9. NOTES.

These articles (indexed under the heading of "Notes") have been compiled in response to specific requests from Engineer Officers.

It is desired that Officers will forward suggestions or enquiries regarding matters of general engineering interest, with a view to initiating future articles in these Papers. Communications of this nature should be addressed to—Editor of Engineering Notes, Engineer-in-Chief's Department, Admiralty.

(*a*) Oil in Boiler Feed Water.

Oil in the Feed Water for Water-Tube Boilers.

In the early days of the introduction of water-tube boilers into H.M. Navy, it was recognised that the entry of appreciable quantities of animal or vegetable oils into the feed system would inevitably result in the formation of fatty acids, which rapidly attacked the plating and tubes of the boilers. Instructions were therefore issued that such oils were not to be employed for internal lubrication, with the result that troubles from this particular source have been comparatively rare.

The presence of oil in the feed water is, however, frequently held responsible for the distortion of the boiler tubes, a defect which is the more disquieting because its true causes are not ascertainable in all cases. In a previous article in these Papers (No. VII, page 85) it has been pointed out that distortion of boiler tubes may frequently be traced to lack of freedom of the sliding feet of the boilers, due either to faulty initial adjustment or to failure to maintain the working surfaces in an efficient condition. This cause of distortion has, however, appeared to be inapplicable in many cases, and it has become evident that other causes are at work.

It is necessary, when attempting to trace obscure causes, to seek for features common to a large number of cases, and this is provided in this particular instance by the fact that distorted tubes frequently exhibit signs of overheating, often accompanied by the presence of oil or grease in appreciable quantities. It has been observed that, on removal of such contaminations from the feed circuit and on renewal of the affected tubes, the distortion failed to recur, the natural inference being that the oil was the cause of the overheating which, in turn, resulted in the distortion.

Direct evidence connecting cause and effect in this matter has not yet been obtained, although at least one unofficial but somewhat convincing experiment has been carried out; in one of these tests a damaged boiler was steamed at a moderately high rate while oil was deliberately introduced into the feed, it being observed that the tubes visibly distorted under such maltreatment.

The responsibility for this defect cannot, however, be definitely attributed to the oil until the underlying action is fully understood, and it thus becomes necessary to investigate all possible avenues connecting the two factors concerned. It has been shown experimentally that the presence of even a trace of oil upon a heating (or cooling) surface will cause a marked diminution in the rate of heat transference, and, reasoning from this evidence, the theory has been put forward that the deposition of a film of oil upon the interior surfaces of the tubes may lead to local overheating and subsequent distortion.

The foregoing theory appears to derive considerable support from the fact that traces of oil, or of carbon deposit possibly derived from oil, are frequently observed upon those parts of the tubes where overheating is most apparent. On the other hand, however, it is difficult to account for the adhesion of the oil to the tubes while the boiler is steaming, as the viscosities of oil and water are very similar at boiler temperatures; it is also quite possible that the grease is only deposited during the process of emptying the boiler and that it does not adhere to the tubes under steaming conditions. Finally, it may be objected that the apparent connection between the oil and the overheating cannot be conclusively established owing to the fact that scale is invariably found upon any highly heated surface if the necessary material is present in the water.

Turning from this argument for the moment, it at least appears reasonably clear that many cases of distortion of the tubes are due to overheating, and thus a consideration of the factors which influence the latter may be illuminating.

Ample experimental evidence exists to show that steam is but a poor conductor of heat and thus adhesion of steam bubbles to the heating surfaces is likely to decrease the transmission of heat locally, resulting in overheating of the metal in the vicinity of the bubble. It becomes necessary therefore to provide a free passage for the steam away from the heating surfaces, an effect which will evidently be favoured by a rapid and positive circulation and by tubes of adequate dimensions, suitably inclined to the horizontal.

