local hardening even when silver solders, which melt at low temperatures, are used. On the other hand, the hardness produced on one blade is frequently removed, at least partially, by tempering effects which result from the spreading of the blow pipe flame whilst adjacent blades are being brazed.

Hard backing strips to prevent erosion are frequently made of high speed steel and the brazing treatment for attaching the strip also serves to harden it and must therefore be done at a temperature of 1,050° or 1,100° C. Subsequent tempering at 700° C. is impracticable as it would soften the hard strip. Blades so heated are generally made of stainless iron (12-14 per cent. chromium) and they retain sufficient toughness and ductility, when so treated, to function satisfactorily.

Brazing has no detrimental effect on the special forms of austenitic steels which do not develop intergranular susceptibility; the ordinary forms of these steels, which would of course become susceptible, should not be used for blading, as was pointed out earlier.

No account of brazing operations would be complete, however, without some reference to the danger of intergranular penetration of the steel by the molten brazing alloy. It has been known for at least twenty years that steels are liable to crack if they are under tension whilst in contact with molten brazing alloys. In 1924, Mr. H. M. Duncan of Messrs. C. A. Parsons reported the occurrence of such cracks in 3 per cent. and 5 per cent. nickel steels and experiments carried out by the late Dr Hatfield showed that the cracking was due to the steel being under tension whilst in contact with the brass. Three years later, Dr. Genders* showed that mild carbon steel cracked in a similar manner and further papers by investigators in this country and abroad have made it clear that many, if not all, steels, including austenitic steels, suffer in the same fashion. It has also been demonstrated that steels in contact with molten brazing alloys do not crack in the absence of tensile stress.

Cracks produced in this way are intergranular and they contain larger or smaller amounts of the brazing alloy. If the latter is present in ample quantity, the cracks are likely to be filled with brass, but, as Dr. Genders has shown, a very thin coating of brass on the steel surface is quite effective in producing cracks and, in such cases, the small amount of brass present appears to follow the apex of the crack as it extends through the steel, the already formed portion of the crack being then frequently filled with flux. A reference to Fig. 4 in his paper—a photomicrograph of the apex of such a crack—will show how small an amount of brass is effective in producing cracks.

It follows that care must be taken that blading is not under tension while it is actually in contact with molten brazing alloy. This is generally not difficult to arrange where single brazed joints are concerned, but may be more difficult when blade segments are produced by brazing root fittings, shrouding strip and intermediate lacing wires; unless the sequence of operations is arranged so that the blades are free to expand when heated, local stresses of consider-

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* Institute of Metals, XXXVII (1927), p. 215.

able magnitude can easily be set up. They may be more or less transient but if they develop while the blades are in contact with molten brass, cracking is very likely to occur. For the same reason, splashing of the brazing alloy on parts of a blade surface where no brazed joint is located should be avoided as it provides additional areas where cracking may occur. Fig. 6 shows three blades in a segment which had been badly splashed on the convex surfaces near the trailing edges; in the small area photographed, there are eight cracks easily visible, all of them connected with and due directly to the splashing of molten brass.

One further point; the intensity of the stresses set up in a blade by local heating will increase, other things being equal, with the coefficient of expansion of the material of which the blade is made. For this reason more care is required in dealing with the austenitic steels than with stainless irons and the hardenable stainless steels; these two latter types are, in fact, less liable to cause trouble in this way than ordinary mild steel.

It may not be out of place to point out that brazing, although a convenient means of making the numerous joints required in many forms of blading, has the range of its usefulness limited on account of the very rapid fall in its strength as temperature rises. Curves A and B in Fig. 7 are plotted from data obtained at the National Physical Laboratory regarding the creep strength of a rolled bar of 60:40 brass. Curve A refers to stresses producing the rate of creep—10^{-5} in./in./day—adopted as standard by that laboratory and shows the very low strength of the brass at temperatures above 450° F.; even if one allows the very rapid creep rate of 10^{-4} in./in./day (curve B) the creep strength value is equally low at 500° F.

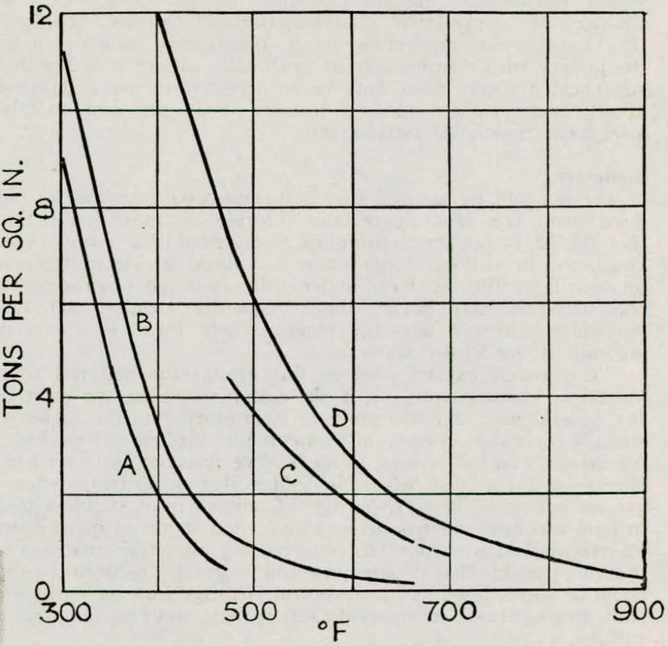

FIG. 7.—*Creep Strength Values.*
A and B.—"60 : 40" Brass; C and D.—Phosphor Bronze.
A and C.—Corresponding to a creep rate of 10^{-5} in./in./day.
B and D.— ,, ,, ,, 10^{-4} in./in./day.

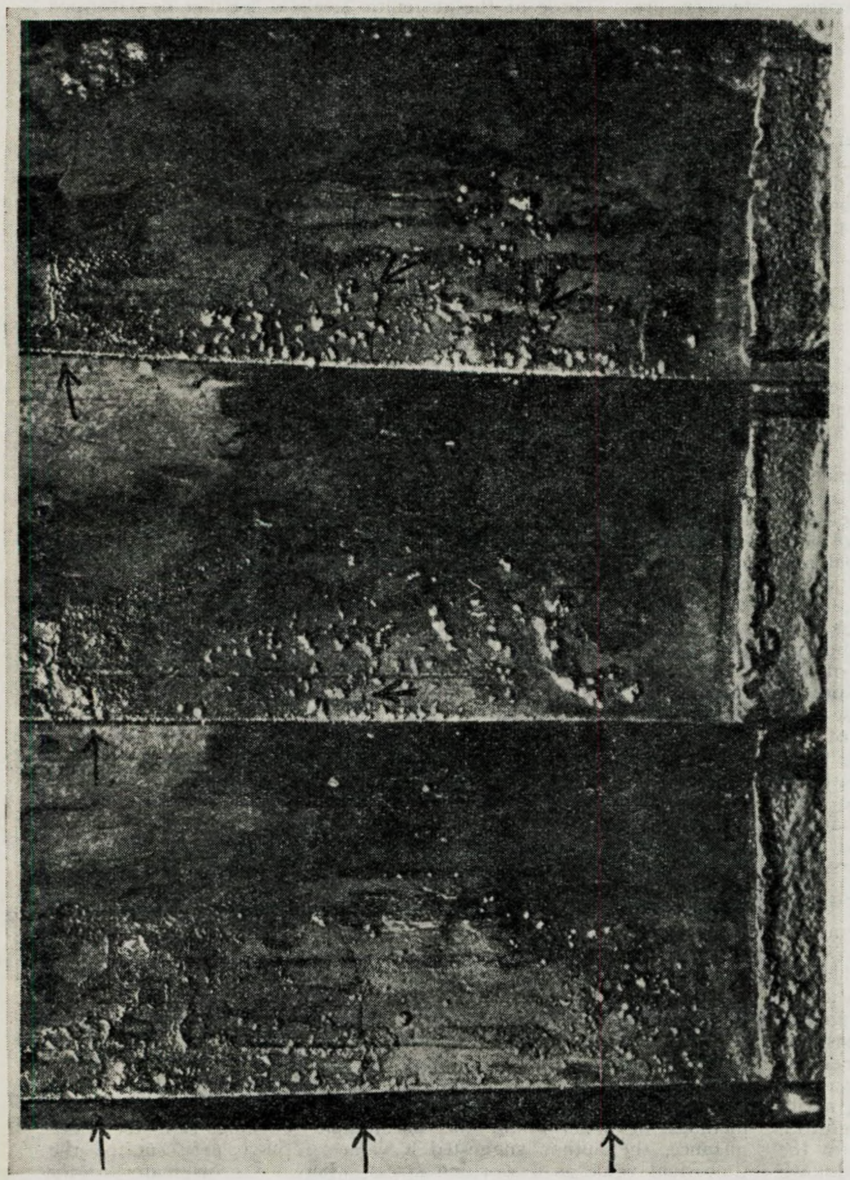

FIG. 6.—*Intergranular cracks in blading (austenitic steel) produced during brazing and due to splashing of the blades with brass.*

The vanes of nozzle boxes are sometimes inserted in position by a process generally known as "casting-in". The vanes, often formed from sheet which has been cut and bent to the required shape and contour, are inserted in their proper positions in the mould into which the metal forming the box—bronze or cast iron—is to be cast. During the operation, the vanes are heated above the melting point of the metal forming the box (1,075° C. or so for bronze and 1,150°/1,200° C. for cast iron) and afterwards they cool down more or less rapidly, depending on the size of the casting. If bronze is the metal used, considerations of rates of expansion and contraction as well as the possibility of electrolytic action suggest the austenitic steels as the most suitable material for the vanes; it should be remembered, however, that intergranular penetration occurs as readily with bronze as with brass if the steels are under tension whilst in contact with the molten alloy; experience indicates that the danger of cracking occurring is very much reduced if the steel vanes are coated with a thin film of some non-conducting medium which prevents instantaneous contact of the steel with the molten bronze when the latter is poured into the mould.

When cast iron is used for the nozzle box, vanes of stainless iron (12/14 per cent. chromium) or steels of the S.80 type (containing up to 0·15 per cent. carbon) are suitable for the vanes. Some diffusion of carbon may occur into the part of the vane actually embedded in the cast iron, but the projecting part retains sufficient ductility to function properly; such vanes have been used satisfactorily for a number of years.

At high steam temperatures, built-up constructions from forged steels are much to be preferred. Curves C and D in Fig. 7, for example, give values obtained at the National Physical Laboratory for the creep strength of phosphor bronze; curve C relates to stresses producing a rate of creep of 10^{-5} in./in./day and shows that the bronze retains very little strength at 700° F. whilst even if the very high creep rate of 10^{-4} in./in./day was considered allowable, the creep stress falls to a similar low value at 800° F.., as shown in curve D. For built-up constructions, the use of austenitic steel vanes in a box of non-austenitic steel is undesirable on account of differential expansion effects. If contamination of the steam with chlorides is liable to occur, the author would recommend the use of steel of the S.80 type. In the absence of appreciable contamination of steam, stainless iron (12/14 per cent. chromium) is a satisfactory choice; in fact if the turbine runs continuously or practically so and is fed with highly superheated steam, there may be no necessity to use a stainless steel at all; under such conditions, nozzles of 0·5 per cent. molybdenum steel have functioned satisfactorily.

Summary.

If it could be ensured that a turbine would always be fed with pure steam, free from appreciable chloride contamination, it is certain that the 12/14 per cent. chromium steels would have ample corrosion resistance to withstand operating conditions at steam temperatures up to at least 950° F. Even under ordinary usage when some chloride contamination may occur, they frequently function satisfactorily, particularly in low pressure stages where there is a considerable amount of condensed water.

