# STATUS REPORT ON INCOLOY 800H

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## Introduction

Early in the HTGR Safety Program at BNL a review and assessment of the primary circuit materials indicated that Incoloy 800H is one of the materials that would require further study. In particular, studies were required in general metallurgical behavior of the alloy after long term exposure in HTGR helium and long term creep-rupture and fatigue properties in air and in impure helium. A high temperature testing laboratory has been established with 20 creep-rupture test units, 6 push-pull fatigue units and thermal aging furnaces to carry out these studies on Incoloy 800H and other materials that are critical to reactor safety. Also, the Material Test Loop (MTL) has been built to provide a prototypic HTGR helium environment for the mechanical tests. The purposes of this memo are to discuss some of the results obtained on Incoloy 800H at BNL and to discuss briefly the progress in the development of this alloy for use at temperatures of 1200°F (649°C) and higher.

## Current Grades of Incoloy 800

Incoloy 800 is an iron base alloy with 30-35% Ni; 19-23% Cr; 0.10% Max. C; 0.15-0.60% Al and 0.15-.60% Ti. Two grades of this alloy are available. If regular Incoloy 800 is specified, the material supplied would be in the mill annealed condition which is suitable for use at temperatures up to about 1050°F (566°C) for which creep deformation is limited. For greater creep strength at higher temperatures, the H grade is specified. The H Grade requires that the alloy be solution annealed to provide an ASTM grain size greater than 5 and the C content to be 0.05% minumum. Both grades of the alloy are extensively used in the higher temperature components of the HTGR steam generator. Table 1 which is taken from GA-A12808-Large HTGR Steam Generator-Vol. 3 indicates where the Incoloy 800 material is used.

Prior to about 1974, the specification for material for high temperature use was "Grade II" No restrictions were made on minimum carbon level or minimum grain size. During this period, what is now named Incoloy-800, was designated "Grade I".

Table 2 which is taken from the Fort St. Vrain FSAR, shows that both Grade 1 and Grade II Incoloy 800 were extensively used in the construction of the steam generators for that HTGR.

## BNL Studies on Incoloy 800H

The studies at BNL are concentrated on the Incoloy 800H because the data base for this grade is considerably less than the 800 grade. For Incoloy 800, a considerable amount of data is being generated in Europe and in this country for use in the chemical industry, light water reactor applications and in LMFBR applications.

For the HTGR program most of the mechanical tests have been on a commercial heat (NHH7427A) which has 0.05% C; 32.17% Ni; 19.83% Cr; 0.43% Ti; 0.39% Al and the balance mostly iron. This heat was purchased according to Incoloy 800H specifications in the form of ½ inch diameter rods. In an attempt to obtain a large grain size, all test specimens were given a solution treatment at 2100°F (1149°C). It was found that about half of the specimens attained ASTM grain sizes 3 to 3.5 whereas the other specimens

have fine grain sizes from 8 to 8.5. It appears that specimens from the same length of bar did not respond equally to grain coarsening at 2100°F (1149°C). A similar experience was encountered in solution treating of another commercial heat (#HH3113A). Material from HtHH3113A was used to generate some of the data in ASME Code Case 1592. It should be noted that the 800H material purchased should have met the minimum ASTM grain size without additional heat treatment.