The rate of circulation in a boiler is determined by two main factors, namely, the head available for promoting the flow and the hydraulic resistances opposing it; the former is decided by the vertical height of the tubes, by the temperature differences in the feed circuit and by the rate at which steam is disengaged from the heating surfaces, while the latter is influenced by the arrangement, curvature, diameter and length of the tubes as well as by the roughness of the surfaces exposed to the stream. Very little information exists on this question of circulation, as is well illustrated by the conflicting opinions held regarding the necessity for downcomer tubes: such few experiments as have been carried out in this connection appear to indicate that the velocity of circulation in a Yarrow boiler is low, thus favouring the adhesion of steam bubbles. The formation of eddies is a likely cause fór local failure of the circulation, such disturbances being due essentially to sudden changes in the hydraulic resistance of the circuit; the speed of the water undoubtedly exercises a marked effect in this regard, and there may well be an upper limit to the velocity of the circulation above which eddying will occur: hence , an increase in the speed of flow may actually induce overheating rather than effect the desired cure.

All the factors just mentioned are independent of the presence of oil, which, however, may well be a cause of somewhat obstinate adhesion of the steam bubbles to the heating surfaces, as its effect in promoting foaming in boilers by increasing the skin-tension of the bubbles is well known.

The foregoing points, many of which may appear fantastic, have been mentioned in order to show how unsafe it is to dogmatise on such a question as this in view of the imperfect state of the present knowledge of the subject. It is evident that much experimental work is required before any advance over the present rate of heat transference can be contemplated, and, unfortunately, since the phenomena to be examined occur within the interior of the boiler and of the furnace, any investigations are hedged about by extreme difficulties.

The true causes of overheating and distortion have not therefore been yet definitely established, but the fact remains that all the evidence at present available indicates that the presence of oil in a boiler is definitely detrimental and that the apparent connection between oil and overheating is too strong to be fortuitous. It remains then to consider what steps can be taken to ensure, as far as is humanly possible, the complete exclusion of lubricants from the boilers.

Filters.—When water-tube boilers were first introduced into the service, experiments were carried out with a view to discovering materials which would serve as effective filters, sponges or terry towelling proving to be the most suitable of those tried. Filters embodying these materials were therefore incorporated in the feed circuits of the vessels of the fleet and instructions given regarding the regular cleaning of such devices, it having been found that they became completely ineffective once the filtering material was throughly impregnated with oil. With the adoption of contact feed heaters, however, it became evident that sponges were of little value as a filtering material for hot feed water owing to their rapid shrinkage and subsequent disintegration at temperatures of the order of 120° F. or more.

Further experiments demonstrated that with hot feed water all the filtering materials tested were comparatively ineffective (probably on account of the similar viscosities of oil and water at temperatures over 120° to 140° F.), leading to the conclusion that any filtering of the feed water must be carried out at temperatures below those mentioned, pending the discovery of a material better suited to modern conditions.

The alternative to the provision of effective filters is to ensure that oil cannot enter the feed circuit, and this ideal, despite every possible precaution, cannot be realised with certainty owing to the human element.

The reciprocating auxiliaries are the most probable sources of oil in the feed, as little trouble in this respect should arise from the main turbines or from turbo-driven auxiliaries; special attention appears necessary in the case of vertical turbo-driven auxiliaries, where the arrangement is favourable for the passage of oil to the turbine glands. The best means of avoiding over oiling of Weir's pumps and the like are a matter of personal opinion, but the possibilities of using graphite as a lubricant in such cases offer hopes of an effective solution to the problem.

The considerable collection of oil often seen on the walls of feed tanks, especially when the temperature in these chambers is comparatively low, suggests that the provision of suitable baffling in these tanks may serve to deposit the oil in predetermined positions, from which it may be removed at intervals. In practice frequent attention to the cleaning of the feed tanks, coupled with reasonable care to prevent the abuse of oil, has often been found effective.

In cases where the number of turbo auxiliaries is large it has been found possible to distribute the exhaust steam in such a manner that the condensate from the reciprocating engines is cooled and filtered while that from turbine machinery remains untreated; this principle is being adopted to an increasing extent both ashore and afloat.

The introduction of highly superheated steam has given an impetus to the more general use of rotary auxiliaries and it is hoped that thereby contamination of the feed with oil will be lessened, since the need for clean feed water is even greater with superheater boilers in view of the temperature conditions in the superheaters themselves.

