

SWELLING AND MICROSTRUCTURE OF HFIR IRRADIATED AUSTENITIC STAINLESS STEELS*

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The swelling and microstructural information available from HFIR-CTRs-9-13 are summarized and compared for CW 316 and CW(316 + Ti). These experiments were irradiated to moderate fluences of about 8 to 16 dpa and 500 to 1000 at. ppm He at irradiation temperatures ranging from 285 to 670°C. These results are compared to higher fluence HFIR irradiation of CW 316 from HFIR-CTRs-2-8 irradiated at 375 to 680°C at fluences up to 61 dpa and 4200 at. ppm He. Both the high- and low-fluence cavity volume fraction swelling curves for CW 316 have a similar shape. The curves show a definite swelling minimum at 470 to 570°C that corresponds to the temperature of maximum precipitation. The swelling increases rather sharply with temperature at the higher and lower temperatures. The moderate fluence swelling levels are all below 0.5% $\Delta V/V_0$. The temperature dependence of swelling for CW(316 + Ti) parallels the CW 316 behavior and the magnitude of swelling is measurably lower at all temperatures. There is nearly complete association between cavities and fine MC particles in the irradiated CW(316 + Ti) that is responsible for the lower swelling of this material. CW 316 irradiated at 375 to 385°C shows an unusually sharp fluence dependence that includes gamma-prime dissolution, Frank loop unfaulting and reprecipitation of eta phase. The microstructure of CW(316 + Ti) has the advantage of exhibiting much less phase instability and much less fluence sensitivity compared to CW 316.

Table 1. Alloy Composition^a
(weight percent)

| | 316 (DO Heat) B ^b | 316 + Ti (R1 Heat) F ^b |
|----|---------------------------------|--------------------------------------|
| Cr | 18.0 | 17.0 |
| Ni | 13.0 | 12.0 |
| Mo | 2.6 | 2.5 |
| Mn | 1.9 | 0.5 |
| Si | 0.8 | 0.4 |
| Ti | 0.05 | 0.23 |
| C | 0.05 | 0.06 |
| P | 0.013 | 0.01 |
| S | 0.016 | 0.013 |
| N | 0.005 | 0.006 |
| B | 0.0005 | 0.0007 |
| V | 0.01 | 0.01 |
| Nb | 0.0005 | 0.01 |

^aBalance Fe plus trace
impurities.

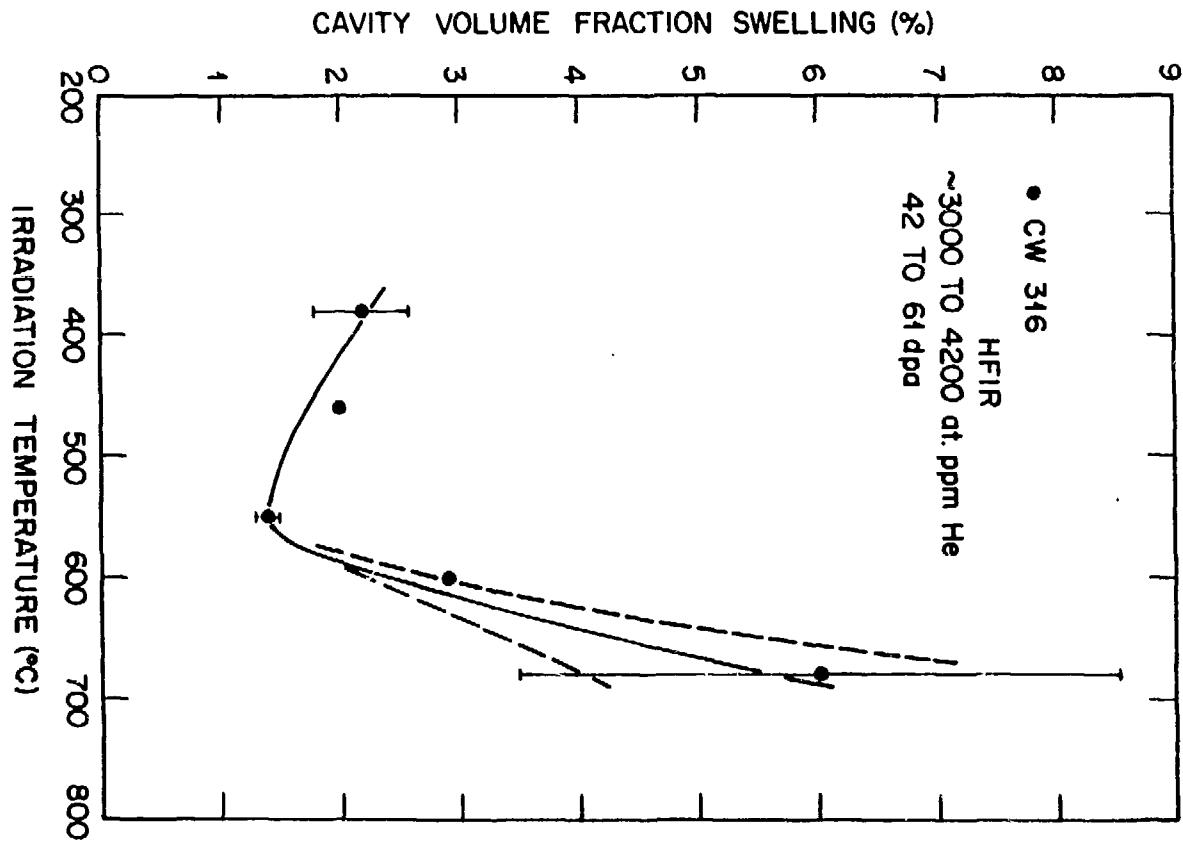
^bAlloy designations for samples.

