exceeding the limits established in the ASME Rules for Construction of Power Boilers for radiographic examination should be cut out and rewelded.

CONCLUSIONS

Austenitic steel (Type 347 18 per cent chromium, 8 per cent nickel, plus columbium) was used for the 1100 F steam piping of two 145,000-kw units installed this year by the Public Service Electric and Gas Company of New Jersey in its Kearney Station. This is the first commercial installation for 1100 F steam. A report of the problems encountered and results obtained is awaited with interest. Experimental work there and elsewhere indicates that no serious difficulties should be encountered in using Type 347 material with 1100 F steam.

The $641 question remains whether it is necessary and economical to use austenitic steels for 1100 F steam service. On the strength of information reviewed in the present paper, the authors conclude that it should be feasible to extend the use of low-alloy ferritic steels from their present top steam temperature of 1050 F at turbine throttle to a possible 1100 F at turbine throttle. Before doing so on a wholesale scale, however, it is suggested that a trial installation be made in which the 1100 F steam piping consists in whole or in part of low-alloy ferritic steel. One of the items worth further investigation is the permanence at 1100 F of superior physical properties imparted to certain ferritic steels through favorable heat-treatment.

ACKNOWLEDGMENT

The authors are indebted to the contributors of the numerous papers listed in the Bibliography for use of the material contained therein and, in several cases, for extensive help offered through correspondence supplementary to the papers. This assistance is gratefully acknowledged.

BIBLIOGRAPHY

7 "Changes in a High-Pressure Drum to Eliminate Recurrence of Cracks Due to Corrosion Fatigue," by A. E. White, Trans. ASME, vol. 61, 1939, pp. 597-609.
14 "Proposed Revisions and Addenda to Section on Power Boilers of the ASME Boiler and Pressure Vessel Code, Part P-25(a)," Mechanical Engineering, vol. 74, 1952, p. 934. (This formula also has been adopted for the Power Section of the ASME Boiler Code for Pressure Piping.)

Discussion

E. G. BOISSIER. 1 Design Temperature. Reference is made in the paper to the differential temperature obtaining between the inside of a pipe and the outer wall, particularly at the position of flange joints, valves, and so on.

We have been faced with a similar problem in England, and it is one of the factors, unfortunately, which has to be accepted. In one particular case we are using chrome-molybdenum-vanadium...
steel pipes with mild-steel weld metal (mainly because the alloy weld metals available at present give us creep-resisting properties considerably less than those of the parent metal). Because of this, it has been decided that the joint shall be supported by flanges and suitable bolting arrangements.

It so happens that we were instructed as to the type of steel to be used for the pipework of this particular installation but, had it been left to us, it is certain that we should have employed 18-11-1 stainless steel so that the tubes could have been joined by plain butt welding. Thus the differential-temperature problem created by the use of flanges could have been avoided.

Selection of Materials for 1100 F Service. We consider that for pipes which are to operate at 1050 F–1100 F the limits for the chrome and nickel contents of type 347 steel are too wide, and we should prefer to keep these within the range chrome 17 to 18.5 per cent and nickel 11 to 13 per cent.

Chrome-Molybdenum-Vanadium Steel. Reference is made to the importance of correct heat-treatment of the foregoing type of steel in order to obtain the optimum creep-resisting properties, and also to the fact that after such heat-treatment the steel may have a low ductility and possibly be liable to brittle failure.

The opinion is held, in this country, that after heat-treatment as suggested by the authors, the steel would be expected to have a low ductility, particularly in view of the coarsening effect of the 1875 F to 1975 F treatment. We also consider that there is no advantage to be gained with molybdenum contents in excess of about 0.5 per cent, and chrome additions in excess of about 0.5 per cent will reduce the creep-resisting properties.

At the present time we are installing pipework for 1050 F conditions, made from 0.5 per cent chrome, 0.5 per cent molybdenum, 0.25 per cent vanadium type steel, and our heat-treatment consists of normalizing from 1740 F–1790 F, followed by tempering at approximately 1275 F for 3 hr minimum.

After the foregoing treatment, specimens have shown an elongation of at least 8 per cent after varying periods of time, up to 10 years, at 1020 F. The authors expressed doubts regarding the permanence of the creep-resistant properties of the chrome-moly-vanadium steels; but specimens tested in this country with a load of 6 tons psi at 1020 F are unbroken at 120,000 hr.

Austenitic Versus Ferritic Steel. It must be agreed that the cost of stainless-steel tubing is higher than that made from chrome-moly-vanadium steels; but this may not necessarily imply that there will be a corresponding difference between the cost of the finished pipework installations. Additional cost may be incurred where chrome-moly-vanadium tube is used, due to the following:

(a) The thickness of tube to be employed may entail the use of a greater length of pipe in order to obtain the necessary flexibility.