In conclusion it may be observed that one of the principal difficulties in connection with oil in the feed water will be removed if and when a simple method of detecting its presence is evolved.

(*b*) Effect of Tool Marks and Scratches upon Strength of Parts.

The statement is frequently made that any discontinuity in the surface of material under stress will result in concentration of the stress at the boundaries of any such holes, sharp edges, etc., with a consequently increased liability to failure; much interesting research work has been carried out on the effect of holes in parts under stress, the experiments of Dr. Coker with his ingenious optical apparatus being well known in this connection. These experiments, together with research work and mathematical analysis by eminent scientists, have been concerned principally with the effect of comparatively large discontinuities: logically, however, it is reasonable to suppose that tool marks and surface scratches will also result in similar concentrations of stress, but possibly to a lesser degree, and it is of interest to see to what extent rough finish and blemishes will affect the reliability of the finished product.

It has been shown mathematically that the increase of stress at the bottom of a notch or groove depends uopn the ratio d/ρ where d is the depth of the notch and ρ is the radius of curvature at the extremity, and, in order to test the validity of these calculations, experiments were carried out on solid test pieces of various materials, using a machine of the Wohler type, whereby the specimen may be subjected to any desired number of repetitions of stress. The specimens were very carefully polished with finest emery and scratches or grooves of the desired depth and extent were cut in the prepared surface by special tools, a micrometer device being employed to measure the depth.

Measurements of the scratches were taken by making gelatine casts which were subsequently sliced into sections and projected on to a suitable screen by an optical apparatus.

The scratches examined were mostly small and of the same order of magnitude as those left after various workshop processes, but in a few cases larger scratches were also examined in order to find the "scale effect" and for comparison with deep grooves such as screw threads.

The experimental loss of strength, while considerable, was found to be markedly less than that indicated by theory, and it was found that there exists a very decided scale effect, which has not yet been fully explored.

Briefly, however, it may be stated that the reduction in the fatigue strength of a part due to small scratches not exceeding $2\frac{1}{2}$ thousandths of an inch in depth may be as much as 30 per cent. if the ratio d/ρ is high. Similar grooves of 1/100th inch in depth may reduce the strength by nearly 60 per cent., although the theoretical decrease would be about 85 per cent.

Owing to the scale effect, the increase of stress due to a scratch is approximately proportional to $\sqrt{\frac{d}{\rho}}$ in accordance with theory, provided, however, that the variation in the dimensions of the groove is small.

The following table gives some of the types of finish examined and the resultant reduction in fatigue strength :—

Type of Finish.	*Estimated maximum reduction in fatigue strength.*
	Per cent.
Turned - - - - -	12
Coarse file - - - -	18 to 20
Bastard file - - - -	14
Smooth file - - - -	$7\frac{1}{2}$
Coarse emery (No. 3) - -	6
No. 1 emery - - - -	4
No. 0 or FF emery - - -	2 or 3
Fine Carborundum - - -	2 or 3
Fine ground finish - - -	4

Scale effect.—It has been stated that the experimental strength of metals is much less than the theoretical strength calculated from other physical properties. The presence of minute flaws and cracks in the material may serve to explain this statement. If scratches or grooves in the surface of a part are of such a size as to be comparable with the existing flaws, their effect will be small, and it will only be with the large-sized grooves that the theoretical loss of strength is approached. It may be noted in passing that according to theory a uniform series of grooves produces a less marked reduction in strength than an isolated scratch.

These experiments were only carried out with specimens subjected to alternating stresses, but there is little doubt that similar laws hold good for grooves in material under steady stress.

The practical application of this work may be seen in the modern practice in automobile and other engineering work where crankshafts and other parts subjected to alternating stresses are finished with a polished surface. The importance of avoiding rough surface finishes is receiving increasing attention in boiler work, where it is now Admiralty practice to specify that the machined surfaces of boiler plates shall be smooth-finished. Concentrations of stress in all work subject to pressure or alternating stress is avoided as far as possible by rounding off all corners to the largest practicable radii, and by making any changes of section as gradually as the circumstances will permit.