HFIR CTRs 9-13EXPERIMENTAL CONDITIONS

- IRRADIATED IN HFIR IN SYMMETRIC PTP POSITIONS
- TEMPERATURE RANGE: 285 to 670°C
- FLUENCE RANGE: 1.0 to 2.1 ($\times 10^{26}$ n/m²)
7.7 to 16.0 dpa
380 to 1020 at. ppm He
- IRRADIATION TIME: 5 cycles (2770 h)
8 cycles (4400 h)
- MATERIALS: SA and 20% CW 316
SA and 20% CW 316 + 0.23 wt % Ti

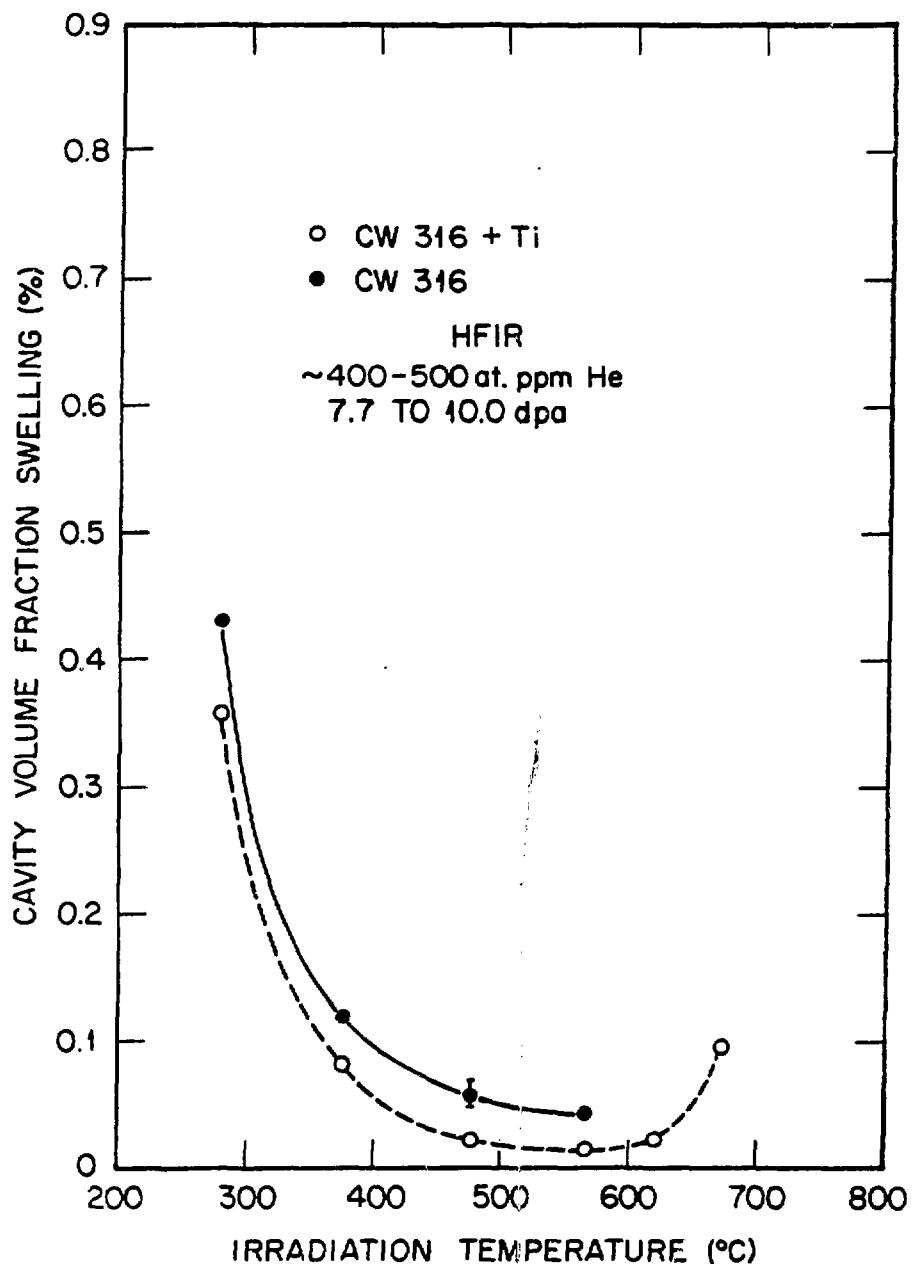
SWELLING AS A FUNCTION OF TEMPERATURE

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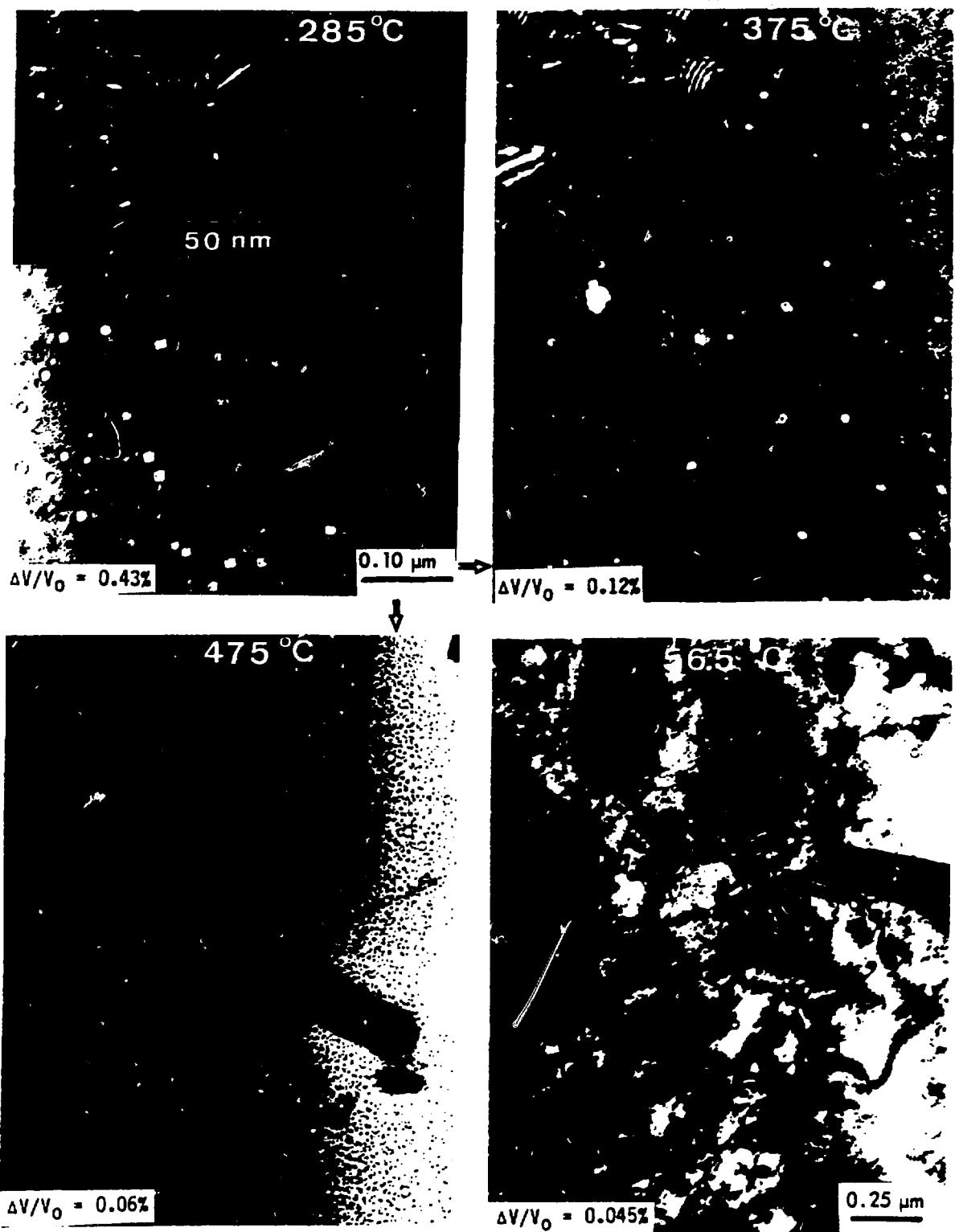
SWELLING AS A FUNCTION OF TEMPERATURE