The lowest carbon steel of this group—the material commonly known as stainless iron—is, in the author's opinion, the most suitable for general use; it is certainly to be preferred to the higher carbon steels of similar chromium content for blading which has to be brazed or "cast-in"—owing to its relative freedom from air hardening effects—and for that which is cold rolled or drawn, owing to its greater softness. It is frequently the only form of stainless steel used in land turbines and has given satisfaction in many marine turbines. Where marked corrosion has occurred, e.g. in certain marine turbines, it seems possible that its amount could be greatly reduced if conditions could be so modified as to prevent air leakage into the turbine during shut down periods when condensation may occur in all parts of the turbine.

Greater resistance to chloride attack can be obtained by raising chromium content to 16/18 per cent. or by adding about 36 per cent. nickel to the 12 per cent. chromium steel. Extensive corrosion tests show that these two classes of materials have about the same degree of resistance to chloride attack. Still greater resistance is obtained with austenitic steels containing 18 per cent. chromium and sufficient nickel to make them completely austenitic, generally not less than 8 per cent. These steels are probably sufficiently resistant to meet any conditions likely to occur in normally run turbines, but if still greater resistance is deemed desirable, it can be obtained by raising chromium and nickel contents to about 25 per cent. and 20 per cent. respectively, or by adding two or three per cent. molybdenum to the "18-8" variety.

Stainless irons containing 16-18 per cent. chromium and no appreciable amount of other alloy are not suitable, in the author's opinion, for turbine blading on the grounds of the notch brittleness. These irons, however, can be given a satisfactory degree of toughness by incorporating in their composition small amounts of certain other elements; such "toughened" irons have similar mechanical and physical properties to the 12/14 per cent. chromium stainless irons and merit serious consideration in turbines where chloride contamination is likely to occur, particularly for cold drawn or rolled blading where a soft material is advantageous. Alternatively, the higher tensile steels of the S.80 type (containing not less than 16 per cent. chromium and about 2 per cent. nickel) may be used, particularly for blading machined from bars or forgings; such blading has in fact, functioned satisfactorily for a number of years in turbines fed with contaminated steam.

At high steam temperatures, differences in rates of expansion must be taken into account. Root fittings of stainless irons and the hardenable stainless steels will become somewhat less tight at such temperatures. Those of the austenitic steels will either be deformed to some extent or will expand the groove into which they are fitted, or both; they will remain tight while hot but will tend to become less tight when they cool down again.

At temperatures of 900° F. and over, the "18-8" and "25-30" types of austenitic steel are considerably stronger than all the other turbine blading materials which have been described; they are also the most resistant of the stainless steels to chloride attack. If it were necessary, greater strength at these higher temperatures—and also greater resistance to chloride attack—could be obtained by a suitable addition of molybdenum to the austenitic steel.

Discussion.

On the **Chairman's** invitation, before the meeting was opened for discussion, **Mr. H. Bull**, a close colleague of the author, referred to the circumstances in which, owing to Mr. Monypenny's serious illness, **Mr. H. Allsop** had consented to read the paper and reply to the discussion.

Mr. F. J. Cowlin (Associate Member) said the author had rendered a service to the turbine industry generally in collating most of the available data regarding the various classes of stainless steel that were suitable for steam turbine blading. It would perhaps have been more interesting if similar data for 3-5 per cent. nickel steel and for some of the new non-ferrous materials now coming into vogue could have been included for purposes of comparison. It might not be generally realised that 3-5 per cent. nickel steel was still quite frequently used on land turbines, and particularly on industrial machines, where costs were important and where the cost of the blading represented an appreciable percentage of the total cost of the turbine. That class of steel was appreciably cheaper to use than any of the stainless steels, owing to the lower first cost of the material and the lower machining costs in producing blading from bar, and it had been found perfectly satisfactory up to a temperature of, say, 850° F., if the operating conditions on the turbine were properly controlled. Quite recently, for instance, he had had an opportunity of examining a turbine rotor fitted with nickel steel blading which had been in operation for some seventeen years, and the condition of the blading was almost as good as on the day when it was installed; there were no signs of corrosion on the steam faces of the blades, and the discharge edges—it was an impulse machine—were still true and sharp.

That raised the whole question of the reasons for blading corrosion, and in that connection the author suggested that one cause might be the cutting out of a number of the high-pressure stages of the machine on fluctuating loads, with the possibility of condensation occurring due to that practice. There were, of course, three methods of controlling the load of a steam turbine. The first was by throttle governing, and in that case it was obvious that the steam would be drier at partial loading than at full load, and therefore condensation definitely could not occur. He was referring to the high-pressure stages as mentioned in the paper; it was well known that one passed the saturation line in a condensing machine and got moisture at the low-pressure end. The second method of control was nozzle control, and in that case, although the amount of superheat was somewhat reduced at partial loads, it was hardly likely under modern conditions to be sufficiently so for the steam to become wet. The third method was by by-passing a number of stages for overload conditions, and in those circumstances it was still necessary to maintain appreciable steam flow through the by-pass stages for cooling purposes; if that was not done, the windage losses on the blades and wheels would give excessive temperatures on the rotor and the blading. The steam would consequently be appreciably drier throughout the machine with that method of control. In none of those cases, therefore, was the condensation referred to likely to occur.

He had been, fortunately or unfortunately, connected with turbine construction for some thirty years, and he was still convinced that blading corrosion, as distinct from erosion, was due to one of two causes, those causes being either ineffective drying out of the machine on shutting down and ineffective maintenance of that dry condition during the shut-down period or, alternatively, moisture leakage into the machine during shut-down periods, either from a humid atmosphere or, more frequently, from leaky steam valves. It was essential that during shut-down periods dry conditions should be maintained, and in some cases the expedient of the circulation of dry air during shut-down periods was resorted to in order to avoid blading corrosion, particularly where corrodible materials such as nickel steel were used. Leaky steam valves, of course, were entirely a maintenance problem. There was no doubt, in his opinion, that those two causes were responsible for more blading replacements than any others, and, if chlorides were present in the steam, even stainless iron suffered a similar fate to nickel steel, or even mild steel.

Turning to the properties given in the paper for materials at high temperatures, he felt somewhat disappointed that the Hatfield time-yield values had been used in comparing the various classes of steel. This was, at any rate in his opinion, the least useful criterion, as it did not give a designer any method of evaluating the total deformation at the end of the life period, which was what the designer was primarily concerned with, and it led to quite arbitrary methods of determining the permissible working stresses. For instance, the author suggested a value of 50-60 per cent. of the time-yield value as a working stress, whereas the originator of the time-yield value, Dr. Hatfield, suggested two-thirds, which was very much higher. The engineer generally required much more reliable data from metallurgists than was at present available before the design of high-temperature turbine components could be placed on a satisfactory basis.

Coming to the latter part of the paper, the author had been rather fortunate if he had encountered only rare cases of fatigue cracks in turbine blading, and those in the blade roots themselves. It could be quite categorically stated that all mechanical blade failures were due to fatigue, and they might occur at any part of the blade height, though they were usually through the blade section adjacent to the root, and not in the root. Such failures had become much more prevalent on the larger machines now in use, owing to the longer blades necessary and the denser fluid being used owing to the increases in steam pressures. The causes of those failures were quite well understood on a qualitative basis; the failures were due to impulses set up by inequalities in the steam flow in resonance with the natural frequencies of the blade or blade batches. All turbine designers had methods of dealing with this problem, but the quantitative analysis was extremely involved, introducing as it did not only the fatigue limit of the material but also its damping properties, the damping characteristics of the fixing and of the supporting wheel or rotor. In addition, the surface condition of the blading undoubtedly had some effect. In one case within his experience there could be no doubt whatever that caustic attack contributed largely to the initiation of fatigue cracks. The whole subject was extremely involved, and warranted much more attention on the part of research workers and metallurgists than it was receiving at the present time.

He would like Mr. Allsop to convey his thanks to the author for a very interesting paper. He hoped that the few remarks which he had made would induce both of them to continue their efforts to assist designers to produce even more reliable blading than was at present procurable, and so meet the demand for increased efficiencies by working at even higher temperatures than were now possible.

Dr. S. A. Main (Visitor), said he would like to compliment the author on his very fairly expressed and informative exposition of the facts regarding non-corroding blading materials. It was rather his judgment and assessment of their respective merits which he would question.

The burden of the paper seemed to be that there was a need for something better than stainless iron, but that a now well established type was too high in first cost because of its unnecessarily high content of nickel.

Whether that was the case or not depended it seemed to him on the value placed upon having complete reliance on the performance of the blading in all circumstances, as well as maintenance of efficiency of the turbines. Such reliability was important whether as regards safety on the high seas, rigid maintenance of sailing schedules or in the case of war vessels of readiness for any emergency.

Since the material in question was well known he trusted that convenient reference to it under its name of A.T.V.—or in this country Hecla A.T.V.—would not be out of place.

That this material went a long way towards achieving the ideal mentioned could not be questioned. Since its introduction twenty-five years ago the steady realisation of this fact had resulted in its ever-growing use until the figure of tonnage installed had become an impressive one. It would he hoped be instructive to go briefly into its origins.

The possibilities of the nickel chromium system of iron alloys were first investigated by the group of French scientists and technicians which included such famous names as Dumas and Guillaume, working in co-operation with Messrs. Commentry Fourchambault of Imphy. These investigations it was which led to—among others—the alloys known as Invar and Elinvar which have become so important to surveyors, instrument makers and in manufacture of watches. It was as the result of still further exploration of this group of alloys that M. Chevenard in conjunction with the firm mentioned, introduced A.T.V.*

For the introduction of all these steels a very high standard was demanded by their originators in relation to their proposed uses. In the case of A.T.V. complete stability—mechanically, chemically and under the influence of heat—was decided to be a *sine qua non.*

This complete stability was not to be found in the alloys such as those with 18 Cr. 25 Ni. or 25 Cr. 20 Ni., nor in any other alloy short of the composition represenetd by A.T.V., and these lesser alloys were therefore discarded.

From the point of view of its use in turbines, he questioned the author's description of "18/8" as a stably austenitic steel. It was not sufficient that under ideal conditions of preparation a steel should have an austenitic structure. For decorative uses or where no serious stresses or heating were involved that might be all very well. For use in turbines it was far from achieving—even in its improved types—the standards of stability demanded by the French investigators.

It might certainly be argued, but he thought not very successfully, that such stability was too dearly bought. The French engineer no more than his British confrère was willing to spend two pounds where one or even thirty shillings will do; yet in many cases his policy was to use A.T.V. for the whole of the blading of a turbine rather than for those selected portions where trouble was otherwise most likely to be experienced.

When the super-liner *Normandie* was being designed, this policy was similarly extended to the whole of the blades of its turbines, to the amount of 180,000 H.P. In the larger considerations of the deplorable fate of this fine vessel it is certainly unfortunate that it prevented the possibility of full justification of this bold decision. It may, however, be said that there was from the first never the slightest trouble or cause for anxiety in the working of the turbines. Could that be said of several of our own large ships where a similar course was not taken?

Many turbine builders in this country are it is true, now convinced of the real economy of using the best possible material. Experience has been mostly that such conviction has resulted from the many completely successful re-bladings with this steel in cases of failure.

The slides which he exhibited would he hoped demonstrate both the serious nature of the corrosion which had occurred through salty steam and the satisfactory manner in which it could be overcome by the use of the right steel.

Alloys of a less highly alloyed nature have far to go before their use could establish the same confidence—it would appear that some of those now put forward have had very little actual use at all. Their adoption must therefore be on the first cost rather than of proved merit.

With regard to the question of extra difficulties imposed on the turbine builder by the use of the austenitic steels, it is true that his indulgence must be requested in this respect. He would ask him to recognise that in most, if not all cases where special steels have been introduced into industry some modification of workshop technique had been found necessary. We should to-day be without our stainless steel cutlery if the Sheffield cutlers had not accommodated themselves to the more difficult technique in forging and heat treatment necessary. In another direction fabricated structures of the non-corrodible and heat resisting steels would not have got very far with the use of the old materials and technique of welding.