(c) Purity of Feed Water—Silver Nitrate Test.

Chemists and other research workers have from time to time stated that by means of the Silver Nitrate Test extremely small proportions of Silver Chloride are detectable in boiler feed water, the published figures varying from 1 part in two hundred million parts of water to a dilution of 1 in 30 million. In view of the widely differing results quoted it was decided to carry out tests to determine the limiting degree of contamination of feed water by the presence of salt or chlorine which could be detected by the test. The limiting condition was taken to be when the addition of two drops of 10 per cent. solution of $AgN \cdot O_3$ to a test tube full of water caused the formation of a " cloud " which could only just be discerned while the drops of silver nitrate sank to the bottom of the tube; that is the cloud should be discernible in 5 to 10 seconds.

The method of test employed was to provide a standard solution of Silver Chloride and to dilute this to a greater and greater volume until a solution was obtained in which the test just failed to detect the presence of the chlorine.

During these tests the tube was strongly illuminated by daylight from the side, and was viewed against a dark background.

The following representative results were obtained with the solutions at room temperature :—

Dilution of Silver Chloride.	Grains of Cl per gallon.	Observed Effect.
1 in 100,000 -	·42	Instantaneous cloud.
1 in 1,000,000 -	·042	White opalescence formed in about 3 seconds.
1 in 2,000,000 -	·021	Opalescence in 15 seconds. This was like wisps of smoke in the clear solution, and was just detectable when the solution was shaken up.
1 in 5,000,000 -	·008	Opalescence not detected for almost 1 minute and then only by careful adjustment of the light.

The concentration of 1 part in 5 million appears therefore to be the smallest which can be detected by this means. The delicacy of the test depends largely upon the illumination and also to some extent upon the observer, but it is evident that under average conditions 1 part of NaCl in 2,000,000 parts of water should be detected with certainty.

It is of interest to consider dilutions of this order in terms of the resulting rise in the density of a boiler under average conditions, taking the case of a small tube boiler with a working weight of water of 6 tons (= 1,344 gallons), and assuming that 5 tons of " make up feed " are used per day.

Let " y " grains of Cl per gallon represent the purity of the make up feed, and assume that the boiler is not blown down at all.

The daily concentration will be $(5 \times 224)\ y$ grains of Cl in 1,344 gallons or $\frac{5 \times 224}{1,344}\ y = 0 \cdot 832y$ grains per gallon per diem.

In sea water of 10° density there are 1,330 grains Cl per gallon, and hence it would take $\frac{13 \cdot 30}{0 \cdot 832y}$ days to attain a density of $\frac{1^\circ}{10}$.

Allowing for Engine Room conditions of illumination it appears that a concentration of 0·2 grains of Cl/gallon should be immediately discernible by the Silver Nitrate test in practice. Assuming, therefore, that $y = 0 \cdot 2$, the period before a density of $\frac{1^\circ}{10}$ should be formed under such conditions is about 80 days even if boilers are not blown down; obviously this only refers to rise of density due to salt in the feed water.

Salinity Detectors.—While it is therefore established that a silver nitrate test will give reliable indications of the presence of salt in the feed water, it is obviously desirable to make use of some apparatus which will give a continuous indication of the purity of the feed water. Such instruments are now produced commercially and are being increasingly used not only ashore but also in new construction for the Navy.

All these instruments make use of the well known fact that the electrical resistance of pure water is very high, but falls off rapidly if certain compounds—of which salt is one—are added.

Essentially the apparatus consists of a vessel which is fed from the particular part of the feed system to be tested, two suitable electrodes being arranged to dip into the water in the vessel and current from the mains being passed in series through the electrodes and an electric lamp. The lamp not only serves to indicate the purity of the feed by the brightness of its filament, but also enables the sensitiveness of the apparatus to be varied by the use of lamps having different resistances; the distance between the electrodes is also made variable for the same reason.