MAJOR FEATURES:

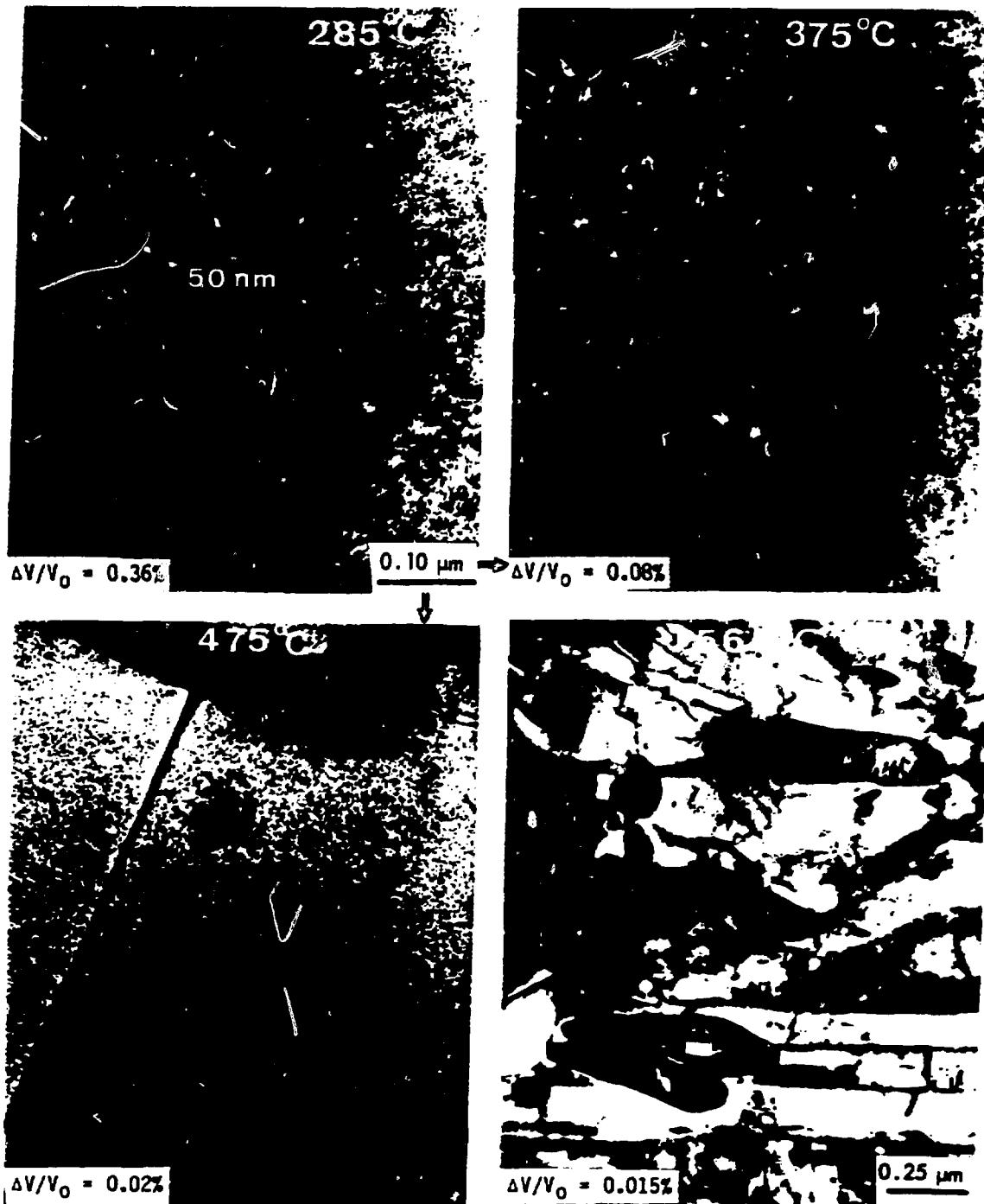
- SIMILARITY BETWEEN HIGH AND LOW FLUENCE CURVES FOR CW 316
- SWELLING MINIMUM RATHER THAN A SWELLING PEAK AS OBSERVED IN FAST-REACTOR-IRRADIATED MATERIALS
- SWELLING DOES NOT QUIT AT LOW TEMPERATURES AND IS QUITE SIMILAR FOR CW 316 AND CW 316 + Ti DESPITE RADICALLY DIFFERENT MICROSTRUCTURES
- SWELLING IS SIGNIFICANTLY LOWER IN CW 316 + Ti IN THE 400-600°C RANGE
- ALL CAVITY SWELLING VALUES ARE LESS THAN 0.5%

