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HIGH-STRENGTH MATERIALS FOR PRESSURIZED-
WATER IN-PILE TUBES

by

Ward F. Simmons
Walter K. Boyd
Raeman P. Sopher
Fred H. Lyon

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BATTELLE MEMORIAL INSTITUTE
505 King Avenue
Columbus 1, Ohio

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HIGH-STRENGTH MATERIALS FOR PRESSURIZED- WATER IN-PILE TUBES

Ward F. Simmons, Walter K. Boyd, Raeman P. Sopher,
and Fred H. Lyon

BMI-1224

The preliminary work done by Westinghouse on properties of materials suitable for the in-pile testing facility was reviewed. Information was collected on a selected list of promising materials in the following classifications: alloy steels, chromium steels, precipitation-hardening stainless steels, and superalloys. On the basis of the information obtained from Westinghouse, from the literature survey, from Battelle files, and from visits to producers, it is recommended that Phase II of the program be confined to Inconel X hot rolled and aged, AM-350 subzero cooled and tempered, and Discaloy solution treated and aged. The future work necessary is detailed in a separate proposed research program.

The process of making coextruded tubes developed by The Babcock & Wilcox Company appears promising for similar applications (where a high-strength outer layer is required in conjunction with a highly corrosion-resistant inner layer).

INTRODUCTION

Westinghouse is considering the construction of a tubular test facility for in-pile testing of fuel elements. The tubular section desired must be 4.5 to 5 in. in diameter. The tests will be performed in two types of reactors. The first type has a low power density and, consequently, a low gamma-heat-generation rate. For use in this type of reactor, it is important to have minimum perturbation of the neutron flux by the test section. The estimated metal temperature of the tube is 600 F. The second type of reactor has a very high power density accompanied by a high gamma heat. For the high-power-density reactor, it is important to design the test section to minimize gamma heating and the resultant thermal stresses. The estimated temperature of the tube in this reactor is 800 F. The use of thin walls for the pressure vessel would be helpful in either type of reactor. However, the use of the minimum wall thickness requires maximum-strength material.

A program of research is being carried out by Battelle to review and obtain data for several steels and high-temperature alloys of possible interest as materials of construction.

The objective of the program is to provide, by a search of available information and by experiment, additional data needed by Westinghouse to design and construct in-pile test vessels. In accordance with the Westinghouse requests, the program is being undertaken in two phases as follows:

Phase I Review of preliminary Westinghouse data, literature search, and discussions with alloy producers to obtain a maximum of information on possible tube materials.

Phase II An experimental program in close cooperation with Westinghouse directed toward supplying missing information.

This report on Phase I reviews all of the information available to date and recommends the materials to be studied experimentally in Phase II.

DISCUSSION OF MATERIALS

The available data for each of the materials selected for consideration are given in the Appendix to this report. A summary of the strength and engineering properties required to design the pressure tube has been presented by Westinghouse as follows:

- (1) Tensile strength
 - 120,000 psi for the moderate-flux reactor
 - 160,000 psi for the high-flux reactor
- (2) 0.2 per cent yield strength
 - 48,000 psi for the moderate-flux reactor
 - 64,000 psi for the high-flux reactor
- (3) Stress producing a creep rate of 0.01 per cent per 1000 hr
 - 30,000 psi for the moderate-flux reactor
 - 40,000 psi for the high-flux reactor
- (4) Minimum stress producing rupture in 100,000 hr
 - 38,000 psi for the moderate-flux reactor
 - 50,000 psi for the high-flux reactor
- (5) Reasonably good ductility
- (6) Low notch sensitivity
- (7) Thermal conductivity greater than 10 Btu/(hr)(ft)(F)
- (8) Coefficient of thermal expansion less than 10^{-5} per F
- (9) Low neutron-absorption cross section
- (10) Sufficiently good corrosion resistance so as to eliminate the necessity for a corrosion allowance
- (11) Negligible change of the heat-treated properties by exposure to fast-neutron radiation

- (12) Stability of the properties obtained by heat treatment at the operating temperature of the pressure tube
- (13) Weldability to itself and to 18-8 stainless steels.

The materials which were considered in this phase of the work are enumerated under their general classifications in the following list:

(1) Alloy steels

17-22AS
SAE 4340

(2) Chromium steels

AISI 410
AISI 414
AISI 422
Croloy 16-1

(3) Precipitation-hardening stainless steels

AM-350
AM-355

(4) Superalloys

A-286
Discaloy
W-545
Inconel X

Strength Properties

The high-temperature-strength properties of the alloys, along with corrosion resistance and weldability, are of primary importance in this application.

All available strength data have been plotted against temperature in Figures A-1 through A-10 in the Appendix. These data are incomplete, particularly for the creep and 100,000-hr rupture curves. However, the curves tend to indicate whether the short-time or the long-time properties will be the primary factor in design at the temperatures of interest (600 and 800 F). For example, in Figure A-6 the 0.00001 per cent per hr creep-rate curve for AM-350 alloy (although this curve is for sheet material) is below the yield- and tensile-strength curves at 600 and 800 F, indicating the long-time properties would control in design. However, for the A-286 alloy in Figure A-7, the 0.2 per cent offset yield strength is below the long-time data curves at 600 and 800 F, indicating that for this alloy the design could probably be based on the short-time tensile data.

Of the strength requirements, the tensile strength of 160,000 psi at 800 F is probably the most difficult to meet. However, in high-temperature design under conditions where creep is not significant and the short-time-strength properties control, it is the yield strength and not the tensile strength that is important. Therefore, in analyzing the strength properties of the various alloys, the tensile strength has been given less weight than the yield strength or the long-time strengths (creep and rupture strengths).

Alloy Steels

The alloy steels 17-22AS and SAE 4340 can be heat treated to quite high short-time tensile strengths, but the heat treatments that produce the best short-time strengths do not necessarily yield the best long-time creep and rupture properties. The data given in Figures A-1 and A-2 are representative of heat treatments aimed at producing good creep and rupture properties and not the best short-time strengths.

From a strength standpoint, these alloys would probably be satisfactory for this application, but they have not been selected for further study because of their lack of corrosion resistance.

Chromium Steels

The available high-temperature data for the chromium steels AISI Types 410, 414, and Type 422 are shown in Figures A-3, A-4, and A-5, respectively. These steels are all heat treatable and short-time strengths of the magnitude desired are possible. However, long-time properties for AISI Types 410 and 414 are on the border line at 800 F. The long-time properties of Type 422 (this is not a proprietary alloy, but it is usually associated with Crucible Steel Company and it has not been assigned an AISI number) are well above the desired strengths at both 600 and 800 F. However, the suitability of these alloys from a corrosion standpoint is doubtful.

Insufficient data were available to plot the high-temperature strength of Croloy 16-1, but from the limited data at hand, it appears that the strength level of this alloy at 600 and 800 F is too low to warrant further consideration.