In more elaborate forms of the apparatus a voltmeter is provided across the electrodes to give a quantitive indication of the amount of salt present. The voltmeter scale can be calibrated, but the readings will only be accurate at the temperature of the feed water at which the instrument was calibrated, unless some compensating device is fitted.

In one form of instrument the salinity is indicated by the readings of a milliammeter, instead of by the use of a voltmeter, and compensation for temperature is effected by a variable shunt resistance across the terminals of the ammeter. Some sections of the shunt are arranged to be short circuited by the mercury column of a special thermometer, the bulb of which is immersed in the feed supply under observation. This device appears to give adequate compensation under test conditions, but it remains to be proved how the instrument will withstand service at sea.

It may be noted in passing that a partial earth on either lead will render valueless the readings of the instrument.

A further elaboration consists of a warning buzzer arranged to operate when the salt concentration reaches a certain figure; the effect of the temperature of the feed water upon the setting must be borne in mind.

Sensitiveness.—In the usual commercial forms, these instruments are adjusted to read from 0 to 0·5 grains per gallon of chlorine by steps of 0·1. The voltmeter or ammeter is not usually a precision instrument and it is usual for the filament of the lamp to glow before any indication is given by the voltmeter. Compared with the nitrate test under engine room conditions, the lamp filament will glow with water in which a " cloud " would not normally be noted.

Precaution.—These instruments should be fitted with a switch whereby the electrodes can be short-circuited at will in order to determine that the lamp circuit is in order. Without this device and its regular use, too much reliance should not be placed upon the instrument, since the mere fact that it gives no indications does not justify the assumption that the feed water is free from salt, unless it is certain that the circuit through the electrodes is unbroken.

In those instruments, which are provided only with an indicating device, but which have no lamp, arrangements are made so that the circuit is complete when the pointer shows zero or any greater reading: in the event of a reading less than zero being shown by the instrument, this fact should be taken as an indication that the circuit is defective.

The latest forms of indicating instruments are also fitted with a cut-out device, arranged to break the circuit should the salinity exceed that corresponding to the maximum scale reading: this arrangement avoids damage to the instrument in the event of a sudden influx of contaminated water.

(*d*) The Output of Oil Fuel Sprayers.

The measurement of oil fuel consumption by means of periodical soundings of the Oil Fuel Tanks is not infrequently a somewhat haphazard and inaccurate process, the results being especially unreliable over short periods. The precautions necessary for obtaining accurate results depend chiefly upon the beam of the ship, the shape of the tanks and the type of sounding gear provided: by suitable arrangements the personal error in taking soundings may be to some extent mitigated, hence, by applying corrections for the heel of the ship and the temperature of the oil, reasonable accuracy may be obtained, provided that the original calibration of the tanks is correct.

Unless oil meters are available, the only alternative to the foregoing consists in the use of the sprayers themselves as metering devices, and information is therefore frequently sought regarding the output of sprayers under different conditions of temperature and pressure.

The output of a given oil sprayer may be said to depend upon three principal factors, namely the pressure, viscosity and specific gravity of the oil. Experiments have shown that provided the last two variables are maintained constant, the output will vary directly with the square root of the pressure, *i e.*, $W \propto \sqrt{p}$, this being entirely in agreement with theory.

The viscosity and specific gravity of an oil are dependent upon the temperature, which thus becomes an important factor in determining the output of a sprayer. The S.G. of any oil appears to decrease by approximately 0·0004 for every 1° F. rise in temperature, and this rule is sufficiently exact for practical use up to a limit of 200°–220° F.

The relation between viscosity and temperature is, however, far less simple, and no general rule has been found that is applicable to all classes of oil fuels over the usual range of temperature. Experimental work carried out in the U.S.A. has resulted in the issue of a statement that for any fuel oil the logarithm of the viscosity varies inversely as the logarithm of the temperature, and that all oils have the same viscosity at 450° F. Tests made in this country with a view to confirming this statement indicate that while the law is approximately true for American oils up to 150° F., it cannot be applied to oils derived from other sources : even for the former class of fuel oils, the law breaks down at the usual burning temperatures.