In all such cases the steel maker—with the help of the user—has shouldered the burden of ascertaining the suitable technique, and of giving advice accordingly. This is not least true of austenitic blading material.

As regards A.T.V. the suitable procedure in all necessary operations—machining, welding, brazing, riveting and others—is now well established and the information available to all. Where difficulty had been experienced it was usually in machining, but this had resolved itself once the correct procedure in cutting angles, speeds, cuts, feeds and lubricants had been appreciated. In one respect A.T.V. had a distinctive asset which had been found useful in that, unlike other austenitic steels, it is magnetic and so can be machined on magnetic chucks.

He was pleased to see reference had been made to the experimental turbine at Detroit because of the highly successful behaviour therein of its blading of A.T.V. Since the steam temperature had been allowed to reach at times as high as 1,100° F. this should assure engineers that a material is available which will meet the most advanced steam temperatures in view for some time to come.

With reference to the data in Tables 2 and 3 from corrosion tests, he rather doubted their value. In all such cases where pitting was concerned it was a question of how far the loss in weight represented general surface corrosion and how much was due to pitting. It was characteristic of A.T.V. and one of its merits, that such corrosion as occurred was mostly well distributed and so innocuous. Pitting where it occurred was shallow. Pitting in 18-8 on the other hand, though it might show little to the eye, was—due to the special proneness which this material had to what was known as shielding corrosion—liable to run deeply and dangerously in the manner of a worm-hole. This characteristic it possessed in common with plain chromium steel and iron.

Both loss in weight figures, which with steels in the non-corroding class was necessarily small, as well as a purely superficial examination of pitting, were therefore apt to give an erroneous impression of relative merits.

The best standard for the assessment of these materials would

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* Acier Turbine Vapeur.

seem to be that in no case which had come to his notice had corrosion of A.T.V. in service, even after many years, reached a stage such as to cause the slightest anxiety or even to affect materially the profile of the blade.

The author had rightly pointed out the importance of coefficient of expansion in questions of maintenance of root tightness. He might mention that in one particular case within his knowledge, the turbine designer had been sufficiently impressed by his experience in this respect, apart from more general considerations, to adopt A.T.V. in preference to 18-8. In view too of the normal requirement for as high a yield strength as possible, the latter material was rather deficient.

He gathered from the author's omission to mention a high damping capacity as among the desirable properties for a blading material that he did not attach any particular importance to it. So far as he himself, not being a turbine engineer, had been able to ascertain that was the view most generally held. It might be useful if members would give their opinions on this question.

By Correspondence.

Mr. A. Hoare, Wh.Ex. (Member): The writer is to be congratulated on the pains he has taken to present a difficult subject in terms readily understandable by the ordinary engineer, nevertheless, the seeker for information will find blading problems cannot be solved by one particular formula or another; the inevitable compromise has to be faced. War conditions disclosed many weaknesses in marine machinery construction, and turbine blading provided its quota of failures, the most pronounced of which were associated with corrosion of stainless iron used for reaction blades, work hardening of austenitic impulse blades, and the low fatigue resisting qualities of this material. The former has been very fully dealt with by the author, but one would judge from his comments that a non-corrosive stainless iron does not exist, and this seems to be borne out by a drive to substitute Monel metal for stainless iron for turbine blading when the seriousness of corrosive attack was appreciated. True, stress and temperature conditions did not hamper such a move, but there were certain manufacturing methods which favoured the continuance of stainless iron at that time.

High temperature and high stress in later designs, however, bring us again to seek a suitable ferrous alloy for reaction blading, and if it can be made non-corrosive or practically so, then so much the better. It would appear that the high chromium steel, Mark B, Table 3, might offer these qualities. In assessing the strength value of blade material which, of course, is subjected to centrifugal action, the specific weight of the material is not without significance; the addition of chromium in large percentages virtually increases the strength of the material because of this, quite apart from its metallurgical action. Nickel, on the other hand, has a reverse influence, and so has molybdenum.

Mention is made of work hardening qualities of austenitic steel, and it is well known that artificial work hardening by "pelting" the subject with steel balls, raises its fatigue resistance considerably. It seems that the metallurgist could profitably devote some time to investigating this avenue of improvement, since fatigue fracture of blading has caused quite a number of turbine failures. Marine practice here inclines to the method of securing shrouding by riveting over tenons machined on the blade tips which tenons engage accurately with holes punched in the shrouding. Even here, the work hardening of the material at the root of the tenon has been responsible for the shrouding being "shed" when in service, and it seems desirable that the tenon should only be riveted on the sides where it is a continuation of the blade back or face, the sides where a shoulder exists being left.

The author thinks successful blading material should be machinable without difficulty. Requirements are rather more exacting than that it must be capable of repetitive production by form tools, and of permitting a high degree of similarity between each piece; a fine surface finish is also essential.

In this country, welding of shrouding to turbine blades has not been practised to any great extent; the "weld decay" or intergranular attack resisting qualities are not, at the moment, of great importance. American turbine builders have, however, adopted this method of construction, and judging by some examples of their work which have reached this country, they have not escaped the trouble.

Mr. W. Mitchell: In the first place I consider that the subject has been dealt with in a very comprehensive and able manner and the information given in a very useful form for reference.

The data provided in respect of the behaviour of the several materials in service is valuable and generally in line with my own experience. Whilst it is most important to keep the system free from salt and air, particularly with installations operating under advanced steam conditions, there is always the possibility of traces of salt where sea water is the cooling medium. These conditions are, as stated by the author, aggravated if a turbine is standing idle —as in the case of auxiliary electric generating sets—and with twin screw turbo-electric installations operating at low power with one alternator only in use. In such cases it is very difficult to prevent a slight leakage of steam into the casings through the several steam connections.

A material not so sensitive to the presence of chlorides is desirable and, in this connection, I have read with interest the concluding paragraph of the summary. In this paragraph the author makes reference to the use of an austenitic steel containing molybdenum as having greater strength for high temperatures and, at the same time, greater resistance to chloride attack.

Referring to the intergranular penetration which occurs when "casting-in" austenitic steel vanes in cast steel or bronze nozzle plates, many years ago my firm experimented with different coatings of the vanes before "casting-in" and found that lamp black was quite effective in preventing intergranular penetration both with cast steel and bronze plates.

Mr. H. M. Vavra. The Ateliers de Construction Oerlikon have been using stainless iron (12/14% Cr.) for the past 20 years as standard blading material for all their turbines, which are of the impulse wheel type. So far excellent results have been reached and corrosion was very seldom noticed, even in power stations with sea or brackish water supply. Difficulties however were experienced on account of the riveting of the shrouds on to the blade tips. It could be noticed that microscopic cracks were likely to occur because of the hammering on to the blades. To prevent these cracks, which were found to be the reason of subsequent blade failures, the blades are nowadays inserted mechanically into the grooves without hammering, and to prevent undue shocks, the blade tips forming the rivets are electrically heated to red heat by means of a patented device with which, according to the size of the rivet, only about 4 to 8 light blows with a medium size hammer are necessary to produce a perfect connection between blades and shrouds. The blade itself, having a much bigger cross section than the rivet, is practically not heated at all, so that air hardening does not take place.

A very interesting test showed that almost any blade having a certain length can be destroyed by fixing it in a vice and hammering on to the blade root with a pneumatic hammer. Irrespective of the material, any blade is therefore liable to break if it is vibrating under the influence of a pulsating force. The pulsating force which is acting on the running blades on account of the backwash of the steamflow behind the stationary blades may be represented by the formula $F=c_1+c_2\cdot\sin(\omega t)$ i.e. by an ideal sine wave, whereby c_1 is a constant and c_1+c_2 the maximum force acting on the running blades. ω is equal to the circular frequency of the pulsating steam force, i.e. equal to $\frac{\pi\cdot n\cdot z}{30}$, if n is the speed of the wheel in r.p.m. and z the number of guide blades arranged along the circumference. It is obvious that the above formula is an approximative one. Actually the pulsating force between two guide vanes, depending on the execution of the guiding blades and the conditions of the steam flow, should be expressed by means of a sum of sine curves, i.e. $F=a_1+\Sigma a_1\cdot\sin(i\cdot\omega.t)$ whereby the values of i may vary between unity and infinity. According to the theory of forced vibrations any multiple of the circular frequency of the pulsating steam force may become dangerous to the blades or a combination of blades with the corresponding shrouding, if it clashes with the first or a higher order of their natural frequency of vibration.

From experience we know that very often this is the case with the medium pressure stages of multi-cylinder turbines of outputs between 20 and 50 mW. For these stages great care has to be taken in choosing the dimensions and the number of blades. The problem is rendered even more complex if varying speeds or long starting periods have to be taken into consideration. In these cases it is sometimes almost impossible to prevent resonance.

The problem of the damping capacities of the blade material is therefore of an outstanding importance. The damping capacity is the part of the energy, transmitted to the blades by the pulsating forces, which is transformed into heat by the internal friction of the blade material. The bigger the damping capacity the smaller the energy will be, which is producing the vibration. The amplitudes of the oscillation are therefore smaller at resonance, with corresponding reduced stresses. The damping characteristics can be measured by means of a torsion-pendulum instrument, as described by J. T. Norton in the "Review of Scientific Instruments", Vol. 10, March, 1939, pp. 77/81.

With high temperature steam or gas turbines it is preferable to use austenitic blade material of the kind described by the author in the present paper, which will be of great help for any turbine builder. Especially the indications given on the difference of expansion for the various steels are of great importance. The disadvantage of the ferritic stainless iron, which becomes less tight in the groove at high temperatures, is enlarged, because with a loosened grip the amount of heat flowing from the blade to the wheel is reduced, so that the temperature of the blade will be higher than that of a blade manufactured from austenitic steel.

Unfortunately the damping capacities of austenitic steels are considerably smaller than those of ferritic materials. From the article "Superposed Turbine Blade Research" by F. T. Hague in Mechanical Engineering, N.Y. (April, 1940, pp. 275/277) it can be gathered that the damping of 12 per cent. stainless iron is about 10 to 15 times bigger than that of austenitic material of the type "18-8" or "15-35". Hague found that 12 per cent. stainless iron had by far the best damping capacities, a fact which, perhaps only explained by recent tests, made this material so popular with all turbine builders.

It would be a great help if, for the austenitic steels described by the author in this paper, the damping capacities could be indicated, because on account of the considerably bigger creep strength values and the better corrosive resistance, beside the other advantages, it will be necessary in many cases to use bladings of the austenitic type of steel.

Mr. Allsop's Reply to the Discussion.

Mr. H. Allsop, in his verbal reply at the meeting, pointed out that while Dr. Main had shown pictures illustrating severe corrosion of stainless steel and stainless iron blades, which compared very badly with the high nickel material, Mr. Cowlin said he had seen some 3-5 per cent. nickel blades which had been in service for seventeen years and they were still in excellent condition. Stainless iron was at least more corrosion-resistant than 3-5 per cent. nickel steel, and if the latter was suitable for a general purpose turbine, stainless iron must have something in hand.

He did not think that it had been the author's intention to suggest that the high nickel steel to which Dr. Main referred was unsatisfactory as a turbine blading material; the author's object had been to show that there were other materials which possessed certain properties equal to those of the high nickel material, and in some respects, perhaps, even superior to it, while in other properties —the coefficient of expansion was a case in point—not quite so good. The author did not wish to imply that the 35 per cent. nickel steel was not a good turbine blading material, but, in so far as other, cheaper materials would do the job, the fact that the 35 per cent. nickel steel was a very expensive material ought not to be neglected. His firm had had an inquiry only a short time ago from a turbine builder for a cheaper material than the one to which Dr. Main referred, showing that the question of price did matter to the turbine maker. It would be interesting to know the conditions which the very badly corroded blades shown by Dr. Main had been under, because personally he had never seen anything so bad as those.