It is well known that grain coarsening of Incoloy 800H depends upon many variables. Prior thermo-mechanical history, amount of cold work prior to solution annealing, carbon content, and probably the distribution of Al and Ti in the alloy affects the temperature needed for coarsening the grain size to greater than ASTM 5. Figure 1 shows a curve by J. Orr on the grain coarsening of cold drawn tubing with various carbon contents. It is pointed out that the grain size vs. temperature curve is very steep, particularly for the higher carbon material. From this curve, it is obvious that the solution annealing has to be above 2100°F (1149°C) to assure a coarse grain material. Other heats of Incoloy 800H might reasonably be expected to show similar behavior. Figure 2 and Figure 3 show cross sections of a test specimen from HtHH7427A solution annealed at 2100°F (1149°C). Coarse grains were obtained in the center of the specimens but the grain size remained fine at the outer part of the bar. Reasons for this anomalous grain-coarsening behavior are not known. Figures 4 and 5, respectively, present the stress-rupture and creep data of material from the same heat (HH7427A) studied at BNL. The solid lines are drawn through the in-air test data points of the coarse grain materials. The fine grain material data points are indicated by (F.G.). Also shown on Figure 4 are the dotted lines which represent the ASME Code Case 1592 expected minimum for Incoloy 800H. All the coarse grained specimens show strength at or above the minimum specified by the ASME Code. However, at 1400°F, the fine grain specimens show strengths which are about 30% lower than the minimum anticipated for coarse grain material. In terms of the time to rupture, the fine grain material shows a reduction of about an order of magnitude. Figure 5 shows that the creep strengths of the fine grained material is about 30% lower than the coarse grained material and the minimum creep tate is about two orders of magnitude higher. Clearly, the creep strength of Incoloy is extremely dependent on grain size; a significant percentage of small grains will lead to low strength at elevated temperatures.

Specimens made from heats #HH7427A and HH3113A have also been tested in high cycle fatigue. All of those specimens were solution annealed at 2100°F (1149°C). Some of the test specimens were fine grained and some were coarse grained. It was found that high cycle fatigue properties up to 1400°F (760°C) were not noticeably sensitive to grain size variation within the range of ASTM 3 to 8.

Experience of Other Investigators

It is well known to investigators who have tested Incoloy 800 or Incoloy 800H that the creep properties are sensitive to grain size and probably to Al and Ti distribution in the material. Figure 6 taken from a paper by R. H. Cook, shows the micro-structure of two specimens taken from the same bar which was given the same solution treatment. One specimen strained 0.15% in 5543 hours while the other strained 28% in the same duration. In this case, the grain sizes of the two specimens were similar. According to the author, this is just one example of property variation in Incoloy 800, at temperatures of 700°C or higher, which could be attributed to local differences in Al and Ti distribution.

The importance and complexity of Incoloy 800 is reflected in the fact that two International Conferences have been solely devoted to it s study. The first was in 1974 at the University of Reading (England) and the last at Petten (Netherlands) in

March 1978. We attended the Petten Conference and presented two papers. Discussions with R. H. Cook of HTMP, R. Huddle and J. A. Board (all have had many years of experience in studying Incoloy 800 for gas cooled reactors) were enlightening. These individuals expressed concern that properties at temperatures above 700°C can vary so greatly. Hence, they felt that the material should not be used in reactor components until it's behavior is better understood.

In summary, several independent studies indicate that in order to meet the ASME minimum creep properties, precautions must be taken on the following points:

. Solution annealing at a sufficiently high temperature to ensure that a consistently large grain size is achieved. It appears that temperatures higher that 2100°F (1149°C) are required.

. Cold working effects during fabrication which could induce a small recrystallized grain size during service should be minimized.

. Compositional effects on recrystallization and grain growth should be examined more fully.

Areas of Concern

Since materials for the Ft. St. Vrain steam generators were ordered in 1967, it is clear that the effects of small grain sizes on creep strength were incompletely quantified. In addition, effects of inhomogeneities of Al and Ti were not understood. On these bases, it is believed that it would be of benefit to:

. Reevaluate the data base used to design the Ft. St. Vrain steam generators.

. Review the specifications and quality control procedures that were used in the construction of Ft. St. Vrain components operating at 700°C and higher.

. Conduct additional stress analyses on these components using a more comprehensive data base.