Practical experience indicates that the best results are obtained when the viscosity of the oil at the sprayer is about 40 No. 1 Redwood seconds. This fact immediately suggests the possibility of defining for each oil the temperature at which the foregoing viscosity is reached, and thence providing a chart from which the output of a standard service sprayer could be read off at various pressures and at the above temperature, when burning the usual fuels.

Unfortunately many fuel oils used in the Service reach their flash points long before the desired viscosity is attained, and thus in many cases the " best burning temperature " has no relation to that mentioned above. It has also been found that the great number of Admiralty Mixtures and the wide variation in the viscosities of the different samples precludes any possibility of preparing useful information of the nature suggested.

The combined effect of viscosity and specific gravity is found to be such that an increase of the burning temperature is accompanied by a decrease in output—in other words the decreased specific gravity overrides the increased volumetric output obtainable on account of the lowered viscosity.

The investigations which have been made on this subject indicate that there is no known method whereby the viscosity of the oil at burning temperature can be predicted from a measurement of the viscosity at atmospheric temperature, and that on account of the variables involved it is not possible to estimate the output of oil fuel sprayers within 15 per cent. unless the sprayers are calibrated with the particular oil in use. The unavoidable variations in the manufacture of sprayers are such that the output of units of the same nominal capacity may differ by as much as 5 per cent. from the rated discharge, and thus, apart from the viscosity question, any conclusions drawn from measurements made in this way may be most misleading.

The employment of oil sprayers in this manner is, however, often more accurate than tank measurements over very short periods, especially if the sprayers have been calibrated against the tank readings over long runs, using a particular oil, burned at one particular temperature.

(e) "Creep" of Materials at High Temperatures.

In modern steam installations, both afloat and on shore, the principal factor defining the ultimate possibilities of the plant is the physical characteristics of the materials used in construction.

It has been frequently pointed out that future major improvements in the economy of steam-driven installations can only be attained (apart from the discovery of some new principle) by the adoption of higher initial steam temperatures and pressures. The whole trend of modern progress is indicated by the fact that steam temperatures up to 750° F. to 800° F. at pressures of 600 lbs., and in one or two cases 1,200 lbs., are in use commercially, while even higher temperatures and pressures are contemplated.

The effect of high temperatures upon the physical properties of the usual materials of engineering construction has therefore been under investigation in many countries during the last few years, and these researches have brought to light the importance of the time during which a material is under load at high temperatures.

Numerous tests have revealed the fact that not only is the strength of any material reduced by exposure to high temperatures, the effect being very marked in some cases, but also that a comparatively low stress will induce failure if permitted to act for a sufficient length of time under such conditions; thus cases have been known when a steel bar has sagged under its own weight in much the same way that a candle bends when stood near a fire. This phenomenon has been termed "creep" or "flow," and its investigation is of considerable importance, since without a knowledge of its effects no proper basis can be established for the design of parts subjected to high temperatures.

Preliminary researches appear to establish that for a given material there exists at each temperature a limiting stress, below which the material will not fail even when that stress is applied for a very long time. This limiting stress has been termed the "limiting creep stress," and curves on a temperature base, indicating the relations between this limit, and other physical properties of a boiler steel have been determined experimentally, being plotted in Fig. 1.

Considerable difficulties have been encountered in the experimental determination of the "creep limit," very accurate control of the furnace temperature having been found necessary as small variations of temperature may in some cases cause the rate of creep to be disproportionately increased; the determination of the point where "creep" appears to cease is also a matter of difficulty, depending to some extent upon the degree of refinement with which the extensions of the material can be measured.