Dr. Main said that although he knew the names of the ships concerned, he did not feel that he had any authority to refer to them. They were, however, ships' turbines. He would be very glad to show them to Mr. Allsop.

Mr. Allsop, said that both he and the author recognised that in terms of loss of weight (which was probably not indicative of the extent of corrosion on a strictly numerical scale, but was broadly indicative) the high nickel steel had greater resistance to chloride attack than stainless iron. The author's initial premise was that in certain conditions stainless iron was not good enough, and something better was required; but the author also showed that the higher chromium austenitic type, the 18/8 (18 per cent. chromium, 8 per cent. nickel) alloy, had, if anything, better corrosion resistance than the higher nickel type. Dr. Main would probably agree that chromium content was the controlling factor in resistance to corrosion, and the 18/8 alloy contained approximately 50 per cent. more of that element than the alloy with 35 per cent. nickel and 12 per cent. chromium.

With regard to Mr. Cowlin's comments, the author did draw attention to that disability of the time-yield value to which Mr. Cowlin referred.

Mr. Cowlin said his point was that it was unfortunate that the author did not give the values of the material based on the first criterion rather than the time-yield. That was presumably because he had not been able to obtain the other values.

Mr. Allsop agreed, and remarked that it was a very long and laborious job to get the long-time test data.

Mr. Cowlin pointed out that unfortunately that was just the information which the engineer must have.

Mr. Allsop said that if engineers would wait a little longer, it would probably be possible to give it to them.

Mr. A. F. C. Timpson proposed, and **Mr. R. K. Craig** seconded, a vote of thanks to the author and to Mr. Allsop for presenting the paper and replying to the discussion.

The vote of thanks was carried with acclamation, and the proceedings then terminated.

Mr. Allsop's written Reply to the Discussion.

Mr. J. Cowlin. By its title, of course, the paper limits the material discussed to stainless irons and steels with some reference to the most important of the non-ferrous materials. It was felt that this material must be included because it is extensively used and it can rightfully be described as a stainless material even though not a stainless steel. Otherwise it was not intended to discuss the full range of materials as this would probably have resulted in a treatise too big for presentation as a single paper.

It is of great interest to have Mr. Cowlin's assurance that a non-stainless steel will give excellent service for long periods under properly controlled conditions; and his description of the method of controlling the loading of a turbine, with the consequent effect on the condensation in the machine, together with the potential source of corrosion are not only very interesting but very instructive. It would appear, however, that the conditions precluding or at least reducing corrosion are not always applied and, where the steam is not contaminated with chlorides, stainless iron appears to have adequate resistance to meet these circumstances, avoidable though they may be. Under certain conditions of steam contamination, even stainless iron appears lacking in resistance to corrosion and under such conditions the nickel steel would appear to have little chance of success.

Mr. Cowlin's disappointment that the properties of the materials at high temperatures are presented as Hatfield time yield values is appreciated, but comparable data on all the types of materials considered were available on that criterion only. The fact that the total extension of the test piece is an important factor to the designer is appreciated and commented upon in the paper.

Although the fatigue failures examined are stated to have occurred generally in root fittings, odd instances have come to our notice where this was not the case and in these instances the failure occurred through the blade adjacent to the root precisely as described by Mr. Cowlin. It is of interest to know that the necessary conditions of fatigue do exist and are appreciated and understood by the turbine engineers and it is agreed that in view of the explanation advanced the damping properties of the materials are of great significance.

Dr. S. A. Main. Dr. Main stresses the reliability and proved suitability of the high nickel type (35 per cent. nickel) material for blading purposes. It was not the intention of the paper to detract from the value of that material but to compare the various stainless steels available under several broad headings.

It appears fairly clear that service conditions in turbines differ very materially in respect of corrosion and probably there is a distinct difference between land and marine machines. In the former the operating and shut-down conditions have been shown to be important and where these are not controlled as well as is possible, stainless iron appears to meet them satisfactorily. On the other hand, in marine service there is no doubt that corrosive conditions may be too severe for stainless iron and Dr. Main's very impressive illustrations show very severe corrosion to that material, whereas the high nickel alloy was not corroded under the same conditions. This result is not at variance with the data presented in the paper but, had Dr. Main's illustrations included the 18/8 and 25/20 austenitic types instead of stainless iron, the comparison would have been very different, since all the evidence indicates that both these types of material have higher resistance to chloride attack than the 35 per cent. nickel alloy.

With respect to properties other than corrosion resistance, there are of course differences between the 35 per cent. nickel alloy and, some of the others considered, but this does not appear sufficient reason for the exclusion of the other materials.

Mr. A. Hoare. It is of interest that Mr. Hoare considers that blading problems cannot be solved by one particular formula and that compromise is inevitable. If for "formula" one may substitute "steel" the statement still appears to remain true since to quote the paper, "Improvement in some particular property of an alloy frequently leads to modifications not always desirable of other properties". This fact should be a stimulus to further investigation.

The term "stainless" should be viewed in correct perspective. If stainless is taken as meaning unattacked by any corroding medium, then there is no stainless iron but there is no stainless anything else either. Stainless iron is completely immune from attack by certain reagents which readily attack ordinary steel but it so happens that it is not completely immune from attack by certain salts which may be present in the steam fed into a turbine under certain circumstances. The steel referred to as mark B in Table 3 does possess greater resistance to chloride attack than stainless iron and its mechanical properties, both at ordinary and steam temperatures, are very similar to those of that material and it has in fact been used successfully in turbines fed with contaminated steam but it is unlikely to cold work and machine quite so readily as stainless iron.

The effect on specific weight of the various alloying elements is of interest and the effects in this respect of chromium and nickel are as described. The evidence in respect of molybdenum does not appear so well established.

The improvement in fatigue strength as a result of cold work is well known and there is no great difficulty in supplying work hardened blading in those sections which can be cold drawn or cold rolled. Such cold worked material would, of course, not rivet so readily at the shrouding strip and any fabrication processes involving brazing, etc., would destroy the cold work effect to an extent depending on the temperature reached. The question as to whether weld decay effects are or are not of importance depends on the conditions of service.

Mr. W. Mitchell. It is agreed that for certain operating conditions a material more resistant than stainless irons to chloride attack is desired. As shown in the paper, the 18/8 type austenitic chromium/nickel steels possess considerably enhanced resistance to this form of attack compared with stainless iron and it is considered that their resistance is probably adequate to meet any conditions likely to occur in a normally run turbine. It is probable, therefore, that the still greater resistance conferred on the 18/8 type by a molybdenum addition may not be required except under extreme conditions.

The successful use of a coating of lamp black for the prevention of intergranular penetration, both of cast steel and bronze during casting in, is noted with interest.

Mr. H. M. Vavra. It is noted with interest that the company with which Mr. Vavra is associated has had very considerable success with stainless iron blading, and that even where sea or brackish water has been encountered corrosion has not been a serious problem. This experience is in agreement with the opinion expressed in the paper that stainless iron is the most suitable material for general use.

The writer has not previously been aware of cracking of stainless iron during riveting of the shrouding and it is rather surprising that such difficulty should have been encountered. The overcoming of the difficulty by local heating of the rivet is of interest. The hardness developed in the stainless iron rivet will depend on the temperature reached; if the temperature did not exceed 750° C. no air hardening would occur. If this temperature is exceeded air hardening of the rivet may occur—to an extent depending on the composition and actual temperature—with the possibility of cracking due to the air hardening. It is evident, however, that the method has been successfully applied.

The importance of the damping properties of blade materials is appreciated and is amply substantiated by Mr. Vavra. With regard to damping capacity values the data available appears confused by the widely different values frequently obtained from steels of substantially the same composition, heat treated in the same way. Consequently it is considered that reliable values cannot be given, but whether the relative values for stainless iron are actually 10 to 15 times greater than those of the austenitic steels as is gathered from F. T. Hague's results (Mechanical Engineering, N.Y.—April, 1940, pp. 275/277) or the proportion is appreciably lower as indicated by Hatfield, Stanfield and Rotherham (Transactions—North East Coast Institution of Engineers and Shipbuilders, Vol. LVIII) it is generally agreed the damping capacity of the austenitic steels is distinctly lower than that of stainless iron.

MERCHANT NAVY TRAINING BOARD.

Report on Post-War Training of Officers and Ratings for the ENGINEROOM AND STOKEHOLD.

This Report has been prepared by the Engineer Section of the Training Board. This Section consists of shipowners' representatives (appointed by the Shipping Federation and The Employers' Association of the Port of Liverpool): representatives of sea-going personnel (appointed by the Amalgamated Engineering Union, the Marine Engineers' Association, the Officers' (Merchant Navy) Federation, including the Navigators' and Engineer Officers' Union on behalf of the Mercantile Marine Service Association, and the National Union of Seamen); and representatives of the Government Departments concerned (the Ministry of War Transport, the Ministry of Education and the Scottish Education Department).

The Report, which was prepared by the Engineer Section of the Merchant Navy Training Board, has been adopted by the Board as a whole.

It is the second Report of the Training Board: the first, on the training of Navigating Officers and Deck Ratings, was published in June, 1943.

I. INTRODUCTORY.

(1) This Report sets out our views on post-war training for the engine room and stokehold. It deals with both officers and ratings.

(2) We have received valuable assistance from many quarters, notably the 1939 Report by the Shipping Federation proposing a system of training engineer apprentices partly on shore and partly at sea; a Memorandum prepared by a technical Committee of Engineer Officers set up by the Navigators' and Engineer Officers' Union; two Reports from the Institute of Marine Engineers, one dealing with foreign practice and one setting out suggestions for improved training; and a statement and oral evidence from the late Sir George Preece, formerly Engineer-in-Chief of the Royal Navy.

II. TRAINING OF ENGINEER OFFICERS.

(3) So far as officers are concerned there is nothing spectacular or revolutionary in our recommendations. That is not because we have not considered fundamental alterations in the present system of training, and considered them carefully, but because we think that shore training is on the whole better than any alternative hitherto suggested, though the present system of shore training is capable of improvement and adaptation.

Under the present system as a general rule no one starts his qualifying sea service to become a certificated engineer officer unless he has had four years' training in an approved type of shore establishment. The regulations governing the type of workshop experience which is approved have been altered from time to time and the modifications have usually been determined by technical developments. During the course of the present war considerations of supply have not been ruled out in making temporary modifications in other parts of the examination regulations.

(4) This insistence on shore training has obvious advantages for the Shipping Industry. It taps the widest possible field for entrants; when a youth does go to sea he is of an age when he may be expected to know his own mind; and, on the whole, much better and more varied technical training can be given ashore than even in the best equipped ships. This is particularly true since the machinery of the best equipped and maintained ships is the least likely to break down or to require opening up at sea.

The main disadvantages are equally obvious. The Shipping Industry has no choice in the early selection of its engineers; a youth may give the sea only a very half-hearted trial without any real determination to make it a career. Moreover, there are engineers who go to sea merely to get a Ministry of War Transport Certificate because it is a useful qualification, highly prized ashore.

But the greatest potential disadvantage of the present system is that if shore industries find any difficulty in absorbing a reasonably steady flow of apprentice engineers, the effects will in due course be felt in shipping.

(5) These difficulties arose between the two wars. For many years shipbuilding and most sections of the Engineering Industry were working at much less than full capacity and the number of apprentices fell sharply and when, in 1936, these shore industries began to show signs of improvement there was still a four-year "time-lag" for shipping.

(6) It was this unsatisfactory supply position which, in 1939, led the Shipping Federation to publish a scheme (*attached in full as Appendix A*) under which the Shipping Industry would itself train some proportion of engineers instead of relying entirely upon shore industries.