MICROSTRUCTURES FOR CW 316 AFTER HIGH IRRADIATION
PRODUCING 7.7 to 10.0 dpa AND 380-500 at. ppm He

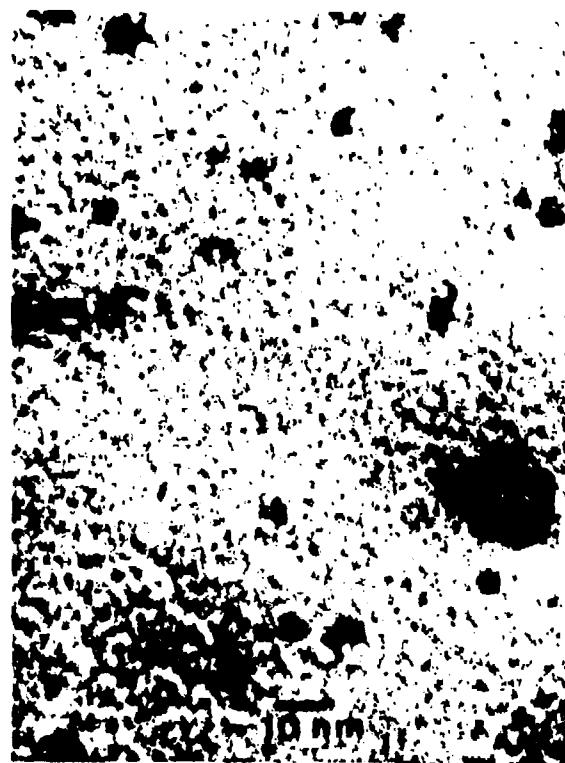


MICROSTRUCTURES FOR CW 316 + Ti AFTER IRRADIATION

PRODUCING 7.7 to 10.0 dpa AND 380 to 500 at. ppm He



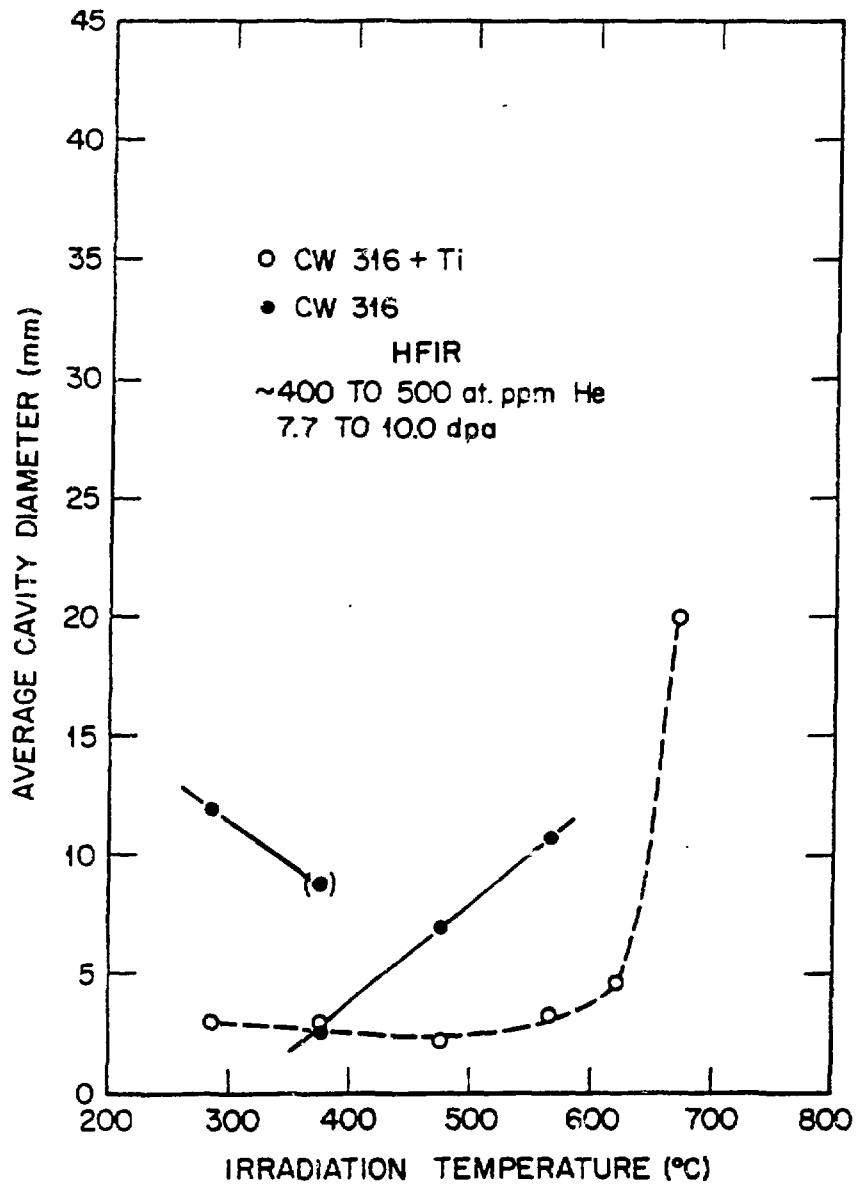
SWELLING AND MC PRECIPITATION ARE DIRECTLY RELATED IN HFIR IRRADIATED CH 316 + Ti