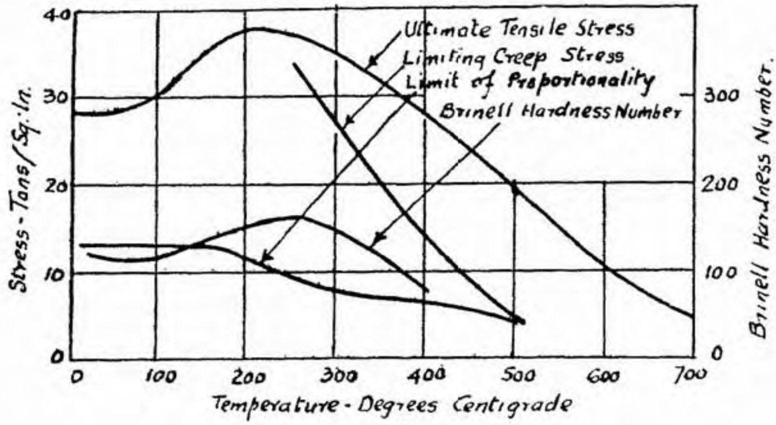
Later researches using more exact methods of measurement have raised a doubt as to whether a limiting creep stress does in fact exist, it being held by some experimenters that creep occurs at stresses and temperatures far below those yet explored. It may even be the case that in all materials under steady stress a very slow and almost imperceptable creep or flow obtains; should this supposition prove to be correct, it will then remain for the engineer in collaboration with the scientist to decide upon what degree of creep is permissible in practical work.

Cause of "Creep."—It has long been known that when steel and many other materials or alloys are worked in a cold condition, both the strength and hardness of the specimen are considerably increased. In order to prevent rupture of the part, due to the increased brittleness, it has been found necessary to resort to frequent annealing when attempting to obtain large reductions in cross-sectional area by means of "cold work."

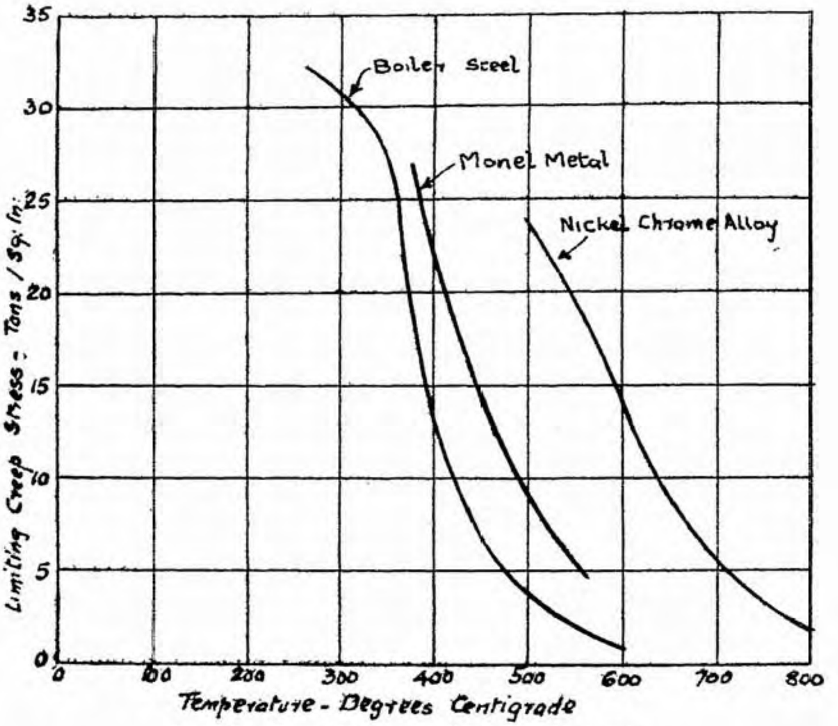
This so-called "strain-hardening" also occurs in the case of a laboratory specimen when subjected to tensile tests. When a material is tested at room temperature, each addition to the applied load causes an extension of the test piece till the induced strain-hardening is sufficient to stop further stretching almost completely; this process is rapid and is repeated for each increment of load, till finally the material fractures. In the case of a material subjected to stress at an elevated temperature the effects of the strain-hardening may, however, be nullified by the annealing effect of the applied heat, and thus extension of the specimen may continue; this affords an explanation of the possible cause of "creep."