Precipitation-Hardening Stainless Steels

Most of the published high-temperature strength data for AM-350 are well above the requirements for this application. The data are given in Figure A-6. The creep data shown in Figure A-6 are lower than desired at 800 F, but it is believed that this may be the result of testing sheet specimens rather than bar specimens. It is recommended that the creep properties of this alloy be checked under Phase II of the project.

AM-355, a modification of AM-350, has higher strength properties than AM-350, but less is known about the production and heat treatment of this alloy. It is recommended that any further consideration of the precipitation-hardening alloys be given to AM-350.

Superalloys

The superalloys as a group were developed to possess high creep and rupture strengths at high temperatures, usually above 1100 F. Also, as a rule, the room-temperature (and low temperature) tensile and yield strengths were of little importance. Therefore, it is not surprising that only one alloy, Inconel X, among the four alloys surveyed met the tensile requirement of 160,000 psi at 800 F. All of the alloys had creep and rupture strengths well above the specified requirements at 600 and 800 F. Figures A-7 through A-10 show the high-temperature strength data for A-286, Discaloy, W-545, and Inconel X alloys.

Most superalloys are age hardening, and their best high-temperature properties are developed by a high-temperature anneal followed by aging at some lower temperature. This is true for all of the alloys under consideration here. However, Inconel X has superior short-time strength properties at 600 and 800 F in the hot rolled-and-aged condition. The best long-time properties at high temperatures (over 1200 F) do result from a solution-and-aging treatment, but at 600 and 800 F the long-time properties of the hot rolled-and-aged material should be adequate.

Inconel X is the only superalloy studied in Phase I which does not require a high-temperature solution heat treatment to develop the required strength properties in the temperature range of interest. In fact, it is the only alloy studied for which only an aging treatment is needed.

Since the strength data were obtained from annealed-and-aged or hot rolled-and-aged bar stock, it is recommended that extruded-and-aged tube material be obtained and evaluated in Phase II of the project.

Inconel X appears to be the most promising superalloy from the standpoint of high strength and ease of heat treatment. Because of its high nickel content and resulting high neutron depression, Inconel X may not be satisfactory for use in the moderate-flux reactor. Therefore, it is recommended that the lower nickel superalloy, Discaloy, also be evaluated in Phase II. Discaloy does not meet the tensile-strength specifications, but it does meet the yield-strength requirement and the creep and rupture requirements. Discaloy has approximately one-third as much nickel as Inconel X.

Miscellaneous Alloys Suggested by Producers

Several alloys were suggested by the alloy producers as possibilities for this application. These are tabulated as follows:

<u>Alloy</u>	<u>Producer</u>
419	Allegheny Ludlum Steel Company
16-15-6	Timken Roller Bearing Company
Incoloy 901	International Nickel Company, Inc.
Coextruded tubes	The Babcock & Wilcox Company

The 419 alloy is a modified 12 w/o chromium steel with strength properties somewhat similar to those of 422. The 16-15-6 alloy is a low-nickel modification of 16-25-6 alloy. It has not been produced commercially in tube form and suitable strength

properties would have to be produced by cold working. Incoloy 901 is an age-hardenable sheet alloy that has attractive properties in sheet form. However, no information is available on heavier sections. None of the above alloys is regarded as outstanding enough to consider further in Phase II.

Coextruded tubes produced by The Babcock & Wilcox Company appear to have considerable merit. Such a bimetal tube consisting of a corrosion-resistant inner layer and a high-strength outer layer (bonded together) could probably be engineered to meet the various requirements of the tubular test section. This production process is just out of the experimental stage, and it is not recommended that these tubes be evaluated in Phase II. However, tubes produced by this process are considered of sufficient interest for the application to warrant further study. It is suggested that Westinghouse engineers contact Mr. R. D. Wylie, The Babcock & Wilcox Company, Barberton, Ohio, for additional information regarding coextruded metal tubes.

Corrosion Properties

Of the considerable corrosion information available in the literature, only a limited amount is directly applicable to the water conditions (pH 9.5 to 10.5 with LiOH and hydrogen and pH 4 to 5 with oxygen) and the alloy compositions under investigation. For this reason, this information is presented in terms of general material classifications. The general corrosion rates shown below for the various materials do not appear excessive from the standpoint of loss in strength. Although these data do provide an indication of corrosion behavior, additional laboratory studies will be required to establish definitely the serviceability of many of the alloys under consideration at this time.

Alloy Steels

Little or no information was found for SAE 4340 or 17-22AS. However, one would expect them to exhibit corrosion properties similar to plain carbon steels. On this basis, the data indicate a general corrosion rate of 100 to 200 mg/(dm²)(month) in 600 F degassed neutral water. At a pH of 10 or 11, this rate might be lowered by a factor of 10. These rates correspond to a penetration of only about 1 mil per year which, from the standpoint of loss in strength, is very low. However, the limiting factor appears to be the pitting rate. The plain carbon and low-alloy steels are subject to rapid pitting attack, especially in the presence of dissolved oxygen. In addition, the low-alloy steels are especially sensitive to crevice and galvanic corrosion. The possibility of hydrogen embrittlement in the presence of high stress levels and radiation also must be considered.

At a pH of 4 to 5 in the presence of oxygen, one would not expect these low-alloy materials to have a useful corrosion life.

Because of the susceptibility to pitting and the short life in low-pH waters, these alloys do not appear suitable.

Chromium Steels

Of the martensitic chromium steels, only the AISI 410 stainless has been extensively investigated in high-temperature water. Data for the 414 and 422 alloys are incomplete. However, the available data indicate that the corrosion resistance of the martensitic alloys in 600 F water is between that of mild steel and the 300 series of stainless steels. The presence of dissolved oxygen in the water increases general corrosion rates, whereas hydrogen reduces corrosion, as does adjusting the pH to 10 or 11. The main disadvantage of the martensitic steels is their low resistance to pitting and crevice corrosion. Both are especially serious in the presence of dissolved oxygen. Consideration must also be given to stress corrosion cracking, especially in the presence of chlorides.

In general, it appears that, at a pH of 9.5 to 10.5 with hydrogen, the martensitic alloys have adequate corrosion resistance. On the other hand, at a pH of 4 to 5 with oxygen, one would predict high, if not excessive, corrosion rates. However, service life in the lower pH water will have to be established.

Limited data are available for the Croloy 16-1 alloy. In general, the data indicate corrosion behavior in neutral and high-pH water comparable to 18-8 stainless steel.

The factors of pitting and crevice corrosion do not make the use of these alloys attractive.

Precipitation-Hardening Stainless Steels

Little or no data were found for AM-350 and AM-355. Scattered data at higher temperatures suggest that these alloys would have corrosion properties comparable to the fully austenitic hardenable grades of Armco 17-7 and 17-4PH. Corrosion rates for the latter alloys are of the order of 5 to 10 mg/(dm²)(month), 0.0001 in. per year, in neutral and high-pH water. Dissolved oxygen increases these rates somewhat, while hydrogen additions lower corrosion rates.