The scheme was never intended to provide the majority of engineers on board ship. It was an alternative, additional to the ordinary shore workshop method. It provided for 4½ years' training. Engineer cadets, apprenticed to owners as in the deck department, were to spend their first year in theoretical and practical training in specially and adequately equipped shore engineering colleges; they were to spend their second, third and fourth years at sea in vessels recognised by the Board of Trade as suitably equipped for practical training and, during that period, they were to keep in touch with their shore colleges by correspondence courses. They were to finish up with six months' further attendance at a shore engineering college to prepare for their Second Class Certificate. The length of the apprenticeship and the allocation of time as between ship and shore were stated tentatively as proposals only. The degree of shore-cum-sea training embodied in the scheme would, it was also hoped, develop sea-mindedness and instil or develop officer qualities.

(7) Our task to-day, however, is different from that of the Shipping Federation in 1938. The problem now is not so much to increase the quantity of the entry but to increase its quality by suggesting the best technical training that can be given. It is, at least in the eyes of an important section of those who have given much thought to this matter, unfortunate that two objects, viz., the best form of technical training during apprenticeship and the development of a "sea bias" in the apprentice at an early and impressionable age, seem, at least at present, to be incompatible. We cannot work out any scheme of sea apprenticeship or combined "sandwich" arrangement which in our judgment might be expected to produce the same degree of engineering competence in the few years available as a training given wholly ashore. In this connection we wish to make it clear that there should be nothing static in any section of education, and we should deprecate anything said in this Report which might discourage useful experiments.

We have considered a draft scheme (***attached in full as** Appendix B*) prepared for the Section by the Navigators' and Engineer Officers' Union. Like the Shipping Federation Scheme referred to in paragraph 6, this scheme is meant only as an alternative method of training, and for limited numbers. It differs in important particulars from the Shipping Federation Scheme. It provides, broadly, for careful selection at the age of 16; for joint education for 9 months with future navigating officers and at the same pre-Sea Training School (the curriculum, however, being adapted for education in theoretical and practical engineering); followed by six months at sea in selected ships fitted out for the purpose; and completed thereafter by 33 months in approved workshops ashore with at least one day per week at a Day Technical School. One of the main objects of the scheme is to discover and to develop officer qualities and to make sure that from the earliest stage the navigating and engineering side work together—a most desirable object.

To be given any real chance of success, however, such a scheme would require modification in the Ministry of War Transport regulations.

We repeat our view that reasonable experiments, however revolutionary, should be supported, always provided they seem likely to produce competent engineers.

(8) We therefore recommend that the training of marine engineers should continue to be in workshops and technical colleges ashore. We are the more encouraged to do this because the day release system of the new Education Act will of itself make for better technical training.

(9) The representatives of the Officers' (Merchant Navy) Federation consider that it would be desirable—and indeed essential in any post-war Pool system—that all entrants who go to sea with a view to becoming engineer officers should be chosen from a list of applicants jointly selected by the Industry. This view is not shared by the Engineer Section of the Training Board as a whole.

(10) Our specific proposals for the improvement both of workshop practice and of technical training for apprentices are as follows:—

FOR ALL. We have two general suggestions to make:—

(i) *Workshop Service Record.* It is generally admitted that workshop experience varies enormously. It is impracticable to draw up a panel of approved workshops conforming to some minimum standard of requirements, although this would be very desirable. The best we can do in this direction is to recommend a standard and reasonably comprehensive form of workshop service testimonial. The sort of document we have in mind is attached. (*Appendix D*).

(ii) *Welding, etc.* We recommend the following additions should be made to the rules regulating qualifying workshop service:—

  (a) *Welding.* Full time up to a maximum of 3 months.

  (b) *Manufacture or repair of substantial electric plant.* Full time up to a maximum of 12 months.

FOR A LIMITED NUMBER OF SELECTED APPRENTICES. Each year a limited number of apprentices should be selected after completion of their third year of apprenticeship for a further two years' special training. These apprentices would receive the following practical and technical training:—

(i) *Before Selection.* Three years in works with not less than two years in the fitting and erecting shops. During this period part-time education should secure them an Ordinary National Certificate.

(ii) *After Selection.* Alternate periods of six months each full time attendance at a Marine Engineering College and at a Works, giving normally one year in each. The College training should lead to the Higher National Certificate, and the College Course should include Marine Engineering and Electrical Technology. The Works training should include experience in erection and in a drawing office. The College training for these selected apprentices should be associated as closely as possible with shipping in port. We regard this as of prime importance. Some (perhaps two) of the existing Technical Colleges would have to be adequately equipped to give the necessary training.

(11) The co-operation and agreement of the Engineering Industry ashore would be required both in order to secure the necessary workshop experience and the release of selected apprentices for full time attendance at a College, and because the period of workshop practice can only give the best results if the apprenticeship is planned, and spent in a Works dealing with the manufacture or repair of heavy machinery. In view of the interest of shore engineering in ship machinery and equipment we believe that this co-operation could be secured.

(12) The selection of suitable apprentices under this proposal would be made by a Board composed of both sides of the Shipping Industry. Candidates would offer themselves with a recommendation from their employers, and although a reasonable standard of general and technical education would be necessary to ensure the probability that the selected apprentice would benefit by special opportunities, we would hope that selection would not be determined primarily by skill in passing examinations. The apparent fitness of a candidate to be an officer and to succeed in that capacity at sea should, we suggest, be a prime factor in his selection.

(13) We must emphasize the fact that our proposal is experimental. It is, therefore, in the first instance at any rate, but an alternative to the present system. It depends for its success entirely on the goodwill of the appropriate shore establishments, but we are confident that with the right approach their goodwill would be readily secured and maintained.

(14) We have given no indication of the number of entries which we think might be expected under this special training scheme. If the number at the outset were, say, 100 per annum, which is one-fifth of the average total number of candidates who used to sit for the Second Class Certificate, and if the cost of tuition and subsistence where necessary during the total College period of one year were, say, £200 per candidate, the scheme would cost £20,000 per annum, plus cost of administration. Results alone would show whether the annual number chosen to launch the scheme should be increased or diminished.

(15) We strongly approve Marine Engineering Colleges maintaining a system of Correspondence Courses for the benefit of engineers and potential engineers at sea.

(16) We now come to the question of how suitable ratings can become certificated engineer officers. In theory it is possible, under the Ministry of War Transport Engineer Examination Regulations, for a candidate to submit sea service, in a prescribed ratio, as equivalent to the whole of the workshop service required, but in practice such candidatures are not put forward. We think, however, that something better is needed, and we recommend arrangements along the following lines:—

(i) Ratings should be selected after 4 years sea service in the engine-room, in the capacity of greasers or donkeymen, for further training extending over 2 years in a Marine Engineering College, after which, if qualifying, they would go to sea as engineer assistants. (See Part III). After service at sea for 18 months as engineer assistants they would be deemed eligible to sit for the Second Class Engineers Examination.

(ii) The selection from the ratings should be made in the first place by the chief engineer of the ship, and candidates would, after nomination by the superintendent of the company, be finally selected by a Central Selection Board representing the Industry and the Government Departments. Direct application by candidates to the Central Selection Board would not be prohibited.

(iii) The bases of selection would be:—

Capacity to qualify in the course in the time prescribed—and due regard would be paid to studies by Correspondence Courses by the rating prior to selection.

Officer-like qualities.

An age range of 23 to 30.

(iv) The College training would be for 2 years and would be partly practical and partly technical. Assuming a College week of 35 hours, it is recommended that 9 hours should be devoted to technical studies and 26 hours to workshop practice and technology. The technical studies would cover:—

English,

Mathematics, Engineering Science, Heat Engines and Engineering Drawing—(to Ordinary National Certificate standards. Qualification would exempt from Part (a) of the Second Class Examination).

The workshop practice would cover:—

Fitting,

Machine Tool Work,

Foundry Practice and

Welding.

Proficiency tests at 6-monthly intervals would be applied during the College Course. It is proposed to give the training in one or two existing Marine Engineering Colleges.

III. A NEW INTERMEDIATE GRADE.

(17) While it seemed to us right and proper to make the provisions in the foregoing paragraph which would enable ratings to become certificated engineer officers, we recognise that the number who will actually avail themselves of these facilities will be relatively small. Accordingly, the Section discussed in detail and at length the desirability and consequences of establishing an intermediate grade, which the National Union of Seamen most strongly advocate, in between the petty officer grade (e.g. Donkeyman) and the certificated engineer officer.

The principle of such an intermediate grade is opposed by the Marine Engineers Association and the Amalgamated Engineering Union, mainly on the grounds that it is a retrograde step which, in practice, might involve de-rating some who have already attained officer status. This view is developed more fully and attached as *Appendix C.* Accordingly it is to be understood that neither of these organisations is associated with any observations in favour of such a grade appearing in this section of our Report. The shipowners' representatives are fully in favour of an intermediate grade such as is strongly advocated by the National Union of Seamen.

In view of the division of opinion amongst the representative sections of the Industry on this matter, which the Government Department members of the Section regard as one for the National Maritime Board, the Government Department members took no part in the discussions on this part of the Report and are not committed one way or another so far as it is concerned.

(18) The Section realises that several consequences would follow the institution of an intermediate grade but, with the exception of those parties already mentioned, they are in favour of the principle in outline tor two main reasons:—

(a) that it would give a practical chance of promotion to ratings who could never hope to obtain a professional qualification but who have proved themselves competent and reliable;

(b) the feeling which is known to exist, and to exist very strongly, amongst senior Engineer Officers on board ship that the title "officer" is far too lightly bestowed and that this is detracting from the status of ships' engineers as a whole.

(19) We appreciate that the engine room is not the only place where this problem exists and that as important problems of selection, remuneration, manning and accommodation are involved it is a matter for final determination by the National Maritime Board. But, in order to assist the National Maritime Board, the Section, subject to the exceptions and reservations named, puts forward the following comments.

(a) It is considered that an intermediate grade is desirable. The problem is to find a practicable solution.

(b) It is impracticable to confine the status of officer to engineers with certificates because this would cut out many uncertificated men who are, and have for long been, in charge of a watch.

(c) The need for an intermediate grade is most acute in the largest types of ship and becomes less acute as the total engineroom complements become smaller. But this does not mean that the need is confined to the largest type of vessel. It means only that any solution must be one which does not adversely affect the smaller ships.

(d) The same uncertificated engineer might have the choice of being an engineer officer (uncertificated) in a smaller ship, or an "intermediate grade" in a larger. The grade would be filled by two categories—the young man prior to taking his certificate, and the older man, perhaps a steady rating who, however good at his job, could never hope to take his certificate.

(e) We have considered various descriptions of the grade we have in mind, and the description is important because feelings are easily roused on this subject. "Mechanic", "assistant engineer", "engineroom artificer"—all have their advocates, but on the whole perhaps the best title is "engineer assistant".

(f) It is believed that such a grade of "engineer assistant" is practicable and that its institution would be beneficial equally in improving the status of engineer officers and in widening the field of advancement open to ratings. They could then aspire to be engineer officers in smaller ships, or rise, with certificates, to the top as engineer officers in any ship.

IV. TRAINING OF RATINGS.

(20) The Law stipulates that no one can go to sea as a trimmer or stoker under the age of 18. For that reason we have no problem under the compulsory sections of the new Education Act.

(21) Before the war it was usual for ratings to enter the engineroom or stokehold without any preliminary training. Although the transfer to oil fuel, however, meant a cleaner job, and attracted better men, it must also be recognised that some were not of the best type.

As the war developed it was felt essential to build more and more coal burners as part of our reply to the U-boat and air menace. But coal-burning firemen were becoming rarer. Accordingly the Shipping Federation started an experiment—the first of its kind—a special School for training coal-burning firemen. The course was a short one—two weeks' training as a fireman, including muscular development as well as an elementary knowledge of the purpose of good firing, followed by one week's training in seamanship.