A further complication, recently discovered, arises from the fact that material, which has been stressed, is liable to harden under the influence of temperature. Thus, if a specimen is subjected to load at a moderate temperature, say, 200° C., for a few days and then, after unloading, is soaked at the same temperature, it has been found to harden, the effect appearing to increase with time. Hence, up to certain temperature limits there are two effects tending to correct creep, namely, strain-hardening and temperature hardening, and it is the combination of these two which makes probable the existence of a limiting creep stress; above these limits, annealing sets in and creep is experienced.

It is of interest to record that test pieces of mild steel have successfully withstood loads equal to 60 per cent. of their normal yield point, for periods exceeding five years, the temperature being maintained steady at 500° C. These specimens failed to fracture, the only marked change in their physical properties



Tests on Boiler Steel.



Limiting Creep Stress for Different Materials.

being a pronounced increase in hardness, an effect which probably accounts for the absence of any objectionable creep over this prolonged period.

Curves (Fig. II) are appended indicating the nature of the apparent curve of limiting creep in the case of three well-known materials, but these results must not be regarded as being in any way final.

Conclusion.—The following remarks may be made as to the immediate practical value of the results so far obtained. It must be remembered in this connection that there is a decided difference of opinion even among investigators who accept the existence of critical stress values below which a material will not creep indefinitely. One such school suggests that continuous creep will always occur when the stress exceeds the limit of proportionality, while others find definite limiting stresses below which continuous creep does not occur, which limiting stresses may be well above the elastic limit, and even beyond the yield points. It has been found, however, that at the apparent limiting creep stress there is a permanent strain, and that when this permanent deformation has occurred, no further strain appears to ensue under the same stress, or in other words there is no observable creep. Experimental evidence up to the date of writing appears to indicate that, if the permanent strain developed at the limiting creep stress is permissible, a long life may be expected from the material under this stress. Above the limiting creep stress, however, continuous creep will occur, and sooner or later the material will fail. It is probable therefore that for each material there exists a temperature below which the value of the limiting creep stress exceeds the limit of proportionality at that temperature; in other words, the curves of limiting creep stress and limit of proportionality recede from one another as the temperature is lowered, the difference between the two at any given temperature depending upon the ability of the material to " strain-harden " at that temperature.

The extent of the permanent strain at the limiting creep stress has only been obtained in isolated cases, but at the higher temperatures it may be comparatively small, as is shown by the fact that for Armco Iron at 355° C., the permanent deformation at the limiting creep stress is only 2 per cent. attained in some 30 days. At lower temperatures, however, the permanent distortion will be considerable (it may attain 15 per cent. or more), since under these conditions the limiting creep stresses may be much higher than the yield stresses. For practical purposes the curves of limiting creep stresses may therefore be considered as the true ultimate strength curves when the effect of time at high temperatures is to be taken into consideration. In using them for purposes of design a factor of safety must be applied to bring the working stresses either below the elastic limit if no deformation is permissible, or sufficiently below the limiting creep stress, but above the limit of proportionality, if a certain amount of permanent deformation can be allowed.

In applying a factor of safety of this nature, consideration must be given to the *maximum* temperature to which the material may be exposed, since at temperatures of the order of 800° C. a variation of only 20° may correspond to one of 20 per cent. or more in the limiting creep stress.

The extensive research work now in progress, both in this country and elsewhere, regarding the properties of materials at high temperatures has two main objects in view, namely, (1) to determine definitely the true cause of creep and (2) to develop materials which will be as stable in this respect at high temperatures as the normal materials of construction appear to be under atmospheric conditions. Subsidiary researches are being made regarding the causes of the scaling which occurs in most materials at high temperatures.

The phenomenon of " creep " gave rise to some apprehension when first discovered, but in view of the satisfactory results which have been obtained from the practical trials of suitable existing materials, it is not anticipated that any serious trouble will arise until the present limits of temperature are appreciably exceeded.

In service installations creep has been definitely observed only in the case of superheater supports, but this action may also occur in boiler and superheater tubes which may on occasion attain undesirably high temperatures. The temperatures in the steam circuit are not at present sufficiently high to engender trouble from the particular phenomenon under discussion, but it is obvious that any advances in the working temperature and pressure of the steam can only be made with extreme caution till the causes of creep are fully understood.