UNCLASSIFIED

BMI-913(Del.)

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

UNCLASSIFIED

PROPERTIES OF STAINLESS STEEL—
URANIUM DIOXIDE FUEL PLATES

By
J. R. Keeler
L. J. Cuddy

Photostat Price \$ 3.30

Microfilm Price \$ 2.40

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

This document is
PUBLICLY RELEASABLE

Barn Steele
Authorizing Official

Date: 1-10-07

May 11, 1954

Battelle Memorial Institute
Columbus, Ohio

UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service Extension, Oak Ridge, Tenn.

CLASSIFICATION CANCELLED

DATE MAR 6 1957

For The Atomic Energy Commission

H. F. Canale
Chief, Declassification Branch

904-1

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

5 and 6

TABLE OF CONTENTS

	Page
ABSTRACT	7
INTRODUCTION	7
PREPARATION OF PACKS	8
Powder-Metal Core Compacts	8
Jacketing	8
ROLLING	10
PROPERTIES OF FUEL SHEET	12
Tensile Strength of Core in Thickness Direction	12
Longitudinal Tensile Strength of Composite Sheet	12
Creep and Stress-Rupture Properties	16
Resistance to Thermal Cycling	16
Electrical Resistivity	19
CONCLUSIONS	19

~~SECRET~~

904 2

~~SECRET~~

7

2

PROPERTIES OF STAINLESS STEEL - URANIUM DIOXIDE FUEL PLATES

J. R. Keeler and L. J. Cuddy

A method for fabricating 30-in.-long stainless steel - UO_2 fuel sheet was developed, and the properties of the fabricated sheet were investigated. A core containing 30 w/o of UO_2 was roll clad with Type 347 stainless steel. The core matrix consisted of iron - 18 w/o chromium - 9 w/o nickel, prepared by powder-metallurgy methods from the elemental powders. The resulting sheet was 0.020 in. thick and had 0.004 in. of cladding per side on a 0.012-in.-thick core. The rolled sheet was 34 in. long by 2-1/2 in. wide.

The tensile strength of the composite sheet at temperatures up to 1300 F was measured and the creep properties in this temperature range were determined. The stability of the sheet during thermal cycling was excellent.

The electrical resistivity was determined to provide data for the electrical heating of fuel elements in simulated-service tests.

INTRODUCTION

A method of fabricating the required clad sheet on a small scale was developed. The effect of several variables on the ductility and strength of the sheet has been reported in BMI-904. The length of the sheet produced in these initial studies was limited to 10 in.

On the basis of the data obtained on these small samples a matrix of elemental iron - 18 w/o chromium - 9 w/o nickel appeared to have the best over-all characteristics. Full-size elements with this matrix were to be prepared. The sheet was to be 0.020-in. thick with a 0.012-in. core containing 30 w/o of UO_2 in the elemental metal matrix. The 0.004 in. of

~~SECRET~~

904-3

cladding per side was to be of Type 347 stainless steel, and the finished element was to be 5/8 by 30 in. Because of the length and narrow width, it was not considered practical to roll clad the edges of the individual elements. Therefore, a wide sheet, from which several elements could be sheared, was fabricated.

PREPARATION OF PACKS

The method used to prepare small-size samples, with only a few modifications, was used to prepare the full-size fuel-element sheet. The core was prepared by powder-metallurgy techniques, jacketed in a welded picture frame-type can, and hot-rolled to obtain bonding. Final sizing and surface finish were produced by cold rolling.

Powder-Metal Core Compacts

Elemental iron, nickel, and chromium powders in the desired proportions were blended by tumbling in a 1-qt ball mill. Uranium dioxide, sized to 7 to 44 μ by air elutriation, was mixed with the blended matrix powders in the proportion of 30 w/o UO₂ to 70 w/o of metal powders. After tumbling 1 hr, weighed charges of 110 g of powder were placed in a 6 by 1-in. die cavity, leveled, and pressed under a load of 150 tons (50,000 psi). The pressure, which was limited by the capacity of the press available, is less than that used for smaller compacts. The green strength of the compacts, however, was high and no difficulty was experienced in handling them. The low pressure also resulted in comparatively low density in the sintered compacts, but no deleterious effects were observed in the rolled sheet.