(b) Flanges and bolts at present will be employed to support the mild-steel weld metal used for butt joints.

(c) The necessity to temper finished pipes for a comparatively long time.

We feel that we can make satisfactory butt welds between stainless-steel pipes, when using a controlled “ferrite” electrode, and numerous tests have shown that crack-free welds can be produced.

It has been argued that the amount of delta ferrite present in the weld metal (usually between 3 and 6 per cent) will result in embrittlement during the expected service life of the joint; but short-time tests indicate, fairly conclusively, that the amount of “sigma phase” produced will not be significant.

Reference is made in the paper to floating-type superheater headers. It has been our experience that these do not always move as intended.

As pipework fabricators, we prefer the superheater header to be anchored, as calculated stresses in the pipework can then be accepted with confidence.

A. W. RANKIN. With the continual advances in average throttle conditions which are occurring in the power-generation industry, it is necessary for both manufacturer and purchaser alike to give careful consideration to the steels which are available for long-time high-temperature service. On both economic and strategic grounds it is necessary to minimize the employment of strategic alloys, particularly when their use does not necessarily insure more reliable performance. This paper raises many pertinent questions concerning piping and valve steels for the higher temperature levels, and the writer is pleased to make available to the industry his Company’s experiences which bear upon those questions.

Considering first the chrome-moly-vanadium steels, it is somewhat surprising to find that the statement that “vanadium may be a rather tricky addition” since vanadium has been used in bolting alloys for close to 15 years and is now in widespread use for steam-turbine shells, valves, and rotors, both in this country and abroad. In addition, there has been much recent development work in alloys containing up to 1 per cent vanadium, and alloys with 0.8 per cent vanadium are now commercially available. The writer does not wish to imply that vanadium is an element which can be employed carelessly, but in constructing steam stations for the higher temperature levels, the purchaser can rightfully demand that only competent vendors, manufacturers, and engineering organizations be used, and that all processes be adequately controlled. In particular, however, it appears that only by introducing vanadium or some equivalent precipitation-hardening element is there any possibility of employing the ferritic steels at the higher operating temperatures, and experience already available within the organizations of the major steel producers shows that vanadium additions can be adequately controlled. As a further illustration of the growing recognition of the vanadium-bearing steels, a recent ASTM specification A356-52T has been issued which contains several different turbine-casting alloys which utilize vanadium at about the 1/4 per cent level.

It is useless, however, to add a precipitation-hardening element without introducing a heat-treatment to make such additions effective. In the case of the vanadium-containing steels, this means a normalizing and tempering treatment, and if only an annealing treatment is used the vanadium addition has no advantage. In answer to the question of the permanence of the superior properties obtained by the normalizing and tempering treatment, it should be noted that it is general practice in large steam-turbine rotors and shells to utilize normalized and tempered steels, and to a considerable extent this practice is also followed on major valve castings throughout industry; in addition, of course, a normalizing and tempering treatment has been used for many years for high-temperature bolting as is outlined in ASTM A193. The degree of permanence of the resulting structure is indicated by the tempering-response curves of which several examples for chrome-moly-vanadium piping steel are shown in the authors’ reference (9). Starting with a value of 210 Bhn, 100,000 hr at 1050 F would drop this to only 175 Bhn, while 100,000 hr at 1100 F would drop it to 160 Bhn. This decrease in hardness proceeds more slowly as time increases, and subsequent softening beyond the 100,000-hr point would be relatively insignificant. Specifically, the writer’s company has run rupture tests on this steel out to 16,000 hr, and creep tests to 30,000 hr and, accordingly, the high-temperature physical pro-
ties reported for this steel already contain the major effects of pro-
longed exposure to high temperature.

Further test data are available on the rupture strength of the
chrome-moly-vanadium alloy, and the writer is taking the liberty of summarizing these in Table 6.

**TABLE 6 100,000-HR RUPTURE STRENGTH: 1 PER CENT CHROMIUM, 1 PER CENT MOLYBDENUM, 1/4 PER CENT VANADIUM**

<table>
<thead>
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<th>Temperature (°F)</th>
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<th>1000 F</th>
<th>1100 F</th>
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<td>34400 (2395)</td>
<td>34400 (2395)</td>
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<td>21000 (2638)</td>
<td>21000 (2638)</td>
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<td>18400 (2435)</td>
<td>18400 (2435)</td>
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<tr>
<td>120000 (2434)</td>
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<td>14200 (2688)</td>
<td>14200 (2688)</td>
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<tr>
<td>140000 (2645)</td>
<td>12500 (2688)</td>
<td>12500 (2688)</td>
<td>12500 (2688)</td>
</tr>
</tbody>
</table>

**NOTE:** Numbers in parentheses are laboratory item numbers.

Item 2355 was a 115-lb induction-melt ingot which was given only a short temper, and this accounts for the relatively high rupture strength at 900 F. Although some of the values reported in Table 1 are lower than the corresponding values presented in reference (9) of the paper, the average values substantiate the average rupture-strength curve given in the writer’s previous publication on this alloy (reference 9). In particular, the rupture strength is clearly superior to the rupture strength of the more common ferritic alloys.