Corrosion rates in the low-pH water are not available at this time, as are data concerning the effect of stress-corrosion behavior.

Superalloys

The Discaloy and related alloys (A-286 and W-545) have acceptable corrosion resistance to degassed 600 F water. Reported rates are of the order of 12 mg/(dm²)(month). Somewhat lower rates are obtained in the presence of hydrogen and at pH levels of 10 to 11. In the presence of dissolved oxygen, the Discaloy alloys exhibit a substantial increase in corrosion rates and a loose, black corrosion deposit.

Although corrosion resistance appears to be adequate under conditions of high pH and hydrogen, their behavior in low-pH waters is unknown. In addition, little or no data are available concerning the effect of applied stress.

Of the materials under consideration, the Inconel X alloy appears to be the most resistant. In general, the corrosion behavior of Inconel X in high-temperature water compares with that of the austenitic 300 series of stainless steels. In addition, one

would predict that, although corrosion rates in the low-pH water would be higher than those for neutral or high-pH waters, they would be lower than most of the other alloys under consideration. The published information also indicates good corrosion behavior of Inconel X under conditions involving high stress levels.

Weldability

A major problem in fabricating the pressurized-water in-pile tube is the weldability of the materials which are chosen. The selected high-temperature alloy must be welded to itself as well as to an 18-8 stainless steel piping system. All of the alloys investigated appear capable of being joined to themselves by resistance welding (flash welding). However, since this welding process requires extensive and specialized equipment, the choice of the alloys was made on the ability of the alloy to be joined by an arc-welding process to itself and to 18-8 stainless steel. In some cases, a less weldable alloy was chosen over a more weldable alloy because of the lower and, therefore, unacceptable strength and/or corrosion properties of the more weldable alloy.

Alloy Steels

The 17-22AS and SAE 4340 alloys are probably the most weldable of the high-temperature materials studied. These alloys can be joined to themselves by a manual electric-arc process using a 400 to 500 F preheat and interpass temperature. In order to obtain maximum uniformity of properties, heat treatment of the weldment would be required. Inasmuch as these alloys have the least corrosion resistance under the specified conditions of all the high-temperature alloys being considered, further study of these alloy steels is not recommended.

Chromium Steels

The second most likely group of high-temperature alloys which would be chosen from the standpoint of weldability would be the chromium steels (AISI Types 410, 414, and 422, and Croloy 16-1). The only exception would be the AISI Type 422 martensitic stainless steel, which appears to require exceptionally high preheat and interpass temperatures (1100 F). However, as with the alloy steels, the corrosion resistance of the chromium steels is questionable. For this reason, a selection of one of these high-temperature materials has not been made.

Precipitation-Hardening Stainless Steels

AM-350 and AM-355 steels are less desirable from the standpoint of weldability than the two previously mentioned groups of alloys. However, these steels can be joined if care and proper welding procedures are utilized. Since these two alloys appear to possess acceptable corrosion and strength properties, one of the precipitation-hardening stainless steels should be chosen for further study. Inasmuch as AM-355 has a higher carbon content than AM-350, the weldability of AM-350 might be slightly better. For this reason, consideration of a precipitation-hardening stainless steel should be given to AM-350.

Superalloys

The superalloys, except for Inconel X, are probably the poorest high-temperature materials from a standpoint of weldability when compared with the other groups of alloys considered in this study. Conversely, however, these superalloys are probably the most corrosion resistant of the materials studied. Because Inconel X alone appears to have suitable corrosion resistance and weldability, this material should be studied further. The A-286, W-545, and Discaloy alloys appear to have equal weldability characteristics, since the composition of these alloys is essentially the same. Therefore, the choice of one of these three alloys for further study must rest on the mechanical and corrosion properties of the alloys.

RECOMMENDATIONS

The information presented in the Appendix and discussed in the preceding section of this report leads to the recommendation that three materials be investigated experimentally. The materials are: Inconel X, hot rolled and aged, AM-350, subzero cooled and tempered, and Discaloy, solution treated and aged. In addition, Westinghouse personnel may want to investigate the possibilities of coextruded tubing.

The above alloys were chosen because they seemed to meet best the requirements of properties and availability. Discaloy was chosen over W-545 because too little information is available on W-545. It is believed that W-545 will ultimately prove to be the better alloy, but at this time the recommendation must be for Discaloy. Somewhat the same situation is true for AM-350 and AM-355. Not enough information is available on AM-355 to determine properly its potential.

Subsequent to the selection of these materials, the technique of vacuum melting was considered as a possible means of obtaining better and more uniform physical properties. Of the three alloys, only Discaloy has been vacuum melted. All of the data included in this report, however, were obtained on air-melted material. Discaloy is being melted in small quantities in a vacuum-arc consumable-electrode furnace, and preliminary data indicate that creep strength and ductility are improved. More complete data on vacuum-melted Discaloy are now being determined by the producers.

Allegheny Ludlum engineers do not believe that vacuum melting of AM-350 would significantly improve its properties, and they have no plans for vacuum melting it in the near future.

Inconel X is not being vacuum melted and apparently the International Nickel Company does not intend to vacuum melt it. This is probably because this alloy is being adequately air melted in relatively large volume and in large heats. For a given hardener content, International Nickel Company engineers do not believe that a significant improvement in properties would be produced by vacuum melting, with the exception of increased ductility.

The experimental investigation, which will constitute Phase II of the program, will provide for the three materials information which was unobtainable for this report. The detailed description of the proposed work is contained in a proposed research program for Phase II. A brief résumé is included here, however, for reference.

Short-time tensile tests, creep-rupture tests, and creep evaluations of the three materials are contemplated. Additional tensile and creep-rupture tests will be necessary to evaluate the welding procedures and heat treatments. Additional welding work will be needed to fabricate corrosion specimens and to prepare the tubes to be tested and delivered to Westinghouse.

Corrosion tests on the three materials will provide information on the effects of stress and dissimilar metal joints for autoclave tests with four water conditions. The pH of the water will be adjusted to about 10 to provide three of the conditions and to about 7 for the fourth.

Hydrostatic testing of a shortened model of the full-sized tube will be performed at temperature by cycling the pressure between maximum and minimum values a large number of times. At the conclusion of this test, the pressure will be increased until the vessel bursts.

