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SPECIAL HEAT OF AUSTENITIC STAINLESS STEEL USED
IN THE EXPERIMENTAL BREEDER REACTOR (EBR-I)

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TABLE OF CONTENTS

	<u>Page</u>
I. ABSTRACT	3
II. INTRODUCTION	3
III. BASIS FOR COMPOSITIONS SPECIFIED	3
Carbon: 0.05 to 0.07%	5
Niobium: 10 x Carbon - 0.85% Maximum	5
Manganese: 1.5 to 2%	5
Nickel: 12 to 13%	5
Chromium: 17 to 18%	5
Molybdenum	6
Nitrogen	6
IV. SELECTION OF VENDOR	6
V. MELTING PROCEDURE	6
VI. REACTOR COMPONENTS EMPLOYING THIS HEAT OF STEEL	8
Core-Holding Plates	8
External Blanket Bricks	8
Inner Blanket Rods	8
Fuel Elements	8
Descriptive Figures - Nos. 1 - 7	10-15
VII. REFERENCES	16

SPECIAL HEAT OF AUSTENITIC STAINLESS STEEL USED IN THE EXPERIMENTAL BREEDER REACTOR (EBR-I)

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I. ABSTRACT

This report describes the heat of austenitic stainless steel which was used in the core structure of the Experimental Breeder Reactor. The heat was made by the Crucible Steel Company of America at their Midland, Pennsylvania, mill to conform with a modification of the ASTM specification A-269-47, a niobium-stabilized, austenitic grade stainless steel similar to AISI Type 347. Modification consisted of selecting a narrow range of composition within the broad range ordinarily permitted for most of the elements specified. This was done to promote austenite stability and freedom from carbide precipitation, without altering the fabricability of the material.

Components manufactured from this heat were intended to operate in sections of varying neutron flux density and temperature. They were to be exposed to NaK alloy and/or air under static and dynamic conditions at peak temperatures in the range 325°-350°C.

The steel was mill fabricated into a number of products, including rounds, rods, light and heavy plate, seamless tubing, and foil (0.020").

No difficulty was encountered in machining, grinding, deep drawing, forging, cold drawing, swaging, or welding this material.

II. INTRODUCTION

The Experimental Breeder Reactor (EBR-I) is a fast reactor built to explore the feasibility of producing nuclear fuel at a rate greater than that at which it is fissioned.⁽¹⁾ It is cooled by liquid eutectic NaK alloy which is pumped through the reactor system. The coolant temperature reaches a maximum of the order of 325°-350°C in the core and a somewhat lower temperature in the heat exchangers.

Corrosion tests in static and dynamic NaK had shown that a number of engineering materials exhibited satisfactory resistance to corrosion at and above temperatures in the range in which the reactor was intended to operate.⁽²⁾ Of these materials, niobium-stabilized, austenitic stainless steel of the AISI Type 347 was selected for use in the reactor core structure.

At the time the material selection was made (1949), little information was available concerning the effects of fast neutron irradiation on metallic materials of construction, and none was in existence relevant to the behavior of the austenitic stainless steels. Because accurate data was not available, considerable concern was felt for the stability of the metastable austenite in respect to its breakdown into delta ferrite and/or sigma phase. Some concern also existed that accelerated grain boundary precipitation of carbides might occur, causing lowered ductility and resistance to corrosion by moist air. In the absence of irradiation test data no positive measures had been developed to prevent these phenomena, and it was decided that the only defense against these difficulties lay in the specification of a material composition which, on the basis of temperature effects, favored the retention of austenite and carbide stability.

The decision to specify a particular analysis suggested the possibility of using a single heat of stainless steel for the reactor core which, in addition to providing the necessary amount of material, would allow studies to be made of the effects of wide variations in temperature, time, and flux density on material of the same analysis. Fortunately, the shape and dimensions of the core components permitted their use as test specimens in many instances. In other cases, material sections were sufficient to allow machining of test specimens after irradiation if desired.

Calculations made by members of the Reactor Engineering Division indicated that approximately 30,000 to 40,000 pounds of material would be required for the core. This amount is a significant fraction of a small heat, and the proposal that a single heat of material be purchased was accepted.

III. BASIS FOR SPECIFIED COMPOSITION

It was at first believed that a satisfactory analysis for an AISI Type 347, niobium-stabilized, austenitic stainless steel would be.