The equivalent pipe sizes presented in the authors’ Table 5 are valuable in expressing the additional costs entailed in using the austenitic stainless steels. However, this table does not present any evaluation of the additional welding costs which arise with the austenitic steels because of the growing demand for the elimination of the backing rings, or because of the special electrodes and high postweld temperatures needed to insure minimizing the possibilities of sigma formation. Furthermore, the strategic alloys needed for the stainless steels may become difficult to obtain if defense requirements should increase unexpectedly.

With respect to the evaluation of the chrome-moly-
vandanium steel, further emphasis should be given to the conservative S-value suggested for this alloy by the authors. In particular, it will be noted from the creep and rupture-strength curves that this alloy is comparable in strength at 1100 F to the Type 347 steels, whereas the authors suggest for it an S-value considerably below that of the Type 347 steel. The writer’s company is not yet utilizing in piping the full potentialities of this chrome-moly-vanadium steel, and this is simply a conservative approach taken while getting rather prolonged field experience with a new alloy. The writer suggests that a more complete picture of the steels available for 1100 F service would be obtained if the authors would furnish, in addition to the evaluations based on their suggested conservative S-value, an evaluation of the possible cost savings if the chrome-moly-vanadium steel is utilized on the same bases as the other ferritic and austenitic alloys.

With respect to welding of steam piping, the concept of using an electrode that deposits weld metal with the same composition as the base metal is a generalization from which frequent departures are made. The most obvious of these is the welding of carbon steels in which the carbon content of the weld deposit is appreciably lower than that of the base material. Another obvious example is in the welding of the titanium-stabilized Type 321 austenitic stainless steel on which a columbium-stabilized Type 347 rod is used whenever it is necessary to obtain adequate resistant to intergranular corrosion. In particular, however, one can refer to the very frequent use of austenitic electrodes for making restrained welds in ferritic steel to indicate that the basic concept in selecting the electrode alloy is simply to obtain a reliable weld of the required physical characteristics. With the chrome-moly-vanadium alloy, we are using a vanadium-free electrode because prolonged high-temperature tests have indicated that the vanadium in the form as currently deposited in the weld metal does not contribute to high-temperature strength. We recognize that the resultant weld deposit is lower in strength than the base metal, and we compensate for this, as the authors point out, by building up the pipe ends with weld deposit, which ends are subsequently fully heat-treated. This is basically no different from the practice of utilizing upset ends at the weld joints as shown, for instance, in the ASA B31 Code for Pressure Piping. We have been working quite actively for several years to develop a weld deposit whose high-temperature strength is comparable to the base material, and believe that we now have a particular composition in which the desired results will be achieved.

With respect to the graphitization resistance, we have not been aware of any significant graphitization even in chromium-free weld deposits proper, either in the field or laboratory tests. The serious graphitization which has plagued the power-generation industry has been of the chain form at the heat-affected zone which is well outside the zone of dilution between the weld deposit and the base material. Although we have not encountered any graphitization in weld deposits proper in laboratory tests of over 40,000 hr duration at 1100 F, we are currently developing an electrode with 1 per cent of chromium because of the several questions that have arisen on this point.

Turning now to the austenitic steels, the degree to which such a steel is fully austenitic depends more on the chemical composition than the heat-treatment as suggested by the authors. For instance, an austenitic weld deposit is cooled very rapidly from the completely molten condition, and yet it is not necessarily fully austenitic unless the electrode composition has been balanced carefully. It is the practice of the writer’s company to specify the composition of our steam-turbine austenitic steels so that they are fully austenitic even without a rapid quench; in the austenitic electrodes, however, the composition is balanced so that the weld deposit does contain a small amount of ferrite.

In the welding of the austenitic steels, we also have encountered the problems of root-cracking and sigma formation. In the two 1100 F units which we have constructed for the Kearny station of the Public Service Electric and Gas Company, New Jersey, of which one is already in operation, the welding was done without backing rings by several different methods; the electrode deposited a composition containing between 1 per cent and 5 per cent fer-

te, while a postweld treatment of 1025 F was employed. By these three innovations, we believe we have eliminated the root-

head cracks and at least minimized considerably the formation of sigma at the operating temperature. As a matter of interest, a paper is now being prepared to present to the industry the contribu-
tions by the writer’s company in the development of this electrode and postweld treatment.