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APPENDIX

MATERIAL-PROPERTY DATA

MATERIAL-PROPERTY DATA

This Appendix contains all of the detailed material-property data gathered in a survey of available literature and by visits to various manufacturers. The data are arranged in the following manner according to the alloys included in the survey:

(1) Alloy steels

17-22AS
SAE 4340

(2) Chromium steels

AISI 410
AISI 414
AISI 422
Croloy 16-1

(3) Precipitation-hardening stainless steels

AM-350

(4) Superalloys

A-286
Discaloy
W-545
Inconel X

(5) Miscellaneous alloys suggested by producers

419 alloy
16-15-6 alloy
Incoloy 901
Coextruded tubes

Detailed corrosion properties were not available for each of the alloys, consequently, the corrosion data are discussed in the body of the report for the first four groups of alloys. The other properties of interest are listed under each alloy as follows:

(1) Tensile strength

(2) Yield strength

(3) Creep strength

(4) Rupture strength

- (5) Ductility
- (6) Notch sensitivity
- (7) Thermal conductivity
- (8) Thermal expansion
- (9) Neutron absorption
- (10) Radiation damage
- (11) Thermal stability
- (12) Weldability
- (13) Fabricability
- (14) Availability.

In gathering the data, visits were made to the following companies:

The Babcock & Wilcox Company
Timken Roller Bearing Company
International Nickel Company, Inc.
Allegheny Ludlum Steel Corporation
Crucible Steel Company of America
Westinghouse Electric Corporation.

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Alloy Steels17-22AS

Manufacturer

Timken Roller Bearing Company

Chemical composition

	<u>w/o</u>
Carbon	0.28-0.33
Manganese	0.45-0.65
Phosphorus	0.040 maximum
Sulfur	0.040 maximum
Silicon	0.55-0.75
Chromium	1.0 -1.5
Molybdenum	0.40-0.60
Vanadium	0.20-0.30

Heat treatment

Normalized from 1725 F, tempered 1200 F

(1) Tensile strength

600 F	137,000 psi
800 F	123,000 psi

(2) 0.2 per cent offset yield strength

600 F	118,000 psi
800 F	102,000 psi

(3) Creep strength (0.00001 per cent per hr)

600 F	Estimated over 100,000 psi
800 F	66,000 psi

(4) Rupture strength (100,000 hr)

600 F	Estimated over 60,000 psi
800 F	Estimated over 50,000 psi

(5) Ductility (elongation)

Short time	
600 F	17 per cent
800 F	17 per cent
1000 hr	
1000 F	2.0 per cent

- (6) Notch sensitivity
- Notch sensitivity was observed in rupture tests at temperatures of 1200, 1100, and 1000 F at various times between 1 and 1000 hr on specimens having a very sharp notch (0.002-in. radius). Notch strengthening was obtained at 900 F for all times out to 1000 hr, the duration of the longest tests. Notch sensitivity would not be expected at the lower temperatures of 600 and 800 F.
- (7) Thermal conductivity
- Thermal conductivity has been established from steels of similar composition to be between 25 and 20 Btu/(hr)(ft)(F) in the temperature range from 80 to 800 F.
- (8) Thermal expansions
	10^{-6} per F
70 to 400 F	7.01
70 to 600 F	7.40
70 to 800 F	7.61
70 to 1000 F	7.85
- (9) Neutron absorption
- No data
- (10) Radiation damage
- No data
- (11) Thermal stability
- 17-22AS should be completely stable even at 800 F after heat treating and tempering at 1200 F. Some decrease in hardness has been observed in long-time bolting applications at 1000 F.
- (12) Weldability
- 17-22AS may be joined to itself with a 17-22AS filler material. Welding can be performed in the annealed or the normalized-and-tempered condition; however, normalizing from 1750 F followed by an 1100 to 1200 F temper is required after welding for maximum uniformity of properties. A preheat and interpass temperature of 400 to 500 F should be utilized during welding if the 6-in. - diameter tubing is in the heat-treated condition.
- In joining 17-22AS to an 18-8 stainless steel, the stainless should be buttered with a low-carbon electrode containing 2.25 w/o chromium and 1 w/o molybdenum. 17-22AS filler wire should then be used to complete the joint. A second

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method of joining 17-22AS to 18-8 stainless would be to use an 18-8 stainless steel-coated electrode.

(13) Fabricability

No problem

(14) Availability

No problem

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FIGURE A-1. STRENGTH-TEMPERATURE DATA FOR 17-22AS ALLOY

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SAE 4340 Alloy Steel

Chemical composition

	w/o
Carbon	0.40
Manganese	0.70
Nickel	1.80
Chromium	0.80
Molybdenum	0.25
Iron	Balance

Heat treatment

Oil quenched or normalized from 1550 to 1750 F, tempered 1000 to 1200 F

(1) Tensile strength

Bar stock 0.25 to 0.40 in. in diameter, heat treated to a room-temperature tensile strength of 150,000 to 160,000 psi

600 F	144,000 psi
800 F	125,000 psi

Sheet 0.064 in. thick, heat treated to 200,000 psi

600 F	170,000 psi
800 F	135,000 psi

(2) 0.2 per cent offset yield strength

Bar stock 0.25 to 0.40 in. in diameter, heat treated to a room-temperature tensile strength of 150,000 to 160,000 psi

600 F	120,000 psi
800 F	105,000 psi

Sheet 0.064 in. thick, heat treated to 200,000 psi

600 F	135,000 psi
800 F	102,000 psi

(3) Creep strength (0.00001 per cent per hr)

600 F	Estimated over 40,000 psi
800 F	Estimated over 40,000 psi

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(4) Rupture strength (100,000 hr)	Estimated from average data (STP No. 199) by Larson-Miller ^(a) parameter method
600 F	70,000 psi
800 F	40,000 psi
(5) Ductility (elongation)	
Short time	
600 F	18 per cent
800 F	25 per cent
1000 hr	
600 F	19 per cent
800 F	--
(6) Notch sensitivity	Notch behavior similar to 17-22AS.
Notch sensitivity was not observed at 900 F at times out to 1000 hr. At the lower temperatures of 600 and 800 F, no notch sensitivity would be expected.
(7) Thermal conductivity	Similar to 17-22AS
(8) Thermal expansion	Similar to 17-22AS
(9) Neutron absorption	No data
(10) Radiation damage	No data
(11) Thermal stability	No data
(12) Weldability	SAE 4340 may be joined to itself by the electric, inert-gas tungsten-electrode, or consumable-electrode arc-welding processes. A high-strength coated electrode, such as P & H 21 or a 4340 filler wire should be used. The material can be in the annealed or heat-treated condition prior to welding, and preheat and interpass temperatures of 500 F should be maintained during welding.
(13) Fabricability	No problem
(14) Availability	No problem

(a) Larson, F. R., and Miller, James, "A Time-Temperature Relationship for Rupture and Creep Stresses", Transactions ASME, 74, (5), 765-775 (July, 1952).

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FIGURE A-2. STRENGTH-TEMPERATURE DATA FOR SAE 4340 STEEL

Chromium Steels

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AISI Type 410

Chemical composition

	<u>w/o</u>
Carbon	0.15 maximum
Manganese	1.00 maximum
Silicon	1.00 maximum
Phosphorus	0.04 maximum
Sulfur	0.03 maximum
Chromium	11.5-13.5
Iron	Balance

Heat treatment

Fully hardened by oil quenching from 1800 F. Light sections may be fully hardened by air cooling. This steel will harden to various degrees at temperatures as low as 1500 F. Temper to desired strength.