Table 1

DEFINITION OF MATERIALS USED AND PROJECTED MAXIMUM OPERATING TEMPERATURE

| Component | Material | Maximum Operating Temperature (°F) |
|---|---|---|
| Reheater | | |
| Tubes | Ni-Fe-Cr SB163 Cr II | 1280 (mean wall) |
| Lead-in and lead-out tubes | Carbon steel SA-210 Gr A-1<br>Ni-Fe-Cr SB163 Cr II | 700 (mean wall)<br>1200 (mean wall) |
| Tube support plate | Ni-Fe-Cr SB409 Cr II | 1500 |
| Tubesheet (hot) | Ni-Fe-Cr SB408 Cr II | 1160 |
| Tubesheet (cold) | Carbon steel SA508 Cl 2 | 640 |
| Floor plate | 2-1/4 Cr - 1 Mo SA-387 Gr D | 1050 |
| Shrouds near crossover duct | Ni-Fe-Cr SB408 Gr II | 1570 |
| Thermal insulation cover plate | Ni-Fe-Cr SB408 Gr II | 1450 (below reheater)<br>1570 (above reheater) |
| Insulation | Quartz or Silica, fused silica fibrous blanket | 1500 |
| Superheater II | | |
| Tubes | Ni-Fe-Cr SB163 Gr II | 1200 (mean) |
| Lead-out tubes | Ni-Fe-Cr SB163 Gr II | 1200 (mean) |
| Tubesheet | Ni-Fe-Cr SB408 Gr II | 1100 |
| Tube support ladder | Ni-Fe-Cr SB408 Gr II | 1300 |
| Shroud (inner) | Ni-Fe-Cr SB408 Gr II | 1300 |
| Shroud (outer) | 304 SS, SA-240 | - |
| Shroud insulation cover plate | Carbon steel | 660 |
| Upper insulation | Pure silica | 1300 |
| Lower insulation | Kaowool, alumina-silica fibrous blanket | 1000 |
| Economizer-Evaporator Superheater I | | |
| Tubes | | |
| Superheater I | 2-1/4 Cr - 1 Mo SA213, T22 | 1000 (mean wall) |
| Evaporator II | 2-1/4 Cr - 1 Mo SA213, T22 | 900 (mean wall) |
| Evaporator I | 2-1/4 Cr - 1 Mo SA213, T22 | 850 (mean wall) |
| Economizer II | 2-1/4 Cr - 1 Mo SA213, T22 | 700 (mean wall) |
| Economizer I | 2-1/4 Cr - 1 Mo SA213, T22 | 650 (mean wall) |
| Economizer lead-in tubes | 2-1/4 Cr - 1 Mo SA213, T22 | 500 |
| Tube support plate | Ni-Fe-Cr SB409 Gr II | 1300 |
| Tubesheet | Carbon steel SA508 Cl 2 | 500 |

From GA-A12808 -- Large HTGR Steam Generator Volume 3

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Table 2

STEAM GENERATOR MATERIALS

| Pressure Parts | Section | Material | Designation |
|---|---|---|---|
| | Main steam/water tubing and piping and associated components | Carbon Steel<br>C - 1/2 Mo<br>C - Si<br>1 Cr - 0.2 Mo<br>2-1/4 Cr - 1 Mo<br>2-1/4 Cr - 1 Mo<br>1/2 Cr - 1/2 Mo<br>Ni-Fe-Cr<br>Ni-Fe-Cr<br>Ni-Fe-Cr | SA-210-A1<br>SA-182-F1<br>SA-442-60<br>SA-193-B7<br>SA-182-F22<br>SA-213-T22<br>SA-213-T2<br>SB-408 Gr. 1 & 2<br>SB-163 Gr. 1 & 2<br>SB-407 Gr. 1 |
| | Reheater steam tubing and piping and associated components | 1-1/4 Cr - 1/2 Mo<br>2-1/4 Cr - 1 Mo<br>2-1/4 Cr - 1 Mo<br><br>Ni-Fe-Cr<br>Ni-Fe-Cr<br>Ni-Fe-Cr<br>Ni-Fe-Cr | SA-335-P11<br>SA-335-P22<br>SA-182-F22<br><br>SB-408 Gr. 1 & 2<br>SB-409 Gr. 2<br>SB-407 Gr. 1<br>SB-163 Gr. 2 |
| Major Support Structures | Main steam/water sections<br>Reheat sections | 2-1/4 Cr - 1 Mo<br>Ni-Fe-Cr<br>Ni-Fe-Cr | SA-387D<br>SB-409 Gr. 2<br>SB-409 Gr. 2 |
| | Primary closure<br><br>Secondary closure | 2-1/4 Cr - 1 Mo<br>Ni-Fe-Cr<br>2-1/4 Cr - 1 Mo<br>Ni-Fe-Cr<br>C - 1/2 Mo<br>C - 1/2 Mo | SA-182-F22<br>SB-408 Gr. 1<br>SA-182-F22<br>SB-408 Gr. 1<br>SA-182-F1<br>SA-204B |
| | Shroud | 2-1/2 - 1 Mo<br>Ni-Fe-Cr<br>1 Cr - 1/2 Mo | SA-182-F22<br>SB-409 Gr. 1<br>SA-387B |
| | Baffles and cover sheets | 2-1/4 Cr - 1 Mo<br>Ni-Fe-Cr<br>Ni-Fe-Cr | SA-387D<br>SB-409 Gr. 1<br>Hastelloy X |
| Insulation | | Kaowool<br>Metallic<br>Silica Felt | Kaowool<br>Metallic<br>Silica Felt |