The results were so satisfactory that five such schools were established in the country—Cardiff, Glasgow, Liverpool, London and Newcastle, all run under the aegis of the National Sea Training Schools Committee on which the Shipping Federation, the National Union of Seamen, the Ministry of War Transport and the Ministry of Education are represented.

The Course lasts for three weeks. During the first two, trainees receive instruction from engineer officers on boilers and engines, the principles of combustion and the correct method of firing the different types of coal and the elimination of smoke. Trainees are also given practical stokehold work. They learn how to use all firing implements. They also receive special physical training designed gradually to fit them for the heavy work entailed. The seamanship instruction in the third week includes the use of various types of life-saving equipment, launching of lifeboats and boat pulling.

(22) We strongly recommend that training arrangements for coal-burning firemen should be developed from war-time experience and we consider that it would be desirable to extend them to oil-burning firemen.

We also strongly recommend that everyone who goes to sea either in the engineroom or the stokehold, whether as officer, engineer assistant or rating, should undergo the course for the lifeboatman's efficiency certificate.

V. FINANCE.

(23) It is no more possible now to go into the details of finance than it was when the Deck Section Reports were prepared. The Government and the Industry will, of course, have to play their part.

As regards the Government, it seems clear that it will make a considerable contribution in financing technical education for shore industries.

As regards the Industry, it will naturally want to know what the Government is doing for other industries as well as see in broad outline what the training commitments as a whole will be. The Deck Section Reports have already been published, but until the Catering Section submits its Report the total commitments will not be known. This Report contains our suggestions for the engineroom and in this connection we should say that we have had a very welcome offer by the National Union of Seamen to provide scholarships under par. (16) of the Report. The scholarship idea might perhaps commend itself to the Industry also—not only for ratings but for engineer entrants. But the first question to decide is whether the proposals are likely to improve the quality of engineer officers at sea. If, by so doing, they contribute towards the competitive position of British shipping, we do not doubt that the incidence of cost can be satisfactorily settled between the parties most concerned.

But whatever the final allocation of cost may be we attach importance to two principles:—

(a) Within the limits of the scheme as a whole, lack of parental funds should be no bar to training the able youth; and

(b) training should not be given for nothing if the youth or his parents can afford to make a contribution.

31st October, 1945.

APPENDIX A.

THE SHIPPING FEDERATION.

ENGINEER OFFICERS—ALTERNATIVE METHOD OF TRAINING.

Proposals of Engineer Superintendents Central Advisory Committee.

(1) In the opinion of the Engineer Superintendents Central Advisory Committee of the Federation, the time has come when a drastic change should be made in the methods of recruiting and training sea-going engineer officers. The Committee considers that in future the shipping industry should train some engineers for itself instead of relying entirely upon shore industries. This memorandum outlines practical proposals.

(2) The shortage of sea-going engineers has caused great anxiety for several years. The early training and supply of engineers are at present outside the control of shipping. Young men are apprenticed as shore engineers, and employment at sea is regarded—if it occurs to them at all—as only one of many alternatives. During the prolonged slump in shore engineering, apprentices for the shore workshops either did not come forward or were not allowed to come forward, and when shipping recovery did come, it was accompanied by intense rearmament, which compelled shore industries to retain every man they possibly could.

(3) The shortage of engineer officers is international and is not peculiar to this country.

(4) Your Committee reported fully on the shortage in March, 1936, and, as a result, many steps were taken to alleviate it, viz:—

(a) *Improved conditions of service,* e.g., greatly increased pay, institution of a general pension scheme, more time off in port, and supply of bed and bedding.

(b) *Amendment of Board of Trade Examination Regulations.* The Board of Trade has given effect to most of your Committee's recommendations, and in particular, has provided that candidates who have certain national certificates will be completely exempt from any further examination in theory, and that shore workshop experience need not be limited to marine engine construction.

(c) *Establishment of an Employment Register* in all Federation offices, which in 2½ years has already placed over 1,700 engineers.

The effect of (b) cannot yet be estimated, but it is fair to assume that the measures under (a) have at least been partly responsible for the increase in the number of Board of Trade second class certificates from 422 in 1935 to 481 in 1937 and 470 (estimated) in 1938. Although entries into the industry are increasing, however, the drain is also increasing due mainly to the intensive recruitments for the Royal Navy. The stagnation in mercantile shipbuilding is also diminishing the number of apprentices in marine engine works.

The shortage, therefore, still continues—despite the laying up of ships—and the Institute of Marine Engineers has recently recorded its view that "the type of personnel offering as junior engineers has, in any case, been of a much lower standard of training and technical ability than that hitherto available".

(5) Drastic steps are being taken elsewhere. Germany has reduced the apprenticeship of shore engineers from 4 to 3 years; the Royal Navy has adopted a compromise form of entry by accepting youths with two years' shore training. The Merchant Navy also must strike out on a new line if suitable engineers are to be found and retained.

(6) The proposals in this memorandum are only in broad outline, and any scheme based on them would only be workable after full consultation with the Board of Trade, Engineering Colleges, the Intitute of Marine Engineers, and the Engineer Officers' Societies. They are, however, suggested as a basis for discussion with these bodies.

The proposals are for an *additional* method of entry. It is not suggested that the present method of shore workshop training should be abolished.

(7) The essential assumptions underlying the proposals are:—

(a) That it should be open to a boy to start out with the intention of making the career of sea-going engineer officer his definite profession.

(b) That in many vessels there is an adequate opportunity of training young men on board in handling tools and in marine engine maintenance work. Indeed, it is certain that a young man can receive a better all round early training in the right type of ship than in many of the workshops ashore.

(8) Under the suggested scheme of substituting training at sea for training ashore a boy could be apprenticed to a shipowner, in exactly the same way as a navigating apprentice, from the outset of his career.

(9) Under the proposed scheme, selected boys would be accepted as engineer cadets or apprentices between the ages of 16 and 18, and indentured to a shipping company. They should be of good physique and have reached a reasonable educational standard, probably that of the School Certificate or its equivalent.

The indentures should provide for 4½ years' training. The first year and the last six months would be spent ashore, and the second, third and fourth years at sea as follows:—

1st year.	Theoretical and Practical Training in shore engineering college.
2nd year. 3rd year. 4th year.	At sea on vessels recognised by Board of Trade as suitably equipped for practical training. During this period the apprentices would keep in touch with their shore colleges by correspondence courses.
Next ½ year.	Further attendance at shore engineering college to prepare for Board of Trade Second-Class Certificate.

(10) *Shore Training.* The two periods of shore training would be spent at engineering colleges approved for the purpose by the Board of Trade, where both technical instruction and manual training in laboratory or workshop would be given. During a long vacation some apprentices might be enabled to go on a short voyage for preliminary sea experience.

It might be possible to set up an engineering establishment exclusively for the training of Merchant Navy marine engineers, as is done for the Royal Navy at Keyham. The financial problems, however, appear to be formidable and, for the present at any rate, it would appear to be advisable to work through existing engineering colleges.

(11) *Training on Board.* The Board of Trade would have to be satisfied that the ships on which the engineer apprentices are carried were technically suitable for training apprentices. This could be done in individual cases, or by compliance with general rules regarding type of workshop equipment, size of engines, etc.

Engineer apprentices should be additional to the normal complement and should be carried only on ships having four engineers and upwards, the proportion being one apprentice on a ship carrying four engineer officers, an additional apprentice being permissible for each engineer officer carried in addition to four—with a maximum of three apprentices, except on very large ships. Your Committee appreciates that this restricts the scope of the scheme, but (1) the training would benefit the Mercantile Marine as a whole, and (2) smaller ships could still train engineers after a shore apprenticeship, as at present.

(12) *Cost.* During the first year's shore training it is suggested that the shipowner to whom the apprentice is indentured would bear the cost of the tuition fees only (estimated at £12), and the parents would be responsible for board and lodging. In cases where it was impossible for the apprentice to live at home, arrangements could be made for accommodation at a reasonable cost to the parents. Penalties

would have to be provided for breach of indentures and, in particular, for refund of the first year's tuition fees if the breach was by the apprentice.

During the second, third and fourth years, which are to be spent at sea, the apprentice should be paid wages of £10, £12 and £18 per annum respectively. During the last six months ashore preparing for his certificate the apprentice should receive £20 as wages, and, in addition, his board and lodging at, say, 25s. per week, and tuition fees of, say, £6, would be paid by the shipowner. The apprentices would themselves bear the cost of the correspondence courses with the shore colleges, or this might be merged in the inclusive fee for shore training. It might be possible to negotiate with the Ministry of Labour to set off Unemployment Benefit against the board and lodging item.

The cost suggested for the shipowner would therefore be approximately as follows :—

1st year.	2nd year.	3rd year.	4th year.
£12	£10	£12	£18
tuition fees.	wages.	wages.	wages.

Last 6 months.

£20	wages.
£32 10s.	board and lodging.
£6	tuition fees.
£58 10s.	

On this basis, the shipowner would pay £110 10s. 9d., i.e., approximately 14s. 6d. per week spread over the three years of sea training (plus cost of food on board ship).

(13) A National Board, which would supervise the shore training and the scheme generally would have to be established, and should consist of representatives of the Shipowners, the Government Departments concerned, the Institute of Marine Engineers, the Engineering Colleges and the Engineer Officers' Societies. The expenses of the Board would not be large, and could be met by contributions (say 10s. 6d. per annum per apprentice) from the shipowners engaging the apprentices, with perhaps a grant from the Federation and the Board of Education, as is the case for the corresponding and very successful Training Board for Navigating Officers.

(14) It is a condition of the success of the scheme that the Board of Trade should be prepared to recognise the training contemplated as qualifying an apprentice to sit for his Second-Class Certificate. Admittedly, it is a revolutionary change from present methods, but your Committee—as practical men—are satisfied that, with the safeguards they have suggested of the college and ship training being of an approved standard, the scheme is justified on merits.

(15) Is the scheme sufficiently attractive (a) to owners and (b) to boys and their parents and teachers? In this connection, the following points should be considered :—

(i) After the first year the apprentice need not be any financial burden to his parents.
(ii) The apprentice would know that he can be a certificated officer at the end of 4½ years, instead of the present 5½ years.
(iii) The shipping industry would have a supply of engineer officers who look to the sea and not the land as the calling for which they have been trained.

14th March, 1939.

Appendix B.

THE OFFICERS' (MERCHANT NAVY) FEDERATION.

A Memorandum submitted by the Navigators & Engineer Officers Union to the Merchant Navy Training Board.

POST-WAR TRAINING OF OFFICERS FOR THE ENGINE-ROOM DEPARTMENT.

(1) It is assumed that the function of the Merchant Navy Training Board is to outline a scheme or schemes for the training of ships' officers in all departments, and this memorandum outlines our proposals for the post-war training for officers in the engine-room department.

(2) We consider that officer-like qualities should be developed in the future engineer officer in ways comparable to those envisaged in the navigating officers' training scheme; in other words, it is felt that a scheme of training engineer officers should not only aim to develop technical knowledge and craftsmanship but also the qualities required by an executive officer.

(3) It is considered that fundamental changes from present practice are necessary if the desired results are to be obtained, as the highest degree of efficiency will be required from all officers in the post-war years if Britain is to maintain her position as a leading maritime country.

(4) The present system—or lack of system—has revealed many weaknesses; unsuitable types have obtained officer status, unskilled people have been admitted as engineer officers. The lack of uniformity in the training received during periods of apprenticeship has led to unnecessary variations in the standard of efficiency even among time-served apprentices.

(5) The regulations governing workshop experience have been reviewed and varied from time to time, but it is considered that they are still unsatisfactory, with the result that there is no reasonable guarantee of efficiency or of the production of a uniformly good type of ship's officer.