(1) Tensile strength

The tensile strength at 800 F will range from 65,000 to 200,000 psi, depending on the heat treatment

(2) 0.2 per cent offset yield strength

The range for yield strengths at 800 F will be about 30,000 to 165,000 psi, depending on heat treatments

(3) Creep strength (0.00001 per cent per hr)

600 F

The creep requirements can be met by this material at 600 F in the normalized and tempered condition

800 F

The creep behavior at 800 F is doubtful and will have to be obtained if this alloy is to be considered further

(4) Rupture strength (100,000 hr)

The same comments in Item (3) apply to rupture strength

(5) Ductility (elongation)

Short time

600 F

15 to 25 per cent

800 F

15 to 25 per cent

1000 hr

No data

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FIGURE A-2. STRENGTH-TEMPERATURE DATA FOR SAE 4340 STEEL

Chromium Steels

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AISI Type 410

Chemical composition

	w/o
Carbon	0.15 maximum
Manganese	1.00 maximum
Silicon	1.00 maximum
Phosphorus	0.04 maximum
Sulfur	0.03 maximum
Chromium	11.5-13.5
Iron	Balance

Heat treatment

Fully hardened by oil quenching from 1800 F. Light sections may be fully hardened by air cooling. This steel will harden to various degrees at temperatures as low as 1500 F. Temper to desired strength.

(1) Tensile strength

The tensile strength at 800 F will range from 65,000 to 200,000 psi, depending on the heat treatment

(2) 0.2 per cent offset yield strength

The range for yield strengths at 800 F will be about 30,000 to 165,000 psi, depending on heat treatments

(3) Creep strength (0.00001 per cent per hr)

600 F

The creep requirements can be met by this material at 600 F in the normalized and tempered condition

800 F

The creep behavior at 800 F is doubtful and will have to be obtained if this alloy is to be considered further

(4) Rupture strength (100,000 hr)

The same comments in Item (3) apply to rupture strength

(5) Ductility (elongation)

Short time

600 F

15 to 25 per cent

800 F

15 to 25 per cent

1000 hr

No data

AISI Type 414

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Chemical compositions

	w/o
Carbon	0.15 maximum
Manganese	1.0 maximum
Silicon	1.0 maximum
Chromium	11.5-13.5
Nickel	1.25-2.50
Iron	Balance

Heat treatment

Usually oil quenched from 1700 to 1900 F. Small sections may be air cooled. Tempering should be in the temperature ranges 300 to 850 F and 1000 to 1500 F. Reheating temperatures between 850 and 1000 F should be avoided because of resulting low impact resistance.

The following high-temperature strength and rupture data were obtained on bars heat-treated as follows: 1800 F, 1/2 hr, oil quenched, and 1225 F, 4 hr, oil quenched (R_C 21).

(1) Tensile strength

Room temperature

The room-temperature tensile strength of this alloy will range from 100,000 to 220,000 psi, depending on the heat treatment

600 F	115,000 psi
800 F	98,000 psi

(2) 0.2 per cent offset yield strength

600 F	87,000 psi
800 F	74,000 psi

(3) Creep strength (0.00001 per cent per hr)

No data available. Should meet the 600 F requirements. 800 F doubtful, tests required.

(4) Rupture strength (100,000 hr)

600 F	Estimated over 60,000 psi
800 F	Estimated 27,000 psi as heat treated, tests required

(5) Ductility (elongation)	
Short time	
600 F	10 to 20 per cent
800 F	10 to 20 per cent
(6) Notch sensitivity	No data
(7) Thermal conductivity	
212 F	14.4 Btu/(hr)(ft)(F)
932 F	16.6 Btu/(hr)(ft)(F)
(8) Thermal expansion	
68 to 212 F	5.5×10^{-6} per F
68 to 1200 F	6.2×10^{-6} per F
(9) Neutron absorption	No data
(10) Radiation damage	No data
(11) Thermal stability	No data
(12) Weldability	The information concerning Type 410 martensitic stainless steel applies to AISI Type 414 stainless
(13) Fabricability	No problem
(14) Availability	No problem

FIGURE A-4. STRENGTH-TEMPERATURE DATA FOR AISI TYPE 414 STEEL

Type 422

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Manufacturer

Crucible Steel Company of America,
Armco Steel Corporation, and others

Chemical composition

	<u>Typical, w/o</u>	<u>Nominal, w/o</u>
Carbon	0.22	0.20
Manganese	0.65	0.75
Silicon	0.36	0.35
Chromium	11.7	13.00
Nickel	0.70	0.75
Molybdenum	0.95	1.00
Tungsten	0.93	1.00
Vanadium	0.25	0.30

Heat treatment

Oil quench or air cool from 1900 F. Tem-
per at 800 to 1200 F for at least 2 hr.

(1) Tensile strength

Oil quenched from 1900 F, tem-
pered at 800 F (47 R_C)

400 F	227,000 psi
600 F	237,000 psi
800 F	223,000 psi

Oil quenched from 1900 F, tem-
pered at 1100 F (26 R_C)

400 F	151,000 psi
600 F	141,000 psi
800 F	121,000 psi

(2) 0.2 per cent offset yield strength

Oil quenched from 1900 F, tem-
pered at 800 F

400 F	160,000 psi
600 F	145,000 psi
800 F	140,000 psi

Oil quenched from 1900 F, tem-
pered at 1100 F

400 F	125,000 psi
600 F	120,000 psi
800 F	100,000 psi

- (3) Creep strength (0.00001 per cent per hr)
600 F	Estimated over 50,000 psi
800 F	Estimated over 50,000 psi
- (4) Rupture strength (100,000 hr)
600 F	Estimated over 60,000 psi
800 F	Estimated over 60,000 psi
- (5) Ductility (elongation)
Short time	
400 to 800 F	12 to 16 per cent
- (6) Notch sensitivity
- No notch weakening in rupture tests was observed for Type 422 under the conditions investigated, 10 to 1000-hr rupture at temperatures of 1000 to 1200 F
- (7) Thermal conductivity (Type 420)
- 14.4 Btu/(hr)(ft)(F) at 212 F
- (8) Thermal expansion
	<u>10^{-6} per F</u>
70 to 500 F	5.9
70 to 750 F	6.3
70 to 1000 F	6.4
70 to 1200 F	6.7
- (9) Neutron absorption
- No data
- (10) Radiation damage
- No data
- (11) Thermal stability
- No data
- (12) Weldability
- Type 422 material should be welded with preheat, interpass temperature, and postheat of 1100 F
- (13) Fabricability
- Tubing is not available from the Crucible Steel Company of America
- (14) Availability
- This is a production item and, therefore, no problem is expected in getting a billet