- MC PRECIPITATION OCCURS FROM 280 to 670°C
- MC PRECIPITATE DENSITY AND SIZE ARE A FUNCTION OF TEMPERATURE IN HFIR
- MC PRECIPITATE DISTRIBUTION IS TEMPERATURE INDEPENDENT IN THERMALLY AGED MATERIAL

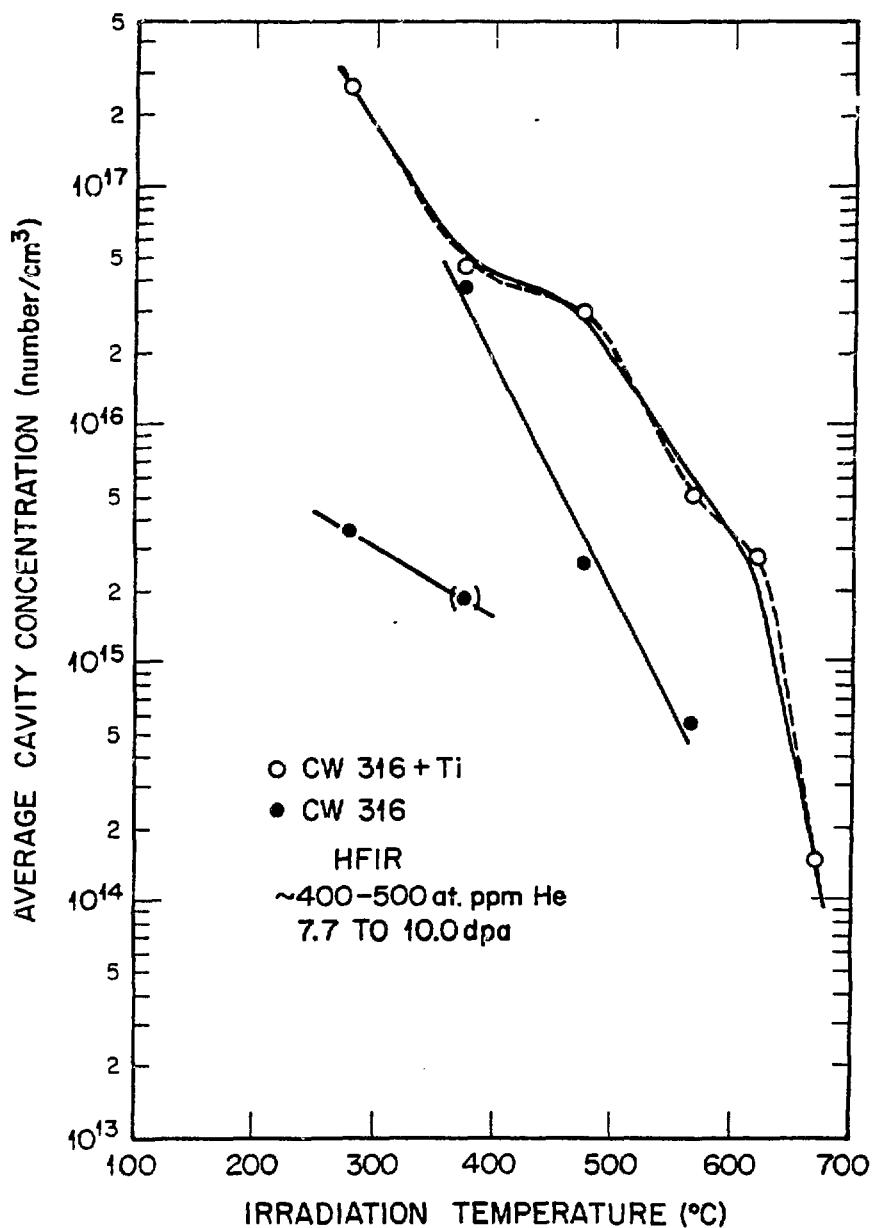
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CAVITY SIZE AS A FUNCTION OF TEMPERATURE