(6) The field of recruitment, in our opinion, has been too wide; insufficient attention has been given to control and selection of entry, with the result that people quite unsuited for sea life are able to acquire officer status, and within a short period of time to revert to repair shops or other forms of shore employment.

(7) It is felt that the Industry must determine as far as possible the number of entrants necessary into the engine-room department and subsequently control and select those who are accepted into the Industry.

(8) It may be argued that the Marine Engineer is in reality an engineer specialised in the maintenance, repairing and building of marine propulsion machinery, but it is considered that equally necessary are officer-like qualities and sound technical knowledge so as to ensure that the ships' engineer officer of the future is the right type of executive officer.

(9) We believe that there need never be a shortage of sea-going engineers, although it is conceivable that there might be a shortage of those who are prepared to remain at sea, and as a consequence it is necessary to consider quality of the future officers as distinct from quantity.

(10) We are of the opinion that it is necessary in the training of future ships' engineer officers that the three following features are included in the fundamental scheme of training :—

(i) Pre-sea training.
(ii) A short period at sea.
(iii) At least 33 months in an approved workshop.

(11) It is also essential that the training be accompanied by approved correspondence courses in all the subjects coming within the examination curriculum.

(12) It is believed that, if the scheme, developed along these lines and including the features we suggest, is put into operation, the wastage or turnover of labour will be considerably reduced, with the result that the training scheme should not embrace an unduly large number of "possible" entrants as at present.

(13) It is suggested that a complete scheme will have to provide opportunities for :—

(a) Youths who complete their apprenticeship in approved yards and wish to enter the profession.
(b) Young firemen who make up their minds within, say, 12 or 18 months at sea that they wish to enter and progress in the profession.
(c) Senior ratings such as greasers or donkeymen.

(14) It is felt, however, that adequate arrangements can be made in the main scheme by the introduction of the necessary variations to provide for the groups referred to in the previous paragraph.

(15) This memorandum suggests a comprehensive scheme of training calculated to cover all those, whatever category they may come in, who are desirous of reaching officer rank in the engine-room department.

(16) We would, therefore, submit in brief outline the scheme which we have prepared, Scheme "A" being the main scheme to which the variations described in B, C and D are interwoven.

Scheme A.

Boys who indicate at the age of 16 or thereabouts that they wish to become a ship's engineer officer should conform with an agreed medical standard, should be of good character and should have reached at least School Leaving Certificate standard. Applicants would be interviewed by Regional Selection Boards referred to in paragraph 22, and on being entered would be required to take :—

(i) Nine months at the same pre-sea training school as the future navigating officer, the course, however, to provide for education in theoretical anl practical engineering.
The technical studies to cover such subjects as English, Mathematics, Engineering Science and Heat Engines, Engineering Drawing and Ship Construction.
The College to be fitted with the necessary facilities to

enable the trainees to handle tools and to become acquainted with the operation of machine tools.

After the completion of this course, then :—

(ii) A minimum period of six months at sea in selected ships, with the possibility, if practicable, of engineering training being given in the same ships as those operated by some Companies for the future deck officers, with trained instructors on board. The necessary facilities would be given in these and other selected ships to enable the youths to continue with their studies under the supervision of the ships' engineer officers.

(iii) After the completion of the sea service, two years and nine months in approved workshops with the minimum of one day per week at a day technical school. The technical training to lead to Ordinary National Certificate standards.

(17) It is considered that a sea and shore course of the kind outlined would be particularly advantageous from the point of view of the future engineer officers' physical condition.

(18) It is considered that the pre-sea training course would include physical training, sports, etc., this course being followed by a short experience at sea, would physically equip the youths for the more arduous work of the workshop.

(19) It is thought necessary that a fund subscribed to by the Industry would be required in order to subsidise those companies whose vessels are selected as training ships, as these companies in effect would be training not only for themselves but for the Industry as a whole.

(20) It is considered highly desirable that the workshops should be approved and limited in number, but located in various parts of the country.

(21) The managements of such approved workshops should be asked to co-operate in the important task of training a limited number of personnel necessary for the maintenance of our normal supply of ships' engineer officers.

SCHEME B.

It is realised that many youths defer making up their minds to go to sea, but the necessary provision will have to be made to accommodate persons in this category. It is therefore considered :—

(i) That there should be a minimum of four years' apprenticeship in approved workshops, and proof of one day's attendance per week at a technical school and evening classes would be necessary.

(ii) The production of an Ordinary National Certificate or its equivalent.

(iii) The physical and character standards required as in "A".

(iv) The six months' minimum sea training as in Scheme "A" to be required after their shore training.

SCHEME C.

The case of a youth who enters the stokehold as a fireman or trimmer at 18 or 19 years of age but within the first 12 months decides that he wishes to progress towards ships' engineer officer status, should, after selection and upon the recommendation of the Chief Engineer, providing he complies with the medical and character requirements, be entered into Scheme A.

SCHEME D.

Accommodation will have to be found for the experienced rating class, that is, a donkeyman or greaser, who, after a number of years at sea, decides that he wishes to enter and progress in the profession. The recommendation of the chief engineer or successive chief engineers will be necessary, coupled with the character and medical standards of the other scheme. So as to warrant that the candidate be given reasonable opportunities, provision should be made for :—

(i) One year at the residential College, but in a special age group.

(ii) At the end of the period, he would be required to pass an examination in order that his technical ability could be assessed.

(iii) A special study scheme will no doubt have to be prepared for this type of candidate.

(iv) A candidate, after completing his shore training, would then be required to proceed to sea in a capacity not below that of an engineer assistant for a period of three years before he would be deemed eligible to present himself for a second-class certificate.

(22) A central Selection Board representative of the Industry would be established, together with regional Boards of a similar character. It would be the function of the Central Board to assess the annual intake and to give any general guidance which might be necessary to the Regional Boards.

(23) On the completion of training under any of the Schemes outlined above, a man would then be classed as an Engineer Assistant.

(24) In the event of the number of candidates from the above Schemes being insufficient to meet the demands of the Industry, control of temporarily relaxed conditions of entry to be exercised by the Regional Boards.

INTERMEDIATE GRADE.

(25) It is considered desirable that an intermediate grade be introduced in the engine-room. There are difficulties, it is realised, but in view of undoubted trends of responsible opinion it is felt that a way should be found to introduce this grade.

(26) As a general criterion it is thought that the ship's engineer officer should be a person :—

(a) In possession of at least a second class certificate; or

(b) in effective charge of a watch.

It is realised that these simple lines of demarcation would not in all cases solve the difficulty, and it is therefore advocated that manning agreements or understandings be determined by the National Maritime Board and be introduced for the engine-room department.

(27) The manning agreement would embrace :—

(i) Ships' Engineer Officers.

(ii) Engineer Assistants.

(iii) Senior ratings.

It would be expected that the number of ships' engineer officers in many liners would be greatly curtailed as compared with the number at present carried.

(28) It is, of course, conceivable that in any manning scale of the kind suggested in large companies, engineer assistants may be in possession of a Certificate, and this would indicate their desire to obtain ships' officer status in the company in which they were serving.

APPENDIX C.

MARINE ENGINEERS ASSOCIATION AND AMALGAMATED ENGINEERING UNION.

MEMORANDUM.

The Representatives of the Marine Engineers' Association and the Amalgamated Engineering Union desire to record in the form of this Memorandum their complete disapproval of Section III (A New Intermediate Grade) of the main Report.

The view is held by the Marine Engineers' Association and the Amalgamated Engineering Union Representatives that the title "Engineer Officer" is applicable to any Marine Engineer serving at sea in a British Merchant Navy vessel who has served a full apprenticeship ashore of the type approved by the Board of Trade as one of the qualifications for examination for a certificate of Competency. That being so, they deprecate any movement, such as that provided for in Section III of the Report, which would take from Marine Engineers so qualified the title of "Officer".

It is stated in the Report that it is considered that the establishment of an Intermediate Grade would be beneficial in improving the status of Engineer Officers. The Marine Engineers' Association and the Amalgamated Engineering Union Representatives, however, do not consider that the effect of such a Grade would be beneficial in improving status, but that the reverse would be the effect. With such a Grade in operation, young men qualified by an approved apprenticeship would experience a sense of frustration on being consigned to a non-Officer Grade on going to sea, instead of being able, from the commencement of their sea career, to assimilate experience of Officer status, with its responsibilities, privileges and disciplinary value. They would be exposed to the risk of discouragement and loss of interest on the ground that their position was precarious and their ultimate emergence from non-Officer status uncertain. Many parents and guardians of desirable youths inclined to adopt the profession as a career might be deterred on this account when considering the question of entry into apprenticeship.

Denial of Officer status to a Marine Engineer until he has attained comparatively senior rank is an unsatisfactory method of fitting him for leading positions in the profession, as the mature value and exercise of Officer status in higher rank can only be effectively achieved by its gradual absorption in an Officer capacity from the lowest rank onward.

The reference in Section III of the Report to feeling amongst Senior Engineer Officers that the title "Officer" is far too lightly bestowed must be viewed as being based on the prevailing dissatisfaction amongst Seniors in respect of the shipping of Juniors with little if any training and no apprenticeship qualification, and cannot be taken as applying to Juniors qualified by an approved apprenticeship.

APPENDIX D.

SPECIMEN FORM OF WORKSHOP SERVICE TESTIMONIAL.

Name and Address
of Engineering Works ....

I certify that the following is a full and true statement of the Workshop Service performed by .... under my supervision at the above works.

Period of Service. Dates.		Total Period.	Nature of Duties. For appropriate description see below.	Particulars of weekly release periods to permit apprentice to pursue technical studies.
From	To			

Report as to Ability ....
Report as to Conduct ....
Remarks (if any) ....
Signature of employer or his representative............................

DESCRIPTION OF DUTIES.

I. Fitting and/or erecting in the manufacture and/or maintenance of substantial machinery (e.g. machinery with main shaft exceeding six inches in diameter).
II. Fitting other than on substantial machinery.
III. Metal turning (good heavy work).
IV. Machine work (other than lathe).
V. Work in Drawing Office, as draughtsman or engineer.
VI. Other work, the nature of which should be specified.

The use of the appropriate numerals is sufficient except in case VI.

ADDITIONS TO THE LIBRARY.

Purchased.

Brown's Nautical Almanac (incorporating "Pearson's Nautical Almanac"): Daily Tide Tables for 1946. Edited by Captain Chas. H. Brown, F.R.S.G.S., assisted by C. W. T. Layton, A.I.N.A. Printed and published in Great Britain by Brown, Son & Ferguson, Ltd., The Nautical Press, 52-58, Darnley Street, Glasgow, S.1. Price 5s.

Shipping Practice. By Edward F. Stevens. Sir Isaac Pitman and Sons, Ltd., London, 1945. Fourth Edition. 137 pp., 5 Appendixes, Definitions and Abbreviations, Forms and Documents. 7s. 6d. net.

In these times it is an essential duty of the individual to be conversant with the business in which he is occupied.

This book is written to guide the student through the various and extensive subjects connected with shipping, without a deep treatment of the law, and the compilation has been arranged in a progressive order of study, and, as far as is possible within the scope of the volume covers the necessary subjects for the Institute of Chartered Shipbrokers, Institute of Transport, Institute of Export, London Chamber of Commerce, and Royal Society of Art Examinations. It is pleasing to note that since its original edition this little volume has been approved by many Institutes and Organizations as a recommended book for study.

Whilst primarily its object is that of a textbook for the student, it is hoped that it will prove of benefit and contain interesting details and information for others engaged in this profession, perhaps leading many to make a more extensive study of "Shipping".

Presented by the Publishers.

The Journal of the Institution of Electrical Engineers. Vol. 92, Part I (General), No. 58, October, 1945; Vol. 92, Part I (General), No. 59, November, 1945; Vol. 92, Part II (Power Engineering), No. 29, October, 1945.