From Fort St. Vrain FSAR

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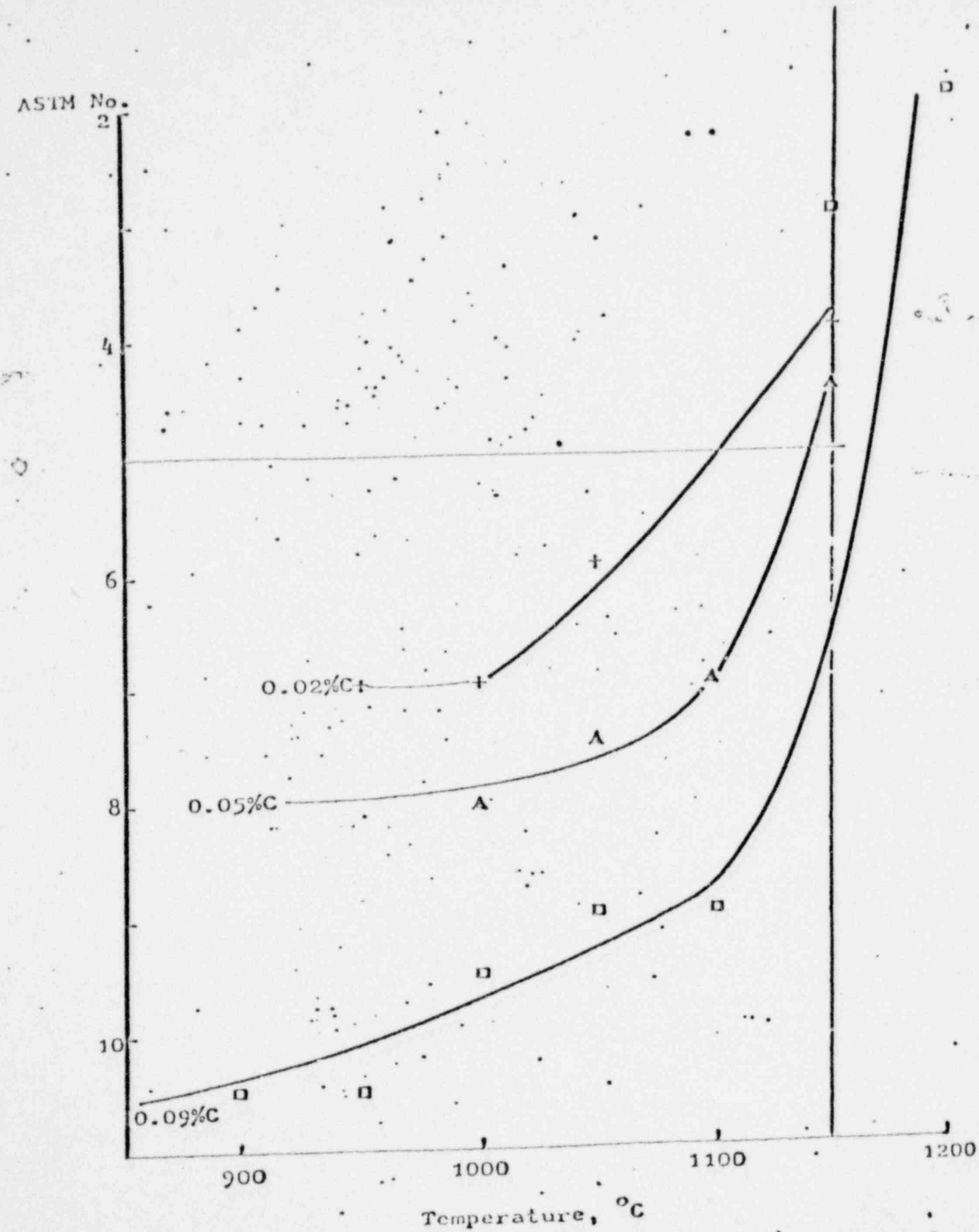