<u>Element</u>	<u>Proposed (%)</u>	<u>AISI^(a) Type 347 (%)</u>
Carbon	0.03 Max.	0.10 Max.
Manganese	2.00 Max..	2.00 Max.
Silicon	1.00 Max.	1.00 Max
Phosphorus	0.04 Max.	0.04 Max.
Sulphur	0.03 Max.	0.03 Max.
Chromium	17.00 to 18.00	17.00 to 19.00
Nickel	10.00 to 12.00	9 00 to 12.00
Niobium	10 x C Min.-0.035 Max.	10 x C Min.

(a) American Iron and Steel Institute.⁽³⁾

A comparison of the proposed analysis with the standard AISI Type 347 specification shows that it more narrowly limits the composition range of four elements, namely, carbon, niobium, nickel, and chromium.

Specification of the carbon in this range was done to minimize the amount of niobium necessary for stabilization, to promote cleanliness of the microstructure, and to keep the niobium down to a low concentration, because of its action as a strong ferrite former. A belief that the 0.03% max. carbon would also minimize the effects of carbide precipitation, especially in the presence of niobium, was the other reason that this range was selected. Carbon, however, is an extremely strong austenite former.⁽⁴⁾ Specification of low carbon thus tended to lessen austenite stability, a condition which was regarded as being serious to fabricators and users. Therefore, it was decided that the analysis be altered as follows to promote maximum austenite stability:

<u>Element</u>	<u>Composition (%)</u>
Carbon	0.05 - 0.07
Niobium	10 x C - 0.85% Max.
Nickel	12 - 13
Manganese	1.5 - 2.0
Chromium	17 - 18
Silicon	1.00 Max.
Phosphorus	0.04 Max.
Sulphur	0.03 Max.

Carbon: 0.05 to 0.07%

These limits definitely avoided the extra low carbon range, providing sufficient carbon for austenite stability without requiring a large amount of niobium.

Niobium: 10 x Carbon - 0.85% Maximum

The amount specified was considered sufficient to combine completely with the carbon without introducing excessive total amounts of niobium.

Manganese: 1.5 to 2%, - Nickel: 12 to 13%

Both of the above elements are strong austenite formers.⁽⁴⁾

Chromium: 17 to 18%

Chromium is a strong ferrite former, and it was requested that it be limited within this range to minimize its effect.⁽⁴⁾

Molybdenum:

This element, a ferrite former,⁽⁴⁾ is a residual in this grade of steel, and it was requested that it be kept to a minimum by the segregation of melting scrap.

Nitrogen:

Nitrogen was to be maintained as closely as possible to the middle of the range in which it is ordinarily found in the austenitic grades. No definite specification beyond this was made on this element.

All other elements were to be in accordance with specifications ASTM: A269-47.

In addition to the chemical specifications, the physical tests referred to in ASTM: A269-47 were required to be performed on the tubing which was to be manufactured from this particular analysis. In addition, leak detection tests, where applicable, were performed with General Electric and Consolidated Helium Mass Spectrometer type equipment. Critical plate and bar stock were inspected ultrasonically and by means of radiography. Deeply etched sections of certain critical forgings were examined macroscopically before use.

IV. SELECTION OF VENDOR

After discussions with a number of steel manufacturers, bids were received, and the Crucible Steel Company of America was selected as the manufacturer of the special analysis. The heat was melted and cast on December 8, 1949, and it was observed by Mr. David E. Walker of the ANL Metallurgy Division.

V. MELTING PROCEDURE

The heat was melted in a 25-ton Herault Furnace (electric), using three 20-inch diameter carbon electrodes. The furnace hearth was basic and it was originally lined with Ramix. Subsequent repairs to the hearth had been made with Dolomite and Magnesite. The melt-down contained 29,900 pounds of basic scrap, consisting of low carbon bloom butts and cool-off scrap (steel remaining from previous basic open hearth melt), 5000 pounds of 35% nickel-15% chrome scrap, 25,000 pounds of 18/8 grade scrap, and 1% lime. After this mixture had come to equilibrium an analysis was made, indicating the following composition (w/o):

<u>Element</u>	<u>Composition (w/o)</u>
Carbon	0.25
Niobium	0.10
Manganese	0.60
Nickel	12.08
Chromium	13.80
Silicon	0.57
Phosphorus	0.027
Sulphur	0.024
Copper	0.18
Molybdenum	0.19