North East Coast Institution of Engineers and Shipbuilders: Transactions. Volume 61. Sixty-First Session, 1944-45.

The Society of Naval Architects and Marine Engineers (29 West 39th Street, New York 18, N.Y.).: **Historical Transactions, 1893-1943.** Bound volume. 544 pp., profusely illustrated.

British Non-Ferrous Metals Research Association, 1920-1945. Bound volume. 47 pages, illus.

Contents: Officers and Council. Introduction, by Sir John Greenly. Research Policy of the Association, by A. J. Murphy. Organisation of the Association, by G. L. Bailey. A Review of Current Work and Recent Research Results, by W. C. F. Hessenberg. Recent Papers and Publications.

Some Practical and Theoretical Investigations of Model Propellers. By Jorgen Marstrand. *Summary in English.* Publication of the Swedish State Shipbuilding Experimental Tank, No. 5, 1945. Price 3 kronor.

Memoires de la Societe des Ingenieurs Civils de France (Jan., Feb., Mar., 1945).

The Manufacture and Production of Aluminium Alloy Forgings and Stampings. Prepared on behalf of the Wrought Light Alloys Association by J. R. Handforth, M.Sc., and J. Towns Robinson. Issued by the Technical Committee, Wrought Light Alloys Association, Birmingham, through the Wrought Light Alloys Development Association, June, 1945. 45 pp., illus., photographs and tables. Price 1s.

British Standards Institution. British Standard 758: 1945. Small Domestic Hot Water Supply Boilers for Solid Fuel. 27 pp. 3s. 6d. net, post free.

Diseases of Electrical Machinery. By G. W. Stubbings. E. & F. N. Spon, Ltd. Second Edition, 1945. 226 pp., illus., 51 figs. Price 10s. 6d. net.

The diseases dealt with in the book are, in general, such as occur in the testing department of a manufacturer's works or before the apparatus is handed over to the user. About half the book deals with electrical theory and design, but somewhat more than elementary knowledge is required to understand this part of the text. The majority of the book deals with considerations of direct current motors and generators and alternating current motors.

Although there is little that would be of assistance in the normal maintenance of an installation, the information given might be of assistance after repairs have been carried out. The marine engineer will find a small amount of useful information in the book in regard to the operation of motors and generators.

The Merchant Service, by Lieut.-Commander L. M. Bates, R.N.V.R. Frederick Muller, Ltd., 29, Great James Street, London, W.C.1. 1945. 160 pp., illus. 7s. 6d. net.

The author offers an apologia for bringing to the market of books yet another on the Merchant Service. His excuse is that the enormous bibliography of commercial seafaring lacks a primer to introduce the landsman to the subject. This contention is hardly borne out by the facts, for there are many books published dealing in a popular style with the Merchant Service, but not everyone will read them. The author's own book may be taken as a "First Reader" into which he has by his own confession introduced some yarns and anecdotes as a means of softening the impact of solid facts. It surveys the history of the Merchant Marine from the days of sail to the present day. For a factual account the book is too discursive, and the reviewer was left with the impression that the author seldom gets to grips with his subject.

The best part of this little volume is probably that dealing with the days of sail and the beginnings of some of our most famous shipping lines. The story of the East India Company, the repeal of the Navigation Acts, and the coming of the clipper ship, is well told. The famous race in 1866 between three clipper ships from the Min River in China to the Thames is recalled in which the second was only twenty minutes behind her rival and the third came in only an hour or two behind the first two ships. The Australian gold rush added to the excitement of those stirring days. So keen was the race in those clipper ship days that in some cases sails were even set in the ship's boats carried on deck!

Types of ships and their cargoes, trade routes, the men who man the ships afloat and manage them from the shore, are delineated. Written in wartime, the book deals with conditions as they obtain in peace, but in the last chapter are recalled some of the epic stories of the recent struggle such as those of the "Jervis Bay", the "San Demetrio", the "Rawalpindi" and the "Hopemount", in which British seamen upheld the finest traditions of the Royal Navy and the Merchant Service. The "Merchant Service!" The author is right in preferring the term to the "Merchant Navy", which suggests an organization born and bred to war. These pages will be of interest chiefly to landsmen with little or no knowledge of the sea.

Colloids—Their Properties and Applications. By A. G. Ward, M.A. Blackie & Sons, Ltd, 133 pp., illus., 28 diagrams, 6 half-tone plates. 5s. net.

This little book contains all the essential facts about colloids so far as they are known to the present but although the publisher's note on the cover describes the book as a "simple account" the term is relative and the reader requires some slight knowledge of physical chemistry in order to make full use of the information.

Thus while Sections one and two (theoretical and experimental) are by far the more valuable from the educational standpoint many engineers will find Section three (practical application) the more readable.

The one subject which would have interested marine engineers more than almost any other—use of colloid materials in boiler water treatment—almost escapes notice altogether and there are no references to tannins, starches, alginates, graphite, etc., in this connection. Perhaps the author was well advised to avoid such a controversial topic.

Chapter XV, dealing with another application of colloids of great importance in everyday life (paints, lacquers, enamels and varnishes) is far too brief and the reader will not readily accept that stock excuse often given by lesser men than Dr. Ward. "A full account . . . would be beyond the scope of this book".

For those with enough basic training the book gives a most lucid, accurate and concise exposition of a field of science which only 20 years ago was called "The Twilight Zone of Matter".

A highly technical subject which requires a terminology of its own, a special technique for its investigation and a set of new conceptions for its understanding must always be rather difficult and cannot be made easy without loss of truth. Dr. Ward has gone further in this direction than one might have thought possible. The arrangement of the text, illustrations, bibliography and reference scheme are all good.

Introduction to Marine Engineering. By Commander(E) A. Funge Smith, R.N., Edward Arnold & Co., 41, Maddox Street, London, W.1. 1945. 158 pp., illus. 5s. net.

Although in no sense a comprehensive survey of present-day marine engineering practice, or even an elementary textbook on the subject, Com'r. Funge Smith's book is by far the best of its kind yet published in this country. It is written in simple language, its descriptive style is unequivocal and the 117 diagrammatic sketches with which it is illustrated are models of clearness combined with compactness which even experienced marine engineers may find useful.

The book is likely to prove of special value to deck officers of the Royal and Merchant Navies, as well as to such civil, mechanical and electrical engineers as may wish to obtain an insight into the marine branch of the profession. It should also find a place in the library of every boys' school.

The author is to be congratulated on the manner in which he has succeeded in filling a long felt want by the publication of this admirable little volume.

History of Travel and Communication—Book I: Travel. By L. Moakes, L.L.A. (Hons.), M.R.S.T. John Crowther (Educational) Ltd., Bognor Regis, Sussex. 1945. 56 pp., illus. 6s. net.

"One of the pleasantest things in the world is going a journey" wrote Hazlitt in the early nineteenth century. But travel is not a modern invention, for throughout the ages man has travelled for one reason or another. However, the methods that he has used have been legion, and in this book the author, by picture and commentary, describes the most representative of these methods throughout the centuries.

Presented by Lloyd's Register of Shipping

Rules and Regulations, 1945-46.

Scales of Fees Chargeable in the United Kingdom for the Survey and Classification of Steel Vessels and for the Inspection and Testing of Materials.

PERSONAL.

The Council are glad to learn that the following Far Eastern Members have returned safely after internment by the Japanese: W. A. Atkinson (Shanghai); R. G. Lapper (Tientsin); W. O. Lambert (Vice-President), E. Ellison, J. W. Lawson and C. Wallis (Hong Kong); F. G. Ritchie (Vice-President), A. R. Bruce, L. Froggatt, J. A. Heaton and T. W. G. Knowles (Singapore); R. C. Fogg (Selangor); A. C. Tidbury (Sandakan); C. W. Jones (Manila).

John S. Ashmore (Associate) has had conferred upon him the Degree of M.A.I.. (i.e. Master in Art of Engineering), by the University of Dublin (Trinity College).

Sir Wilfrid Ayre (Member) and Mr. F. W. Dugdale (Member) have been appointed vice-presidents of the Shipbuilding Employers' Federation for the coming year.

B. L. Duggan (Student) has been appointed chief draughtsman, engine department, Messrs. Aldous Successors Ltd., Brightlingsea.

R. Everett (Member), Chief Engineer, has received the distinction O.B.E. and E. Haver (Associate Member), Second Engineer, M.B.E., for their outstanding services in reboarding and bringing the M.V. "Empire Unity" safely into port after the vessel had been torpedoed in two places and abandoned.

W. Gillespie (Associate Member) has been appointed chief lecturer in the Department of Mechanical and Civil Engineering at the College of Technology and Commerce, Leicester.

R. H. Gummer (Member) has been elected Honorary Treasurer of the Institute of Fuel.

R. D. Heughan (Member) has been appointed Marine Engineer in charge of Workshops, General Repair and Maintenance, Surveys, etc., at the Rio de Janeiro branch of Wilson, Sons & Company, Ltd.

D. A. Keable (Graduate) was awarded the D.S.C. in November, 1944, while serving as Sub.-Lieut.(E.), R.N.V.R., and was promoted to Lieut.(E.) in November, 1945.

J. E. M. Payne (Member) has been appointed marine superintendent engineer, L.N.E.R., Parkeston Quay, in succession to R. C. Banks, who has retired from the service.

J. H. King (Member) has been promoted to vice-president of his corporation, the Babcock & Wilcox Company (U.S.A.). His duties will continue to include the management of the Marine Department of that Company. Mr. King is also vice-president and secretary-treasurer of the Society of Naval Architects and Marine Engineers, N.Y.

MEMBERSHIP ELECTIONS.

Date of Election, 4th December, 1945.

Members.

Arthur Morrell-Anstiss.
Thomas Henry Boulton.
Hugh Coulthard, Lieut.(E.), R.N.R.
Edward Walker Elliott, D.S.C.
Leslie Entwistle.
Alfred John Hebden.
James Holker.
Daniel Horrigan.
Charles Jackson.
Charles Alexander Lucas.
Thomas Joseph McCaffrey.
Dhanjishaw Temuljee Mama.
Thomas Matthews.
William Alexander Miller.
Percy Ernest Nuttall.
David Barclay Ross.
Frederick Arthur Shepherd.
Leonard Thackara, Eng.-Capt., R.N.(ret.).
Adam Shaw Watt.
Robert Llewellyn Pritchard, Lieut.(E.), R.N.R.
Kenyon Roderick.
George Frederick Ross.
Herbert James Shutt.
George Ambrose Stobart.
Harold George Lawrence Wilkinson.
Lindsay Pearse Williamson.

Associate Members.

Robert Cook, M.Sc.
Svenn Eigil Petersen, B.Sc.

Associates.

Alexander Sim Allan.
George Frederick Craggs.
Charles Dearden.
John Stevenson Dillon.
William Ernest Garrod.
James Waldie Greenhill.
John Lionel Hanman.
Frederick Stanley Hardacre.
William Olds Hitchens.
Thomas William Lawrence.
Geoffrey Anthony Lawrenson.
Wilfred McIntyre.
Alfred John Mann.
Harry Kenneth Peterson.

Graduate.

Richard Brown.

Students.

Peter Randolph Brett, Actg. Lt.(E.), R.N.
Pallathucheril Varkki George.
Myles John Nash McLachlan, Sub. Lt.(E.), R.A.N.
Eardley Erroll Rockwell Newman.
Ronald Robert Rolo.
Maurice Arthur Spencer, Sub. Lt.(E.), R.N.

Transfer from Associate to Member.

Pheroze Dinshah Dadahchanji.
Robert Evan Davis.
Bernard Moore, Lieut.(E.), R.N.R.
Brian Scott-Young.
Stanley Smith.

Transfer from Graduate to Associate.

Gordon Dales.

Transfer from Student to Graduate.

Wilfred Fitzgerald Ratcliffe, B.Sc.