EFFECT OF SOLUTION TREATMENT TEMPERATURE ON GRAIN SIZE OF COLD DRAWN TUBING (12)

Figure 1 From a Review of the Structural Characteristics of Alloy 800

Figure 2 HtPH 7427A

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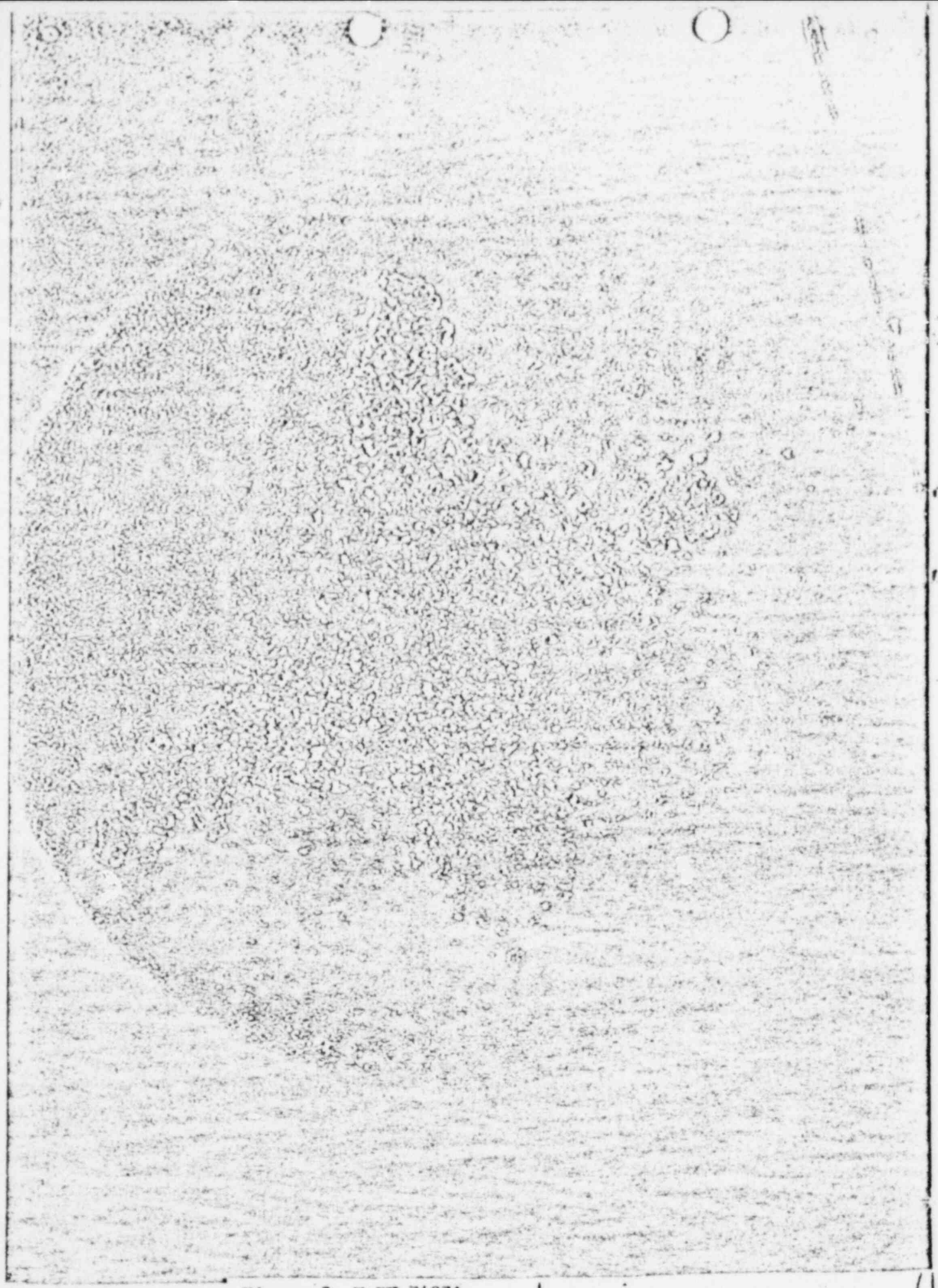