FIGURE A-5. STRENGTH-TEMPERATURE DATA FOR TYPE 422 STEEL

Croloy 16-1

Manufacturer	The Babcock & Wilcox Tube Company
Chemical composition	
	<u>w/o</u>
Carbon	0.03
Chromium	16.0
Nickel	1.0
Iron	Balance
Heat treatment	Normalized 1700 F, temper 1300 F
(1) Tensile strength	
600 F (three heats, eight tests)	62,300-78,600 psi
800 F (one test)	69,800 psi
(2) 0.2 per cent offset yield strength	
600 F (three heats, eight tests)	43,800-64,000 psi
800 F (one test)	58,800 psi
(3) Creep strength (0.00001 per cent per hr)	No data
(4) Rupture strength (900 F)	
	<u>Psi</u>
237 hr	35,000
1666 hr	32,000
5400 hr (in progress)	30,000
100,000 hr (estimated)	25,000
(5) Ductility (elongation)	Good
(6) Notch sensitivity	Should be satisfactory
(7) Thermal conductivity	No data
(8) Thermal expansion	No data
(9) Neutron absorption	Satisfactory
(10) Radiation damage	No data
(11) Thermal stability	No data

(12) Weldability

Croloy 16-1 can be joined to itself and to an 18-8 stainless steel by the inert-gas-shielded tungsten-electrode arc process with a Croloy 16-1 filler material and a filler material containing 25 w/o chromium and 20 w/o nickel, respectively. Welding should be performed on Croloy 16-1 in the normalized-and-tempered condition using a minimum preheat and interpass temperature of 300 F. Post heat treatment should consist of a 1150 to 1300 F stress relief. The mechanical properties of the welded joint at room temperature should equal the properties of the base material; however, there is some indication that the heat-affected base metal may be notch sensitive.

(13) Fabricability

Fabrication into tubes is not difficult for Croloy 16-1

(14) Availability

Availability of Croloy 16-1 is apparently no problem

32 Precipitation Hardening Stainless Steels

AM-350

Manufacturer

Allegheny Ludlum Steel Company

Chemical composition

	w/o
Carbon	0.08
Manganese	0.60
Silicon	0.40
Chromium	16.25-17.25
Nickel	4.0-4.5
Molybdenum	2.5-3.0
Iron	Balance

Heat treatment

Annealed 1740 F plus:

A

Subzero cooled and tempered (2 hr at minus 100 F plus 2 hr at 850 F)

B

Double aged (1 hr at 1350 F plus 1 hr at 850 F)

(1) Tensile strength

Over 160,000 psi for both conditions (A and B) at 600 and 800 F

(2) 0.2 per cent offset yield strength

600 F
800 F

Over 120,000 psi for both conditions
Over 100,000 psi for both conditions

(3) Creep strength (0.00001 per cent per hr), data from AM-350 sheet, Condition A

600 F
800 F

55,000 psi
23,000 psi

The creep strength of AM-350 should be checked for this application in the size and condition of the tubing which would be used. This is true particularly at 800 F where the data for sheet are lower than desired.

- (4) Rupture strength (100,000 hr)
600 F	Estimated over 60,000 psi
800 F	Estimated over 60,000 psi
- (5) Ductility (elongation)
Short time	
600 F	8 to 12 per cent
800 F	8 to 12 per cent
1000 hr	No data
- (6) Notch sensitivity
- No notch rupture data available
- Impact resistance as determined by Charpy V-notch specimens is 51 ft-lb at room temperature and 36 ft-lb at -40 F. This is for Condition A and indicates very good properties.
- (7) Thermal conductivity
- Will be available about December, 1957
- (8) Thermal expansion
	<u>10⁻⁶ per F</u>
68 to 212 F	6.6
68 to 572 F	6.9
68 to 752 F	7.1
68 to 932 F	7.3
68 to 1150 F	7.3
- (9) Neutron absorption
- No data
- (10) Radiation damage
- No data
- (11) Thermal stability
- Satisfactory under conditions of unstressed aging. Work under stress conditions is under way at 700 F and 75 per cent of the yield strength.
- (12) Weldability
- Both AM-350 and AM-355 can be joined to themselves with the use of an AM-355 filler material. The welding process most applicable for joining these materials would be the inert-gas-shielded tungsten-electrode arc process. Welding should be performed on carefully cleaned material which is in the solution-treated condition. In order to obtain a weld-joint efficiency of 95 per cent of the base material, the weldment should be

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annealed at 1750 to 1775 F, cooled to -100 F for 2 hr and tempered at 850 F for 2 hr.

To join AM-350 to an 18-8 stainless steel, an austenitic Type 308 filler material should be used.

(13) Fabricability

Allegheny Ludlum cannot furnish tubing of the size desired, but they can supply billets for extrusion by another fabricator, possibly Babcock & Wilcox

(14) Availability

Billets of both AM-350 and 355 are available in approximately 3 months' delivery

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FIGURE A-6. STRENGTH-TEMPERATURE DATA FOR AM-350 ALLOY

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SuperalloysA-286

Manufacturer

Allegheny Ludlum Steel Company

Chemical composition

	<u>w/o</u>
Carbon	0.08 maximum
Manganese	1.00-2.00
Lithium	0.40-1.00
Phosphorus	0.04 maximum
Sulfur	0.04 maximum
Chromium	13.5-16
Nickel	24-28
Molybdenum	1.0-1.5
Titanium	1.90-2.35
Vanadium	0.10-0.50
Aluminum	0.35 maximum
Iron	Balance

Heat treatment

1800 F for about 1 hr, oil quench, age
at 1325 F for 16 hr, air cool

(1) Tensile strength

600 F	145,000 psi
800 F	140,000 psi

(2) 0.2 per cent offset yield strength

600 F	92,000 psi
800 F	92,000 psi

(3) Creep strength (0.0001 per cent
per hr)

600 F	Estimated over 80,000 psi
800 F	Estimated over 80,000 psi

(4) Rupture strength (100,000 hr)

600 F	Estimated over 80,000 psi
800 F	Estimated over 80,000 psi

(5) Ductility (elongation)

Short time

600 F	22 per cent
800 F	21 per cent
1000 hr	2 to 8 per cent at 1000 to 1200 F

- (6) Notch sensitivity
- V-notch stress-rupture tests at 1200 F and 60,000 psi on specimens from bar stock and wheel forgings have indicated notch strengthening.
- V-notch Charpy impact resistance is as follows:
400 F	59.5 ft-lb
600 F	55.5 ft-lb (estimated)
800 F	51.5 ft-lb
- (7) Thermal conductivity
- No data
- (8) Thermal expansion
	<u>10⁻⁶ per F</u>
80 to 200 F	9.17
80 to 400 F	9.35
80 to 600 F	9.47
80 to 800 F	9.64
80 to 1000 F	9.78
80 to 1100 F	9.84
80 to 1200 F	9.88
- (9) Neutron absorption
- No data
- (10) Radiation damage
- No data
- (11) Thermal stability
- Very good. Up to 800 F there may be a slight increase in properties.
- (12) Weldability
- Thin sections of A-286 can be welded to itself by the inert-gas-shielded tungsten-electrode arc process using an A-286 filler metal. Hot peening can be used to reduce the tendency of this material to hot crack. A-286 can also be welded with a 17-7PH filler material. Welding should be performed in the solution-treated condition without the use of a preheat or interpass temperature. A postwelding treatment consisting of double aging should produce a weld-joint efficiency of 85 per cent of the base material at 1250 F. This material is more readily flash welded than fusion welded.
- (13) Fabricability
- A billet of A-286 would have to be extruded at another plant, probably Babcock & Wilcox

(14) Availability

Approximately 3 months to get a billet.
The greatest difficulty is expected in
working into the extrusion-plant
schedule.