After pressing, the compacts were sintered 4 hr in dry hydrogen at 2200 F. The thickness of the sintered compacts varied from 0.176 to 0.191 in. and the density averaged 72 per cent of theoretical.

Jacketing

A segment-type frame, similar to that used on small packs, was used to enclose these cores. Type 302 stainless steel plate, 3/16 in. thick, was sheared into 1-in.-wide strips of two lengths, 7 in. and 2 in. These strips were abraded, deburred, degreased, and then spot welded to a 3 by 8 by 0.054-in. Type 347 cover plate. The spot-welded frame was pickled to

~~SECRET~~

9

4

remove the welding scale and dried. A lightly abraded powder-metal core compact was placed in the frame, as shown in Figure 1. The top cover was placed on the pack, and the four edges were closed by welding with a shielded tungsten arc in a vacuum-purged, argon-filled dry box.

N9281

FIGURE 1. PHOTOGRAPH SHOWING THE 1 BY 1 BY 3/16-IN. CORE IN ITS FRAME BEFORE TOP COVER IS CLAMPED ON

Although small packs prepared in the above manner rolled satisfactorily, the large packs developed blisters when hot rolled to sheet. This blistering was eliminated by evacuating the packs prior to rolling.

The packs were evacuated through a 1/4-in. tube welded in one end of the jacket. Prior to evacuation, the welded assembly was pressure tested at 10 psi and leaks were rewelded. A mechanical pump was used to evacuate to a pressure of approximately 30μ . During the last hour of pumping, the samples were heated to 500 C to drive off any adsorbed gas and moisture.

~~SECRET~~

9045

Immediately prior to rolling, the tube was heated with an oxyacetylene torch and forged shut to seal the pack.

ROLLING

The fabricating procedure for the first large plates followed closely that used for small samples. It was found necessary, however, to modify this procedure to improve the uniformity of the core dimensions and to reduce the amount of scaling.

The first set of eight packs was rolled at 2200 F; the rolling schedule is shown in Table 1. The samples were heated in an argon-filled muffle for 15 min prior to rolling, and were reheated after each pass. Guides directed the samples into the rolls perpendicular to the roll axis.

The thin sheet cooled rapidly. In order to minimize the effect of temperature on the thickness of the core, the sheets were turned end-for-end and flipped over after each pass.

After being hot rolled the samples were returned to the furnace for a 5 to 10-min anneal. Finally, they were air cooled.

The hot-rolled sheet was descaled by pickling or by sandblasting, and was cold rolled to 0.020-in. thickness. The width of the core in the finished sheet was approximately 2-1/8 in., and the length was about 34 in.

These initial samples were heavily scaled after hot rolling, and the reduction during cold rolling was insufficient to produce a good surface finish. Measurements of the core thickness at intervals along the length of the sheet showed a variation from one end to the other as well as some local thickness variation.

TABLE 1. HOT-ROLLING SCHEDULE AT 2200 F

Pass	Initial Thickness, in.	Roll Opening, in.	Thickness After Pass, in.	Reduction, per cent	Remarks
1	0.310	0.212	0.226	27.0	Cross rolled
2	0.226 (a)	0.113	0.165	27.0	Cross rolled, turned 180 deg. and flipped
3	0.165	0.092	0.113	31.5	Longitudinal
4	0.113	0.053	0.076	32.5	Longitudinal, turned 180 deg. and flipped
5	0.076	0.025	0.050	34.0	Ditto
6	0.050	0.015	0.035	30.0	"
7	0.035	0.005	0.028	20.0	"

(a) After second pass, packs were cooled, excess edge cladding sheared, and sample pickled.

~~SECRET~~

11

6

Several methods for reducing the amount of scale were investigated. Furnace modifications, including a flame curtain, did not reduce the scaling. Electroplating with 1/2 mil of nickel plus 1/2 mil of chromium prior to rolling greatly reduced the amount of scaling and resulted in a good cold-rolled surface finish. It was found, however, that the resistance of the finished sheet to corrosion in steam at 1350 F and 5,000 psi was greatly reduced by the electroplate.

Efforts to protect the surface during rolling by means of an outer steel jacket also were unsuccessful. Although a parting compound was used between the protective jacket and the fuel sheet, the jacket frequently adhered to the sheet. It was difficult to control the thickness of the fuel sheet when an outer jacket was used.