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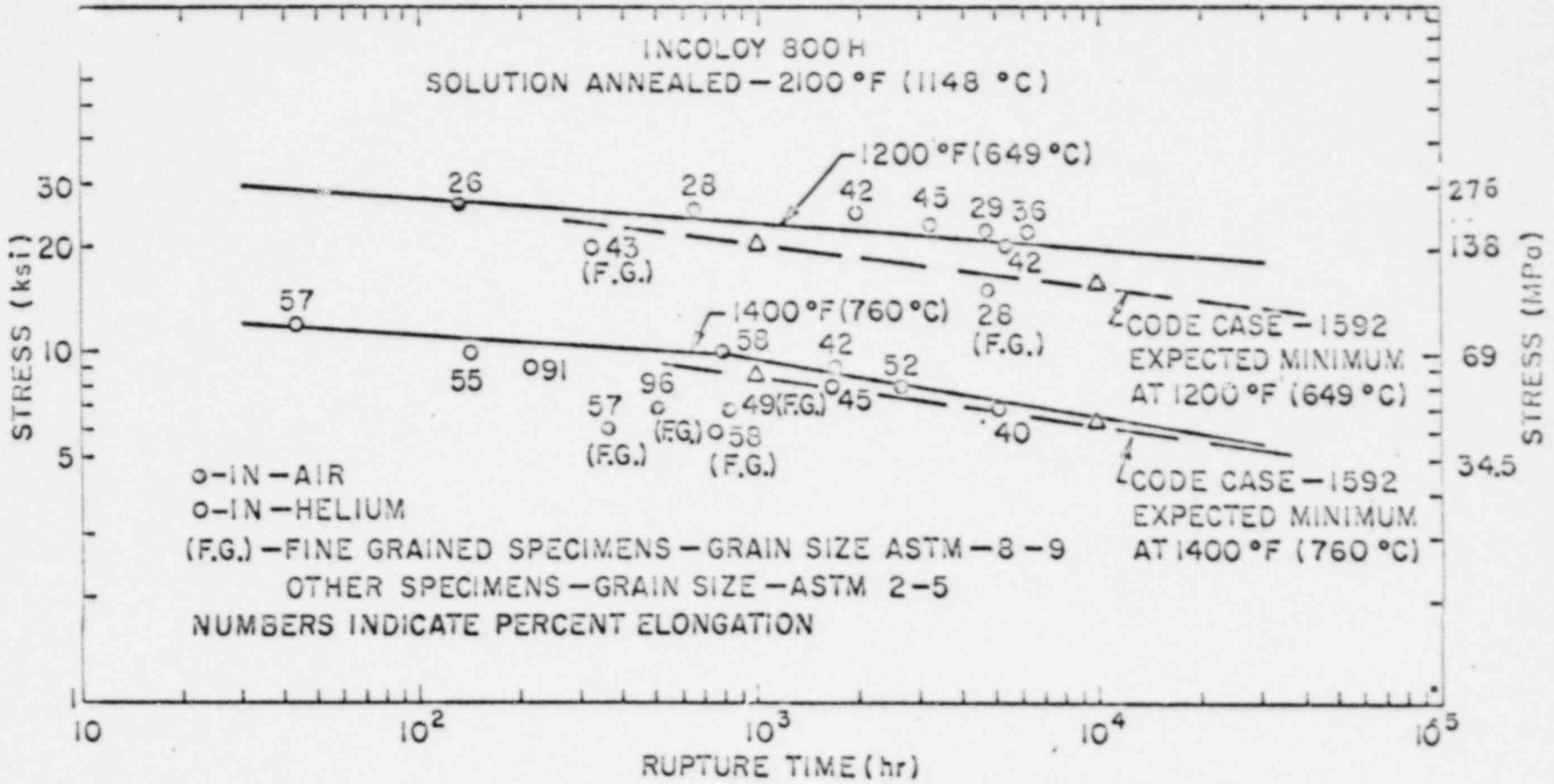
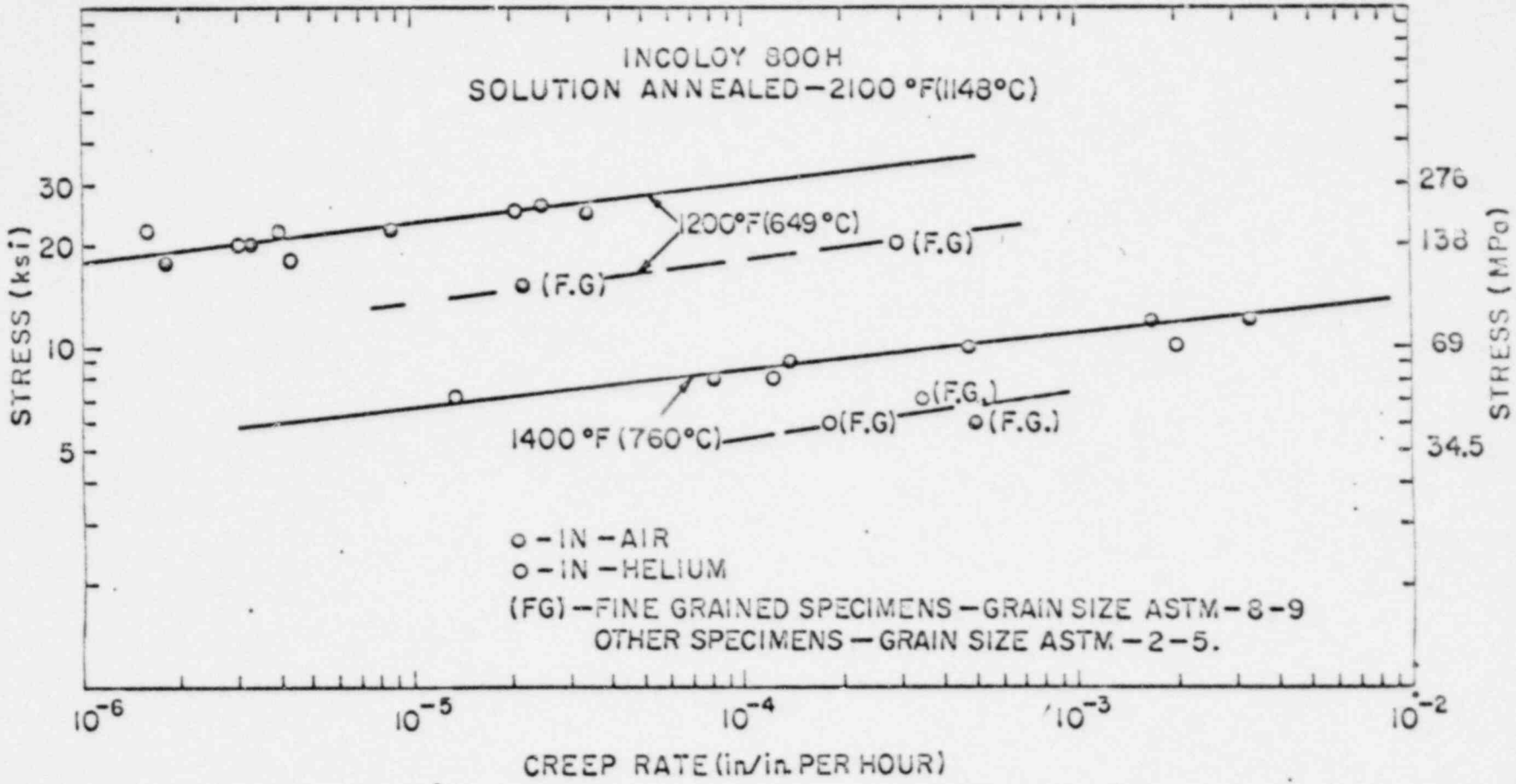