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A-28

FIGURE A-7. STRENGTH-TEMPERATURE DATA FOR A-286 ALLOY

Discaloy40

Manufacturer

Westinghouse Electric Corporation

Chemical composition

	w/o
Carbon	0.08 maximum (0.03 nominal)
Manganese	0.60-1.50
Silicon	0.40-1.00
Chromium	12-15
Nickel	24-28
Molybdenum	2.5-3.5
Titanium	1.45-1.90
Aluminum	0.35 maximum (0.1 nominal)
Iron	Balance

Heat treatment

1800 to 1900 F for about 1 hr, oil or water
quench, age at 1350 F for 20 hr, slow
cool (5 hr) to 1200 F and hold 20 hr, air
cool to room temperature

(1) Tensile strength

600 F	141,000 psi
800 F	135,000 psi

(2) 0.2 per cent offset yield strength

600 F	99,000 psi
800 F	96,000 psi

(3) Creep strength (0.00001 per cent per hr)

600 F	Estimated over 60,000 psi
800 F	Estimated over 60,000 psi

(4) Rupture strength (100,000 hr)

600 F	Estimated over 60,000 psi
800 F	Estimated over 60,000 psi

(5) Ductility (elongation)

Short time

600 F	15 per cent
800 F	15 per cent

1000 hr	1 to 5 per cent at 1200 F
---------	---------------------------

- (6) Notch sensitivity Notch strengthening was measured at 1000 and 1200 F on Discaloy specimens having a hardness of less than 315 DPH. This was associated with a creep-rupture ductility of greater than 5 per cent elongation.
- (7) Thermal conductivity
	<u>Btu/(hr)(ft)(F)</u>
392 F	9.20
572 F	9.93
752 F	10.90
932 F	11.87
- (8) Thermal expansion
70 to 600 F	9.1×10^{-6} per F
70 to 800 F	9.4×10^{-6} per F
- (9) Neutron absorption No data
- (10) Radiation damage No data
- (11) Thermal stability Should be satisfactory at 600 and 800 F
- (12) Weldability
- Discaloy may be joined to itself by the inert-gas-shielded tungsten-electrode arc process. Discaloy filler wire, 17-7PH filler wire, or a 19-9 tungsten-molybdenum coated electrode may be used to make the weld. No preheat should be used and the maximum inter-pass temperature should be 200 F. Hot peening of the weld should be employed to reduce the possibility of hot cracking which may exist in one-half inch or heavier plate. Experience has shown that the material can be flash welded with no problems.
- Discaloy may be joined to 18-8 stainless with a Hastelloy W filler material
- (13) Fabricability Can be formed into tubes by extrusion. Westinghouse is not equipped for this operation, and it would have to be carried out at some other plant, possibly Babcock & Wilcox.
- (14) Availability A special order should be placed through the Blairsville, Pennsylvania, plant of Westinghouse. A billet could be expected in 3 to 4 months' time.

FIGURE A-8. STRENGTH-TEMPERATURE DATA FOR DISCALOY ALLOY

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W-545 Alloy

W-545 is a modification of Discaloy intended for service as a turbine-disc material. Its strength properties are superior to Discaloy.

Manufacturer

Westinghouse Electric Corporation

Chemical composition

	<u>w/o</u>
Carbon	0.08 maximum
Manganese	0.75-2.00
Silicon	0.10-0.60
Phosphorus	0.04 maximum
Sulfur	0.03 maximum
Chromium	12.00-15.00
Nickel	24.00-28.00
Molybdenum	1.00-2.50
Titanium	2.50-3.50
Aluminum	0.35 maximum
Boron	0.02-0.10
Iron	Balance

Heat treatment

A wide variety of mechanical properties is obtained by a variation in heat treatment. The alloy can be solution treated at temperatures between 1600 F and 2350 F followed by quenching in oil or water. Precipitation hardening is accomplished by aging at temperatures between 1200 and 1450 F from 5 to 40 hr in two or more continuous or discontinuous stages. Heat treatments recommended are as follows:

Bar - 1950 F, 1 hr, oil quench, age 20 hr at 1350 F and 20 hr at 1200 F, air cool

Discs - 2150 F, 3 hr, water quench, age 20 hr at 1425 F, 20 hr at 1350 F, and 40 hr at 1200 F, air cool

(1) Tensile strength

600 F	156,000 psi
800 F	154,000 psi

(2) 0.2 per cent offset yield strength

600 F	118,000 psi
800 F	115,000 psi

(3) Creep strength (0.00001 per cent per hr)	Superior to Discaloy
(4) Rupture strength (100,000 hr)	Superior to Discaloy
(5) Ductility (elongation)	Rupture elongation of 6 per cent was measured in a 4000-hr test at 1200 F and 40,000 psi
(6) Notch sensitivity	Similar to Discaloy
(7) Thermal conductivity	Similar to Discaloy
(8) Thermal expansion	Similar to Discaloy
(9) Neutron absorption	No data
(10) Radiation damage	No data
(11) Thermal stability	Should be satisfactory at 600 and 800 F
(12) Weldability	Same as Discaloy
(13) Fabricability	Same as Discaloy
(14) Availability	Same as Discaloy, except that 4 to 5 months would be required to obtain a billet

FIGURE A-9. STRENGTH-TEMPERATURE DATA FOR W-545 ALLOY

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Inconel X

Strength properties given are for Inconel X. No data are available at 600 and 800 F for Inconel X 550.

Manufacturer

International Nickel Company, Inc.

Chemical composition

	<u>Inconel X, w/o</u>	<u>Inconel X 550, w/o</u>
Carbon	0.08 maximum	0.10 maximum
Manganese	0.30-1.00	
Silicon	0.50 maximum	
Sulfur	0.01 maximum	
Chromium	14.0-16.0	
Nickel	70.0 minimum	
Niobium and tantalum	0.70-1.20	
Titanium	2.25-2.75	2.00-2.60
Aluminum	0.40-1.00	0.90-1.50
Iron	5.00-9.00	
Copper	0.20 maximum	

Heat treatment

A.