In conclusion, the writer would like to discuss the welding of dissimilar metals, specifically the welding together of austenitic and ferritic steels. This is a type of welding which usually is avoided where possible, but experience indicates that it can be ac-
cepted when the economic results justify it. In particular, it should be noted that literally thousands of jet-engine wheels were made using an austenitic-to-ferritic weld during the last war, and this process is still being used for gas turbines by the writer’s company. In addition, about twelve austenitic-to-ferritic welds have been made in 1050 F turbine main steam piping, and it is the writer’s understanding that such joints are also made frequently in steam-boiler construction. In addition to the austenitic-to-
ferritic welds made with a Type 347 electrode now in service in 1050 F steam stations, we also have a weld between Type 347 austenitic stainless steel and 21/2 per cent chrome, 1 per cent moly, ferritic-steel pipe sections, of 14-in. OD with a 3-in. wall, made
with an inconel electrode (78 per cent nickel, 15 per cent chrome) which has been in laboratory test for almost 2 years. This weld has been cycled between 300 F and 1100 F more than 250 times with no defects whatsoever being found at any part of the joint. The particular feature of the inconel weld deposit is that it has an expansion coefficient equal to that of the ferritic steel, and accordingly puts the differential-expansion stresses on the austenitic rather than the ferritic side of the weld. The deposit is quite ductile and has high-temperature properties at least equal to those of the chrome-moly-vanadium alloy. A test vessel containing such a weld is now being prepared for installation in a steam station utilizing 1050 F steam, and at this location it will be subjected to full throttle pressure and temperature and will be cycled thermally as frequently as conditions will permit. Based upon the current laboratory tests, however, this inconel weld deposit holds considerable promise in the design of piping for high-throttle pressure and temperatures.

The writer is in complete agreement with the authors' statements that a thorough inspection be made of each individual pipe length. It is the practice of the writer's company to require from the pipe manufacturer a certificate detailing the chemical composition and the physical properties, and stating that etch and flattening tests have been made in accordance with our specification on each end of each pipe length. In addition, the pipe manufacturer conducts the usual hydrostatic tests on each pipe length. All the foregoing data are reviewed by both the fabricator and our own laboratory. Further micrographs are obtained from the fabricator following final normalizing and tempering treatment together with a certificate that the specifications heat-treatment has been followed. The writer wishes to stress particularly the use of the ultrasonic inspection methods detailed in the authors' reference (29). All of our main steam piping is given a complete ultrasonic inspection before fabrication, and, in addition, we subject the bent portions of the chrome-moly-vanadium alloy to a second ultrasonic inspection after bending. In our judgment, all main steam piping should be subjected to an ultrasonic inspection in order to ensure that the quality of the piping is adequate for the intended service.

In their conclusions the authors state that it should be feasible to extend the ferritic steels to 1100 F throttle conditions, but without specifically recommending any particular ferritic alloy. The chrome-moly-vanadium steel, even when so conservatively evaluated as in this paper, offers significant economic gains, but its use demands careful control on all the design, manufacturing, fabricating, and installation operations. At the same time, it is proper for the purchaser of such high-temperature equipment to demand careful control over all the equipment intended for such advanced throttle conditions, and the manufacturers must be prepared to furnish such close control.

D. B. Roshni-k and E. F. Shaffer. The authors have prepared a thought-provoking and helpful paper which is of timely interest to all high-temperature high-pressure piping engineers. The following comments are intended to supplement the authors' treatment of certain aspects of the subject.

**Code Bases for S-Values.** The subject matter treated under this heading might more properly be given a broader title, such as, "Design Stresses and Other Criteria." At the present time, as pointed out by the authors, the ASME Boiler and Pressure Vessel Code governs the suitability of a material for a given service by establishing allowable stresses and by approval of material specifications. In addition, the transition temperature for materials in low-temperature service is regulated by minimum impact values. Shock resistance is not controlled above minus 20 F, there are no requirements on fatigue strength, nor are elevated temperature tests required to assess ductility either on a short-time basis or under prolonged exposure to temperature. Also, as implied in the paper, the data which are used for creep rate and time to fracture are usually extrapolated from values obtained in 500 to 1000-hr tests and hence do not include the effects of structural changes in the metal which may possibly occur over longer intervals of time.

There is considerable difference of opinion as to the influence of ductility on safe performance; however, in services where plastic deformation may occur, we believe there is general agreement that retention of ductility is significant and may be particularly important for the heat-affected zones of welds. In general, it is our feeling that more attention should be paid to high-temperature fatigue and impact properties with greater effort toward assessing the properties of materials which have been subjected to stress at elevated temperature for a considerable length of time. The research physicists and metallurgists can perform a valuable service for the piping engineers in the direction of establishing or clarifying relations between fracture under creep conditions (so-called stress rupture) usually having an appearance of low ductility, and the high ductility exhibited in short-time tests on remaining pieces of the same material.