The carbon was then brought down to 0.06% by the use of oxygen, followed by a reduction of the slag with a 3% lime - 2% silicon addition. The bath composition was again checked and found to be satisfactory. The melt was then de-slagged and a new slag of lime-silicon added. Alloy additions were made and the metal was brought to casting condition. The tapping temperature was 2950°F, and the ladle temperature was 2850°F (as observed with an optical pyrometer). The metal was teemed into five 22" by 22" ingots, four 15" by 20" ingots, and one 27" by 27" ingot. The results of chemical analysis taken from the middle two-thirds of the heat during the pouring were as follows (average of 2):

<u>Element</u>	<u>Composition (w/o)</u>
Carbon	0.063
Niobium	0.82
Manganese	1.72
Nickel	12.79
Chromium	17.28
Silicon	0.58
Phosphorus	0.022
Sulphur	0.009
Copper	0.19
Molybdenum	0.14

Check analyses made after solidification was complete indicated the above analysis was representative of the entire heat. Additional checks were later made on a number of heavy plates which were furnished from this heat, all analyses falling within the required specifications. The analyses were made by commercial laboratories^{a,b} selected because they performed analyses on this type of material on a routine basis.

^aR. W. Hunt Co., Chicago, Ill.

^bChas. C. Kawin Co., Chicago, Ill.

All plates, sheet, flat stock, and rounds were processed by the Crucible Steel Company. Because the Crucible Steel Company did not have the necessary equipment for the fabrication of seamless pipe and tubing, they arranged to have this work done by others. The Babcock and Wilcox Company hot-pierced the tube rounds and fabricated the pierced billets into base tube, which was cold drawn to final size by the Superior Tube Company, Norristown, Pennsylvania.

VI. REACTOR COMPONENTS EMPLOYING THIS HEAT OF STEEL

Some of the components manufactured from the special heat were:

Core Holding Plates: The fuel elements and inner blanket rods used in EBR-I are held in the proper geometry by a series of heavy steel plates bolted together in a vertical array. These plates were machined from forgings which were radiographed and examined ultrasonically before the rather extensive, intricate and precise machining necessary to prepare the plates was begun. Final weight of each plate after machining was complete, was less than half of the weight of the parent forging. A photograph of a 4-inch thick plate is shown in Figure 1.

External Blanket Bricks: A blanket of natural uranium surrounds the core tank, as illustrated in the cutaway of the core zone, Figure 2. The outer blanket (Figure 3) is an assembly of eighty-four keystone shaped bricks which are cooled by drawing air through the internally finned cooling tubes. Each brick is mechanically jacketed in a deep-drawn thin (0.020 inch) stainless steel can, approximately four inches deep (Figures 4 and 5). The cans are sealed at the cover and cooling tube joints by inert gas tungsten arc welding. All welds are required to be leak-free to a helium mass spectrometer type leak detector. A completed blanket brick is shown in Figure 6.

Inner Blanket Rods: Inner blanket rods consist of 15/16-inch diameter by 20 $\frac{1}{4}$ -inch long natural uranium cylinders inserted into 20-mil wall stainless steel tubes. Each tube is closed at one end by a locating tip. The other end is fastened to a long stainless steel handle which projects through the upper shield of the reactor. These rods are located adjacent to the core and are cooled by NaK alloy. Closure welds at the tip to tube and the tube to handle joints were achieved by the inert gas tungsten arc method.

Fuel Elements: The EBR-I core contains 217 fuel elements. Cylinders of natural and enriched uranium make up the active section of the fuel elements.

The active section of each of the 217 fuel elements in the core contains 0.384" diameter slugs of natural and enriched uranium. These are jacketed by a thin wall (0.020"), externally ribbed stainless steel tube of

slightly larger diameter, and are bonded to it by a static layer of NaK alloy. The fuel section is welded to a long rod of stainless steel which acts as a handle. All welds on the fuel section are required to be tight to a helium mass spectrometer leak detector. The inert gas tungsten arc method without the use of additional filler metal was used for all welds. A photograph of the fuel section of a completed element is shown in Figure 7. The stainless steel tube wall has been cut away to reveal the internal arrangement of the fuel section.

10

Figure 1. Stainless Steel Holding Plate for Core Fuel Elements and Inner Blanket Rods

Figure 2. Cutaway Showing EBR Construction

Figure 3. Outer Blanket of Reactor

Figure 4. Deep Drawn Stainless Steel Can.

10,757

Approx. 1/2X

Figure 5. Drawn Stainless Steel Cover.

10,776

Approx. 1/2X

Figure 6

Stainless Steel Jacketed Uranium Blanket Brick

10,766

Approx. 1/2X

Figure 7.

EBR Fuel Element

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