The successful solution to the scaling problem was a reduction in the finishing temperature. The packs were cross rolled at 2200 F, then sheared and pickled as indicated in Table 2. However, the longitudinal rolling was carried out at 1850 F instead of at 2200 F. A thin adherent scale was formed, but it was easily removed. The resulting finish on the cold-rolled sheets was excellent.

TABLE 2. REVISED HOT-ROLLING SCHEDULE

Pass	Furnace Temperature, F	Initial Thickness, in.	Roll Opening, in.	Thickness After Pass, in.	Reduction, per cent	Remarks
1	2200	0.310	0.190	0.214	31	Cross rolled
2	2200	0.214	0.144	0.179	16	Cross rolled, turned 180 deg. and flipped
3	2200	0.179	0.128	0.150	16	Ditto
4	2200 (a)	0.150	0.108	0.125	17	"
5	1850	0.125	0.086	0.098	22	Longitudinal
6	1850	0.098	0.066	0.076	23	Longitudinal, turned 180 deg. and flipped
7	1850	0.076	0.047	0.059	22	Ditto
8	1850	0.059	0.026	0.046	22	"
9	1850	0.046	0.012	0.036	22	"
10	1850	0.036	0	0.028	22	"

(a) After fourth pass, packs were cooled, excess edge cladding sheared, and sample pickled.

~~SECRET~~

904-7

Figure 2 shows the structure of sheet finished at 1850 F and at 2200 F. The lower finishing temperature resulted in a slightly greater tendency for the UO_2 to form stringers in the core matrix, but the change was not marked.

The reduction in scaling also resulted in greater uniformity of core dimensions. The rolling schedule was also changed, as shown in Table 2, in order to obtain more nearly equal percentage reductions per pass. With this rolling schedule, and with reduced scaling, the variation in core thickness was reduced to ± 0.001 in. over the 30-in. length of the sheet.

PROPERTIES OF FUEL SHEET

Tensile Strength of Core in the Thickness Direction

It had been found* that, if sufficient force were exerted on a fueled sheet in a direction normal to the plane of the plate, failure would occur in the core itself, and not at the interface between the core and the cladding. This fact offered a simple method for determining quantitatively the strength of the core of the sandwich sheets. Extension bars were aligned and butt brazed to either face. The composite bars were then turned down to standard tensile specimens with the clad sheets at the center of the reduced section. These specimens were tested at four temperatures: 75 F, 1000 F, 1200 F, and 1400 F. The tensile strength averaged 23,500 psi at room temperature and decreased with increasing temperature to an average of 9500 psi at 1400 F. Figure 3 is a plot of the values obtained. The shape of this curve is similar to that for commercial 18-9 stainless steel, but the strengths are much lower as a result of the 30 w/o of nonmetallic material.

Longitudinal Tensile Strength of Composite Sheet

Standard sheet tensile specimens having a 2-in. reduced section were cut from the large sheet in the longitudinal direction. Duplicate samples were tested at 75, 1000, and 1300 F. Figure 4 shows the results of these tests. Also shown are typical data for commercial Type 347 stainless steel. The average tensile strength at room temperature was 56,800 psi. This decreased to 14,000 psi at 1300 F.

* Keeler, J. R., et al., "The Fabrication of Stainless Steel - Uranium Dioxide Fuel Elements," BMI-904, March 2, 1954 (SECRET).

SECRET

13

8

100X

As polished

N10273

Rolled at 2200 F

100X

As polished

N10275

Breakdown at 2200 F, Finished at 1850 F

FIGURE 2. THE EFFECT OF ROLLING TEMPERATURE ON THE STRUCTURE OF STAINLESS STEEL - UO_2 CORE

SECRET

DECLASSIFIED

904-9

FIGURE 3. TENSILE STRENGTH OF CORE AS A FUNCTION OF TEMPERATURE

A-10491

FIGURE 4. LONGITUDINAL TENSILE STRENGTH OF COMPOSITE SHEET AS A FUNCTION OF TEMPERATURE

A-10492

SECRET

16

The ductility of the sheet was low, showing a maximum elongation in 2 in. of 5.0 per cent at 1000 F and 9.5 per cent at 1300 F. The samples tested at room temperature broke outside the gage length and the elongation could not be determined.