It would have been appropriate for the authors to mention in this section the "stress range" to which the thermal-expansion stresses are related. Essentially, this is a concept which follows from the observation that relaxation takes place during operation, which results in all or the greater part of the expansion effects eventually vanishing only to reappear as a shutdown or cold stress. As a result, piping systems are subjected to a cycle of stress of an amplitude or range which remains relatively constant for initial or subsequent cycles. In accordance with Piping Code rules, this stress range is kept within a value derived from the ambient and service temperature allowable stresses. This approach assumes that failure due to thermal-expansion effects will be essentially of a fatigue nature and related to the number of cycles of temperature change involved.

The authors' brief remarks on the subject of cold spring appear in need of clarification. They correctly point out that a high-temperature line eventually will acquire about the same amount of cold spring regardless of whether this condition is obtained by pre-spruing during erection or by self-spruing during service. This fact, however, refutes rather than supports the subsequent conclusion that prespringing of from 1/2 to the full computed expansion is advisable. The missing point is that prespringing serves two purposes:

1. It reduces or eliminates the amount of plastic strain occurring in the pipe due to relaxation.
2. It reduces or eliminates initial high-order hot reactions on connected equipment.

The first of these is of doubtful benefit since the amount of strain is necessarily small and, as it occurs only once, it is not significant from fatigue considerations. The second is of great importance where sensitive equipment such as turbines are involved, which may be thrown out of alignment or otherwise damaged by hot piping reactions which may reflect the full yield strength of the material before relaxation with time. This philosophy has been accepted in the proposed revisions to the Code for Pressure Piping. In these rules the same allowable stress range is permitted whether or not the system is presprung. The effect of prespringing in lowering initial reactions is recognized to the extent of allowing the hot reactions to be reduced by 1/2 of the prespring.

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1. Chief Mechanical Engineer, The M. W. Kellogg Company, New York, N. Y., Mem. ASME.
Attention also is directed to the fact that these new proposed rules of the Piping Code provide a relation between the anticipated cycles of service and the allowable stress range which may be used, and also for an increase in the basic stress range. In making these rules available for comment and criticism, the Piping Code Committee also presented certain alternative provisions advanced by H. V. Wallstrom in representation of the writers' Company as a member of the Task Force on Expansion and Flexibility. These define the piping for which stress analysis would be mandatory and thus represent an effort to recognize the transition of the Piping Code from a designer's code of good practice to a safety code, suitable for adoption by states and municipalities for enforcement of rules for pipe construction. Interest on the part of enforcement authorities is already in evidence in connection with the new Section VIII on Transmission Lines, which has been adopted or is in the process of adoption by several states, and further by the organization of a Conference Committee composed of the chief inspectors of each state and the provinces of Canada.

**Welded Joints.** In the previous section on Selection of Materials for 1100 F Service austenitic steels are stated to be difficult to weld without producing cracks. In this section under Welding Austenitic Steels, further emphasis is placed on the difficulties of making satisfactory austenitic weldments and undesirability of quenching from above a so-called critical range. It would take considerable space adequately to refute the authors' contentions; however, a companion paper by W. G. Benz and R. H. Caughey11 of the writers' company, presents information to show that satisfactory austenitic welds in heavy-wall pipe can be achieved without undue difficulty. Connecting an initial anneal and carbide-solution treatment with preheating and stress-relieving is not valid, in the writers' opinion. A lack of observed benefit in preheating austenitic steel is in no way connected with the initial treatment of the material. As to postheating, it is true that such treatment or service temperatures above approximately 900 F tends to precipitate carbides with reduced ductility and impact strength. However, the values obtained for both of these properties are quite adequate and usually superior to those obtained for ferritic steels.

In connection with the section, Welded Joints Between Dissimilar Metals, it is recommended that such a weld between a valve and a stub end be made in the shop, so that field welds will be between similar materials. It would be desirable to extend these precautions to further favor the dissimilar weld joint by choosing a location so that stress intensification including bending stress or other local effects are avoided. In the case of a valve, the welding end is of such limited length that discontinuity stresses may be anticipated; accordingly, it would be preferable to first shop-weld a stub end of the same composition to the valve so that the dissimilar weld is located between two short sections of pipe which are, however, of sufficient length so that extraneous stresses will not be imposed upon the weld. It is, of course, always desirable to perform the attachment of welding-end valves to piping in a well-equipped shop rather than in the field, even at the expense of additional welding.

**Herman Weisberg.** The authors have done a thorough job outlining the factors involved in the design of a piping system for 1100 F operation. The principal question raised is the possibility of utilizing ferritic steel in place of the austenitic steel now in use for this service; and a case is made for a chromium-molybdenum-vanadium composition, which in the laboratory shows promise of high strength at this temperature.