	<u>Inconel X</u>	<u>Inconel X 550</u>
Solution treatment	2 to 4 hr at 2150 F	1 hr at 2150 F
High-temperature age	24 hr at 1550 F	4 hr at 1600 F
Low-temperature age	20 hr at 1300 F	4 hr at 1350 F

B.

Hot rolled and aged 20 hr at 1300 F

(1) Tensile strength

A.

600 F	158,000 psi
800 F	152,000 psi

B.

600 F	176,000 psi
800 F	168,000 psi

(2) 0.2 per cent offset yield strength

A.

600 F	91,000 psi
800 F	91,000 psi

B.

600 F	125,000 psi
800 F	120,000 psi

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- (3) Creep strength (0.00001 per cent per hr)

A.

600 F
800 F

Estimated over 90,000 psi
Estimated over 90,000 psi

- (4) Rupture strength (100,000 hr)

A.

600 F
800 F

Estimated over 90,000 psi
Estimated over 90,000 psi

- (5) Ductility (elongation)

A.

Short time

600 F
800 F

25 per cent
26 per cent

1000 hr

0.5 to 3 per cent at 1200 F

B.

Short time

600 F
800 F

26 per cent
24 per cent

- (6) Notch sensitivity

Notch sensitivity has been observed at 1350 and 1425 F on solution treated and aged specimens of Inconel X in 0.5 to 1000-hr rupture tests. Limited data indicate little possibility of notch sensitivity at 1100 F.

- (7) Thermal conductivity (solution treated and aged)

122 F
212 F
392 F
572 F
752 F
932 F
1112 F

Btu/(hr)(ft)(F)
8.50
9.18
10.32
11.65
13.00
14.50
15.66

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- (8) Thermal expansion
	<u>10⁻⁶ per F</u>
100 to 200 F	7.6
100 to 400 F	7.7
100 to 600 F	7.9
100 to 800 F	8.0
100 to 1000 F	8.2
100 to 1200 F	8.4
100 to 1350 F	8.7
- (9) Neutron absorption
- For production heats of Inconel X, the neutron-absorption cross section would be in the range 4.64 to 6 barns per atom. This could be reduced by making a low-cobalt heat (0.06 to 0.15 w/o cobalt). The cost of such a heat is estimated at about \$35 per lb.
- (10) Radiation damage
- Little information is available
- (11) Thermal stability
- Inconel X should be stable
- (12) Weldability
- Inconel X may be joined to Inconel X by the tungsten-electrode or consumable-electrode arc welding processes using 69 Inconel X or 139 Inconel X filler material. Welding should be performed in the annealed condition. Immediately after welding, the weldment should be placed in a hot furnace (1625-1650 F for 4 hr or 1800-1950 F for 15-30 min) and then cooled rapidly in oil. In the aged condition (1300 F), the room-temperature properties of the weld joint should be at least 75 per cent of the properties of the base material.
- Inconel X and 18-8 stainless steel may be joined with Inco Rod A, Hastelloy W, or a new Inco alloy now designated as BP 70
- (13) Fabricability
- Inconel X can be extruded into tubes of the size needed
- (14) Availability
- May be available in 3 to 6 months. If a virgin heat with essentially no cobalt is desired delivery will require about a year.

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FIGURE A-10. STRENGTH-TEMPERATURE DATA FOR INCONEL X ALLOY

Miscellaneous Alloys Suggested by Producers419 Alloy

This is a modified 12 w/o chromium steel somewhat similar to 422 in strength properties, and is manufactured by the Allegheny Ludlum Steel Corporation. The chemical composition range is as follows:

	w/o
Carbon	0.18-0.25
Manganese	0.75 maximum
Silicon	0.50 maximum
Chromium	11.25-12.25
Nickel	0.50-1.50
Molybdenum	0.30-0.70
Tungsten	2.50-3.00
Vanadium	0.25-0.50
Nitrogen	0.03-0.10

Since this alloy is expected to have corrosion resistance similar to the 400 series steels and there is some question about its weldability, it was not considered further.

16-15-6 Alloy

Manufactured by The Timken Roller Bearing Company, 16-15-6 is a low-nickel modification of 16-25-6. It has a high manganese content to balance the composition, and this permits a substantial increase in the nitrogen content which assures a fully austenitic structure and adds to the high-temperature-strength properties of the alloy. The nominal composition is as follows:

	w/o
Carbon	0.07 maximum
Manganese	7.50
Silicon	0.50
Chromium	16.00
Nickel	15.00
Molybdenum	6.00
Iron	55.00
Nitrogen	0.33

Tubing of this alloy can be produced by piercing, but since this alloy is only weakly precipitation hardening, the high strength desired would have to be produced by cold drawing. Suitable creep and rupture strengths have been produced in disc forging of 16-15-6 by hot-cold working, but the desirable strength properties have never been produced in tubing. The 16-15-6 alloy has good welding characteristics.

Because of the possible difficulty in producing tubing of the desired strengths and because of the high manganese content, this alloy was not given serious consideration for further study.

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Incoloy 901

Incoloy 901 is an age-hardenable sheet alloy manufactured by the International Nickel Company, Inc., that would be of considerable interest for this application if information were available on the alloy in other than sheet form. A typical composition is given by the analysis of Heat Y 7983 as follows:

	w/o
Carbon	0.05
Manganese	0.48
Iron	35.02
Sulfur	0.007
Silicon	0.22
Copper	0.22
Nickel	43.15
Chromium	12.77
Aluminum	0.15
Titanium	2.43
Molybdenum	5.68

Although the physical properties of this alloy in sheet form are attractive, no data on heavier sections than sheet are available. Therefore, this alloy has not been considered for further testing for this application.

Coextruded Tubes

The Babcock & Wilcox Tube Company coextruded tubes appear very promising, particularly for the moderate-flux reactor. The coextruding procedures have been worked out for tubes of the size needed and Babcock & Wilcox will now accept orders. (The process is just past the experimental stage in its development.)

Coextruded tubes are bimetal tubes that can be made with a highly corrosion resistant inner layer and a high-strength outer layer. A promising combination for this application would be 18-8 for corrosion resistance and Type 410 for strength. This combination has been fabricated successfully and was recommended by Babcock & Wilcox for this application.

To improve weldability, but at the expense of strength, a carbon content on the low side (0.06 to 0.08 w/o) was suggested.

If the use of coextruded tubing appears feasible to Westinghouse engineers, it seems desirable for Westinghouse to contact Babcock & Wilcox for more information on tubing produced by this procedure. This would avoid transmitting this information to Westinghouse via Battelle.

The possible use of coextruded tubing was brought to the attention of Battelle personnel by Mr. R. D. Wylie, The Babcock & Wilcox Company, Barberton, Ohio.

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