Creep and Stress-Rupture Properties

The creep strength of the composite sheet was determined at 1300 F. Stress-rupture tests were also run. Standard sheet tensile specimens were cut longitudinally from a clad sheet which had been annealed 1/2 hr at 1800 F. Creep tests were run in a vacuum at loads of 6000, 9000, 12,000, 15,000 and 18,000 psi. Figures 5 and 6 show the creep rates and stress-rupture data obtained. The 1000-hr rupture strength was 5000 psi. The creep rate at this stress was 0.0014 per cent per hr. This rupture strength is approximately half that of commercial Type 347 stainless steel at the same temperature.

Resistance to Thermal Cycling

Samples were thermally cycled from approximately 500 to 1500 F at the rate of 2 cycles per min. A narrow strip, 2-1/4 in. long by 1/4 in. wide, was cut from the clad sheet and heated by passing a current of approximately 60 amp through this ribbon for 15 sec. The current was then turned off, and the sample was allowed to cool for 15 sec. This cycle was repeated automatically by a timer.

The sample temperature was indicated by a 28-gage Chromel-Alumel thermocouple spot welded to the center of the strip. The current was adjusted to produce a maximum temperature of 1500 F; the sample cooled to approximately 500 F while the current was off. One end of the sample was clamped in a fixed holder. The other clamp was free to move to accommodate the thermal expansion of the sample. A helium atmosphere was maintained around the specimen to prevent oxidation.

SECRET

REF ID: A66177

904.12

12

FIGURE 5. STRESS VERSUS CREEP RATE FOR QO20-IN.-THICK ROLL-CLAD FUEL SHEET AT 1300 F

Cladding: 0.004-in. Type 347 Stainless Steel

Core: 0.012-in. Containing 30 % UO_2 in Matrix of Elemental Iron-18 % Chromium-9 % Nickel

A-10493

904-13

13

FIGURE 6. DESIGN CURVES FOR 0.020-IN.-THICK ROLL-CLAD FUEL SHEET AT 1300 F

Cladding: 0.004-In. Type 347 Stainless Steel

Core: 0.012-In. Containing 30 % UO_2 in Matrix of
Elemental Iron-18 % Chromium-9 % Nickel

A-10494

SECRET

SECRET

904-14

Samples were cycled for various intervals and examined visually and metallographically for evidence of cracking. No cracking or other evidence of failure was observed up to 17,160 cycles, the number of cycles at which the experiment was concluded.

Electrical Resistivity

The fuel-element subassembly, into which these fueled sheets were to be incorporated, was to be tested under simulated-service conditions. In order to attain service temperature, the subassembly was to be electrically heated. Electrical-resistivity measurements were made on strips of fueled sheet, in order to determine the approximate current required to heat the subassembly.

Measurements were made at 87 F by the double-potentiometer method. Several dummy specimens of Type 347 stainless steel of the same dimensions were measured under the same conditions to serve as standards. The average resistivity of the fuel sheet was 96.52μ ohm-cm as compared to 77.47μ ohm-cm for Type 347 stainless steel. The higher value of the fuel plate is the result of the presence of 30 w/o of nonmetallic UO_2 in the core.

CONCLUSIONS

A method for fabricating 30-in.-long, stainless steel clad - stainless plus UO_2 cored fuel sheet was developed. The thickness of the core can be controlled to ± 0.001 in. and an excellent surface finish was obtained.

The tensile strength of the clad sheet in a direction normal to the surface was measured. These measurements showed that the core-to-clad bond was stronger than the core itself. The strength of the core decreased from 23,500 psi at room temperature to 9500 psi at 1400 F.

The tensile strength of the composite sheet in the longitudinal direction varied from 56,800 psi at room temperature to 14,000 psi at 1300 F. The elongation of the sheet at 1300 F was 9.5 per cent.

The 1000-hr rupture stress was 5000 psi and the creep rate at this stress was 0.0014 per cent per hr.

~~SECRET~~

15
20

The clad sheet was stable during thermal cycling between 500 and 1500 F. No cracking or other evidence of failure was observed after 17,160 cycles from 500 to 1500 F at the rate of 2 cycles per min.

The electrical resistivity of the composite sheet is nearly 25 per cent higher than that of Type 347 stainless steel.

JRK:LJC/lp

~~SECRET~~

904-16