The suitability of a steel for high-temperature high-pressure service, in the last analysis, depends to a large extent on the ability to produce sound field welds in heavy-wall piping. The particular ferritic steel under discussion owes its high-temperature strength to a special heat-treatment. Aside from the fact that the code-writing bodies have been reluctant, and, in fact, up to this time have entirely avoided crediting a material for extra strength at high temperatures, resulting from heat-treatment, there is considerable question whether this steel can be welded in the field without destroying its high-temperature properties at some point in the weld-heat-affected zone of the base material. This is a most dangerous type of impairment of strength because it occurs in a plane directly across the pipe. One pictures the type of failure which occurred due to graphitization at Springdale. We have had in service at Essex Station (1000 F) a similar material, without the chromium addition, for almost 6 years. The design stress, however, is no higher than in the 2 1/4 chrome, 1 moly pipe in the same piping system. Prior to utilizing this type of steel at stress levels which take into account the improvement in high-temperature strength due to heat-treatment, there should be considerably more test data developed on the long-time, high-temperature properties determined from across-the-weld specimens.

Welds in austenitic piping also present a problem, as pointed out by the authors. Considerable progress, however, is being made in developing welding techniques, which result in sound and stable austenitic welds, as related in a companion paper by Benz and Caughey.11 Furthermore, keeping in mind future requirements for still higher temperatures we prefer to stay with this higher-alloy material, which from corrosion and strength considerations is good for considerably more temperature than 1100 F. Therefore we have tended to use more of it rather than revert to the lower alloys, which must be extended to their maximum capability in order to meet the requirements of operation even at 1050 F.

Within the past year we have procured a heat of pierced and rolled seamless stainless tubing for the main steam piping of a 185,000-kw unit being installed at Burlington. This is 10/4-in. OD x 1/2-in-wall, Type 347 stainless tubing made by Timken and is possible in the austenitic material only because of the considerably reduced wall thickness. In order to utilize piping this small in diameter on so large a unit, the steam flow is divided between two leads originating at the quarter-points of the outlet superheated-steam header. The inlet tubing to this header is cross-connected, so that equal steam temperatures result in each of the outlet-steam leads. Steam velocity is 15,000 fps. Piping designed for this velocity and arranged as described is now in service at Kenny and is operating satisfactorily from the standpoint of noise and vibration as well as equalization of temperature between the two leads. In testing the emergency stop valves one lead has been shut off completely at full load, forcing most of the steam through the other lead, without appreciable increase in noise or vibration levels. Inasmuch as the emergency stop valves may be tested during off-peak periods, when, if necessary, the turbine load can be reduced, even higher design velocities are practicable if they are found economical.

It appears, therefore, that this arrangement, utilizing seamless tubing rather than the much more expensive forged and bored pipe, can be extended to any size unit now under consideration. As a result we find that it is possible to install an 1100 F austenitic main-steam-piping system for only slightly greater total cost (Table 7 of this discussion) than a 1050 F ferritic piping system.
which because of the lower allowable working stress must of
necessarily be forged and bored.

<table>
<thead>
<tr>
<th>TABLE 7 COMPARISON OF PIPING COSTS—MAIN STEAM PIPING</th>
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A. E. WHITE.13 The paper is an excellent example of the service
which our specification and codmaking bodies have rendered in the
selection of proper materials for high-temperature service.

The statements with regard to welded joints, as they relate to
both the ferritic and the austenitic types of welds, are most
constructive. The reference to "welded joints between dis-
similar metals" possibly could be extended somewhat to point
out that the difficulty in welding dissimilar metals increases as
the diameter of the metals increases. That is, there would be no
difficulty in welding 2-in. superheater tubes, even though the
welds connected dissimilar metals, but it would be quite a dif-
ficult problem if the diameter of the tubing or piping were of the
order of 10 or 12 in.

The writer quite agrees with the statements made by the
authors that "it is good practice to weld stub ends of pipe
material to the valve ends in the shop." Also, the writer is in
complete agreement with the statement that special care should
be taken in the examination of welded joints, such as the use of
x rays, gamma rays, a supersonic reflectoscope examination, and
other methods which will throw light on the quality of the weld.

The writer wishes to compliment the authors of this paper on
their valuable contribution to matters relating to design of
steam piping and valves for high-temperature service.

A. B. WILDER.14 The authors have presented very helpful
information regarding steam piping for 1100°F steam. Reference
is made to the heat-treatment of ferritic materials for high-
temperature service. Some of the results we have obtained with
Cr-Mo-V steel may be of interest and are shown in Tables 8, 9, and
10.