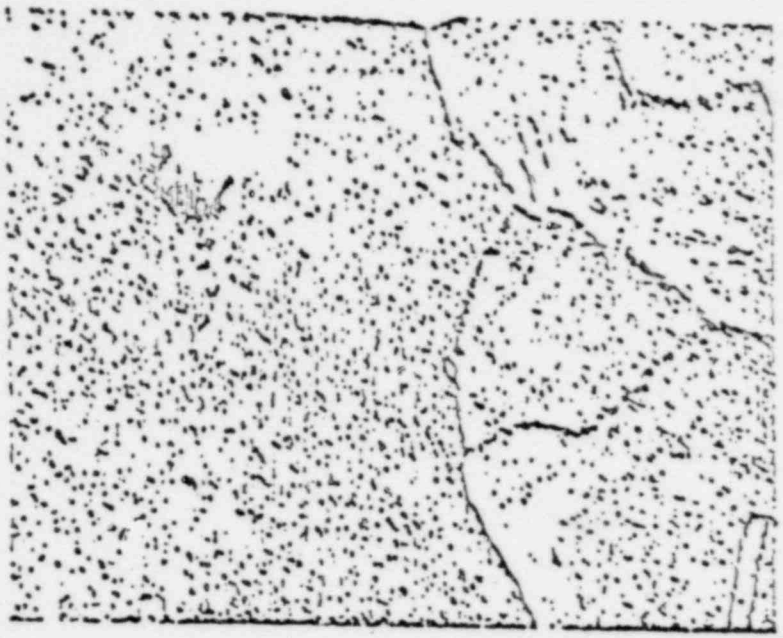

STRESS RUPTURE PROPERTIES INCOLOY 800 H TESTED AT 1200 °F (649 °C) AND 1400 °F (760 °C) IN AIR AND IN HTGR HELIUM

Figure 4




CREEP STRENGTHS OF INCOLOY 800 H AT 1200°F(649°C) AND 1400°F(760°C) TESTED IN AIR AND IN HTGR HELIUM

Figure 5



0.15% strain in 5543h

Hardness change during testing was
+ 20 VPN on head of specimen
+ 22 VPN on shank of specimen

28% strain to rupture in 5543h

Hardness change during testing was
+ 14 VPN on head of specimen
+ 20 VPN on shank of specimen

Fig 6 Microstructures (x 1200) of the bulk of two samples of alloy M (0.046C) tested at 700°C and 77/mm² but showing large differences in creep strength

From HTMP Report #7 Creep and corrosion of Alloy 800 in Simulated High Temperature Reactor Helium at 600-800°C By R. H. Cook Sept. 1977

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