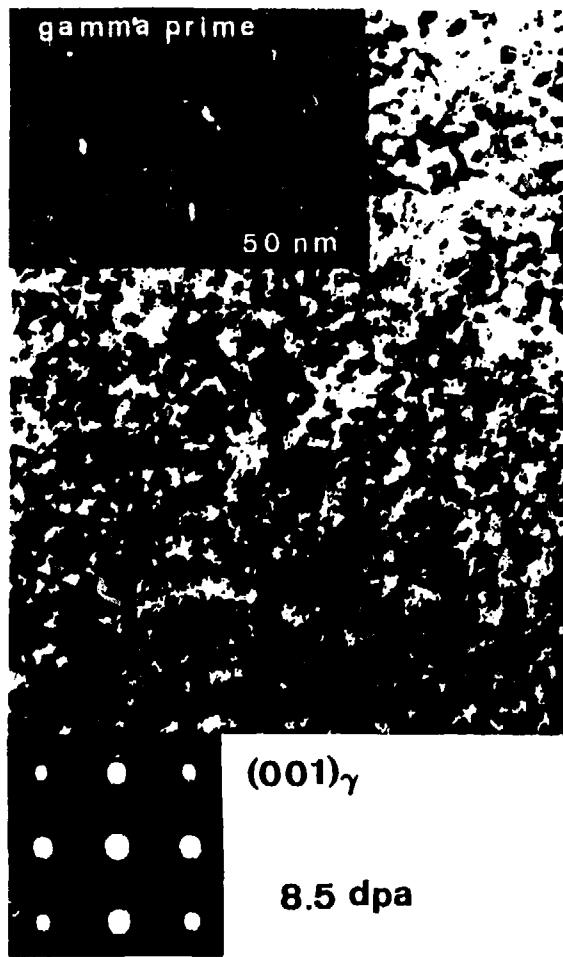


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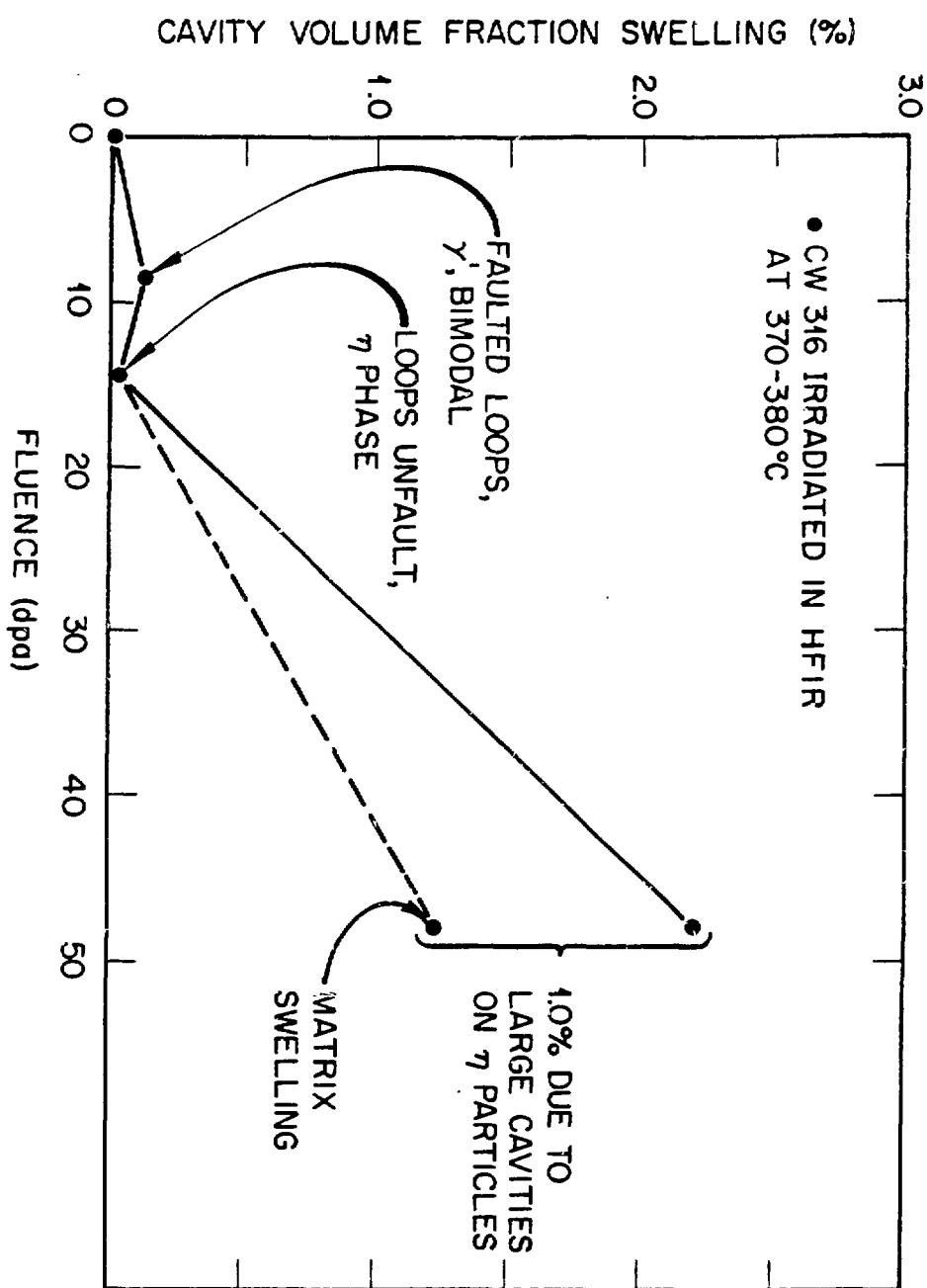
CAVITY DENSITY AS A FUNCTION OF TEMPERATURE



MICROSTRUCTURAL CHANGES WITH INCREASING FLUENCE IN CW 316 IRRADIATED IN HFIR AT 375 to 385°C



SWELLING AS A FUNCTION OF FLUENCE



S U M M A R Y

- HFIR IRRADIATION CHANGES THE TEMPERATURE DEPENDENCE OF SWELLING COMPARED TO A FAST REACTOR (HELIUM EFFECT)
- CAVITY STRUCTURES ARE GENERALLY REFINED (HELIUM EFFECT)
- SWELLING IS LESS IN CW 316 + Ti THAN IN CW 316 IRRADIATED IN HFIR (MC EFFECT ON HELIUM)
- SWELLING AS A FUNCTION OF FLUENCE CAN BE COMPLICATED (LOOP, PRECIPITATION, HELIUM EFFECT)
- CONSIDERABLE INCREASE IN SWELLING OCCURS AT LOW TEMPERATURES THAT IS QUITE UNAFFECTED BY DRASTIC MICROSTRUCTURAL CHANGES (HELIUM EFFECT)
- CW 316 + Ti OFFERS CONSIDERABLE IMPROVEMENT IN SWELLING RESISTANCE AND CONTROL OF UNDESIRED PHASE INSTABILITY AT 375 to ABOUT 600°C