The importance of heat-treatment is illustrated by Steel B.
This material, after exposure at the temperatures indicated for
periods of 10,000 and 100,000 hr, will be creep-rupture-tested.
Alloys of the Cr-Mo-V type require high solution temperatures
for the vanadium carbides, and the mechanical properties are in-
creased by aging at temperatures below the thermal critical range.
The evaluation of the stability of the creep-rupture properties is,
therefore, important.

TABLE 8 CHEMICAL ANALYSIS

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>P</th>
<th>Mn</th>
<th>Mo</th>
<th>Cr</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>A...</td>
<td>0.12</td>
<td>0.52</td>
<td>0.014</td>
<td>0.016</td>
<td>0.18</td>
<td>0.96</td>
</tr>
<tr>
<td>B...</td>
<td>0.12</td>
<td>0.43</td>
<td>0.011</td>
<td>0.010</td>
<td>0.23</td>
<td>0.98</td>
</tr>
</tbody>
</table>

TABLE 9 HEAT-TREATMENT AND TENSILE PROPERTIES

<table>
<thead>
<tr>
<th>Steel</th>
<th>Heat-treat</th>
<th>Yield strength, psi</th>
<th>Tensile strength, psi</th>
<th>Elong., per cent</th>
<th>Red., per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>air-cooled</td>
<td>1050°F—1 hr</td>
<td>1050°F—2 hr</td>
<td>1050°F—1 hr</td>
<td>1050°F—2 hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>37000</td>
<td>42000</td>
<td>37000</td>
<td>42000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35000</td>
<td>40000</td>
<td>35000</td>
<td>40000</td>
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<tr>
<td></td>
<td></td>
<td>31000</td>
<td>36000</td>
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<tr>
<td></td>
<td></td>
<td>28500</td>
<td>33500</td>
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<tr>
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<td>24500</td>
<td>30500</td>
<td>24500</td>
<td>30500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20500</td>
<td>27500</td>
<td>20500</td>
<td>27500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18000</td>
<td>25500</td>
<td>18000</td>
<td>25500</td>
</tr>
</tbody>
</table>

We do not see why a suitable welding rod containing vanadium
with molybdenum and chromium cannot be developed to produce
sound welds. It would be desirable to use a rod which will possess
strength properties similar to the Cr-Mo-V pipe material.

Reference is made to the usefulness of photomicrographs of
each end of each length of pipe. We do not believe this practice
is necessary, but we do appreciate the value of representative
photomicrographs of the product. These would be useful for future
reference.

With reference to the ultrasonic examination of piping material
for flaws, it should be pointed out that this type of testing is not
adapted at the present time to the production of pipe in the pipe
mills. The method is very slow and expensive. The most prac-
tical way to inspect pipe by this method is in the pipe-fabricating
plant. When the ultrasonic method for inspection has been im-
proved to the extent that the interpretations are more certain,
and the time required for inspection is reduced, the method should
receive more favorable consideration throughout the industry.

The user, at his own convenience and with his own facilities, may
inspect pipe by the ultrasonic method. However, rejections
which may be the responsibility of the producer can be based only
upon defects which are beyond the standard ASTM specifications
to which the pipe was produced.

H. W. WYATT.15 The authors are to be congratulated for their
objective and clear-cut presentation of the problem of "austenitic
versus ferritic" steel for 1100°F steam service.

Comments by the writer are from the viewpoint of manufacture
of ferritic castings, and their applications in high-pressure high-
temperature steam valves.

When steam temperatures went well beyond 750°F, and some-
what above 900°F, two casting materials came into the codes and
specifications. Carbon-moly (ASTM A217—Grade WC1) was
the more widely used. Investigations since the 1943 graphiti-
zation occurrence in piping have shown that the less widely applied
grade, the nickel-chromium-molybdenum casting composition,
Grade WC4 of A217, is completely free from graphitization. No
evidence of structural, corrosive, or mechanical deterioration has
been noted in the nearly 20 years since it was brought out. As a
result of investigation and study, the metallurgists with whom
the writer is associated and the writer believed that the load-
carrying capacities of the 1/2 per cent molybdenum types of steels,
such as Grades WC4 and WC6 of A217, are not as high as might
be desirable for services, say, to 1050°F. Therefore a modifica-
tion of WC4, with 1 per cent molybdenum (Grade WC5 of A217)
was developed and used in main stop and other valves in the first
large United States central station operating at 1000°F in 1946.

13 Director, Engineering Research Institute, University of Michi-
gan, Ann Arbor, Mich. Fellow ASME.
14 Chief Metallurgist, National Tube Division, U. S. Steel Corpora-
tion, Pittsburgh, Pa.
Since that time valves of WC5 material have been installed in main steam lines of a number of stations operating from 900 F to 1050 F, at pressures to 2150 psi at 1050 F. Fabricators have met all procedures and operator qualifications in joining same to the following and other wrought piping materials A213-T12 (1 per cent Cr, 1/2 per cent Mo); A213-T21 (3 per cent Cr, 1 per cent Mo); A213-T22 (2 1/4 per cent Cr, 1 per cent Mo). No joint troubles have been reported in service of these weldments to piping.

Grade WC9 of A217, as mentioned by the authors, also has had consideration and use. As shown by the authors, in cast materials (authors’ reference 10) and by others for wrought materials (reference 11), WC9 leaves something to be desired in its stress-rupture characteristics at 1050 F.

The authors suggest that it is desirable that the nominal “chemistry” of piping and casting be similar. It is agreed that it is desirable that the mechanical and structural characteristics of the casting and pipe each be suitable for the contemplated service, and be suitable for joining by the same electrode, i.e., the weld deposit be compatible to casting and pipe. The authors present clearly the problems inherent in suitable joining of austenitic and ferritic materials, also with the vanadium-bearing ferritic steels. Adequate references are given to the inadequacies and/or marked differences in mechanical, structural, expansion, and other characteristics. However, such differences in behavior are not found in joining the compositions, WC5 or WC9 with T22 piping. The casting process is quite different in several respects from wrought processes. In comparison of cast and wrought steels of similar alloy content, the casting process tends to give greater hardenability, both due to the process itself and to the usual higher manganese and silicon which are used to promote casting soundness. The silicon and manganese are alloying elements and in any comparison should be considered as well as the chromium, molybdenum, vanadium, and nickel. The relative hardenability of T22 piping is 10.3, WC9 is 14.5, and WC5 is 10.4. WC5 matches T22 quite closely in hardenability. It also possesses a much more bead hardness before stress relief, much lower than WC9 (carbons the same). WC5 in these respects actually behaves structurally and mechanically closer to T22 than does WC9. The expansion-contraction and dilatometric characteristics of all three materials are closely alike. WC9 and WC5 are similar in creep (1100 F) but WC5 has considerable advantage in stress-rupture. Creep and stress-rupture tests of WC5 at 1150 F show much less drop in strength for an increase of temperature from 1100 to 1150 F than for a fifty-degree temperature increase from 1050 to 1100 F. Final results will be presented later.

The authors present data on the General Electric Company’s cast chrome-moly-vanadium steel and mention another cast chrome-moly-vanadium steel to be introduced into ASTM specification A217. The two materials should not be confused. The General Electric Company’s steel has a special treatment producing high hardness and high creep strength accompanied with low ductility. (High normalizing temperatures and careful age-hardeners are used.) The proposed ASTM chrome-moly-vanadium steel is said to be heat-treated to a low hardness and a more modest creep strength accompanied with good ductility.

The average of the reported values of creep strength at 1100 F of composition similar to the proposed A217 chrome-moly-vanadium steel approximates the creep strength of WC5 at the same temperature.

The writer agrees with the authors that study and trial may show that through proper selection and application the usage of ferritic steels at 1100 F may be safely feasible and, if so, economical.

**Authors’ Closure**

The authors wish to express their feeling that the several discussers of the paper have contributed materially toward fulfilling the objectives of the session at which the paper was presented. The authors were invited to contribute a paper that would survey present knowledge applicable to the design of steam piping and valves for 1100 F, and with a view to stimulating further discussion of the subject. It is indeed gratifying that the discussers have responded so well in bringing different slants on the expected behavior of materials available for 1100 F steam service.

As expressed in the paper, the authors had hoped that others would comment on various angles of the high-temperature problem and bring to bear ideas that will help in obtaining an economic solution. The authors themselves are open-minded on this subject and are chiefly interested in seeing that all avenues of approach are explored so that the possibilities of alternative materials will be better understood.

The relative costs of austenitic and ferritic construction given by Mr. Weisberg are somewhat at variance with the cost data and estimates of the authors. Mr. Weisberg’s figures for P-22, forged turned, and bored pipe are a step higher than those of the authors for this material, whereas his figures for Type 347 seamless pipe are a step lower. Consequently there is a crossing of base prices which tends to magnify the variance in cost ratios derived therefrom and leads to different conclusions concerning the relative costs of the two kinds of steel. In view of the difficulty in reducing such comparisons to the same absolute bases, it is recommended that those wishing to pursue the matter further estimate their own costs for the specific cases they wish to compare.

After the manuscript for this paper was prepared, Braca and Merima presented a valuable contribution concerning several phases of the same subject which is available for reference. In addition to giving easily understood definitions of basic phenomena encountered with metals in high-temperature service their article features data on the corrosion resistance and relative cost of several of the alternative steels considered in the present paper.