THE EFFECTS OF IRRADIATION TO 8 x 10^{26} m^{-2} ON THE MECHANICAL PROPERTIES OF 6061-T651 ALUMINUM

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IRRADIATION EFFECTS ON STRUCTURAL MATERIALS

The effects of irradiation on the mechanical properties of candidate structural materials are being examined.

A key to the generation of useful neutron beams is allowing the neutrons produced in the core to escape. Therefore, an aluminum alloy has been selected for the first wall containment adjacent to the core, the Core Pressure Boundary Tube (CPBT).

- 6061-T651 (Al-1.0Mg-0.6Si-0.3Cu-0.2Cr)
- acceptable mechanical properties in unirradiated condition
- low neutron cross-section
- high thermal conductivity for heat removal

This alloy may also be used for the beam tubes and reflector tank.

An irradiation program is underway to determine the effects of irradiation on the mechanical properties of 6061-T651, in particular the fracture toughness. This data will allow the operating lifetime of the CPBT to determined, which will in turn determine its replacement schedule in the ANS.

- irradiations have been conducted to 10^{26} and 8 x 10^{26} m^{-2} (thermal, < 0.625 eV); these correspond to approximately 1 cycle and 6 months (9 cycles) of ANS operation, respectively
- irradiations are being conducted in the HFIR

- first capsule, designated HANSAL-T1, has been irradiated to 10^{26} m^{-2} (three HFIR cycles) and disassembled
- all specimens have been tested

A second irradiation capsule, HANSAL-T2, has been irradiated in HFIR to 8 x 10^{26} m^{-2} (21 cycles). This fluence is equivalent to approximately 6 months of operation of the ANS for the CPBT.

The capsule has been disassembled and the specimens have been prepared for testing.

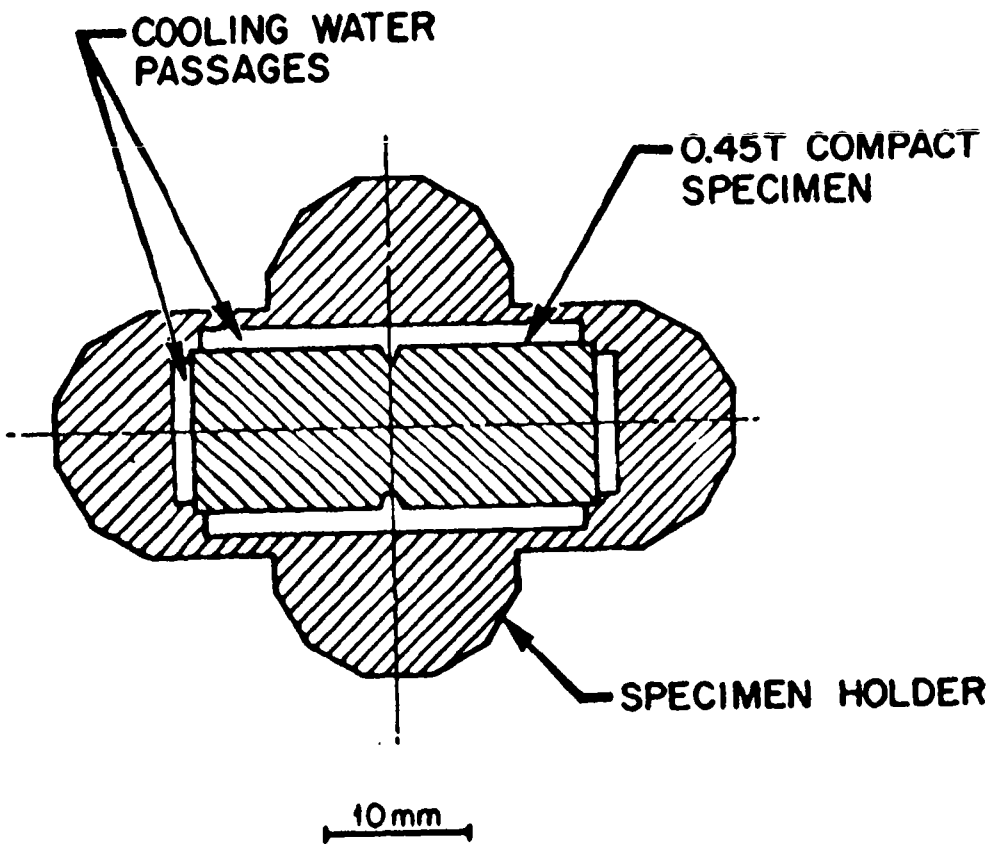
- removal of loading hole and center notch filler pieces from 8 specimens was successful
- the temperature monitor capsules have not been removed from the 8 remaining specimens

The tensile specimens and the first 8 compact specimens have been tested.

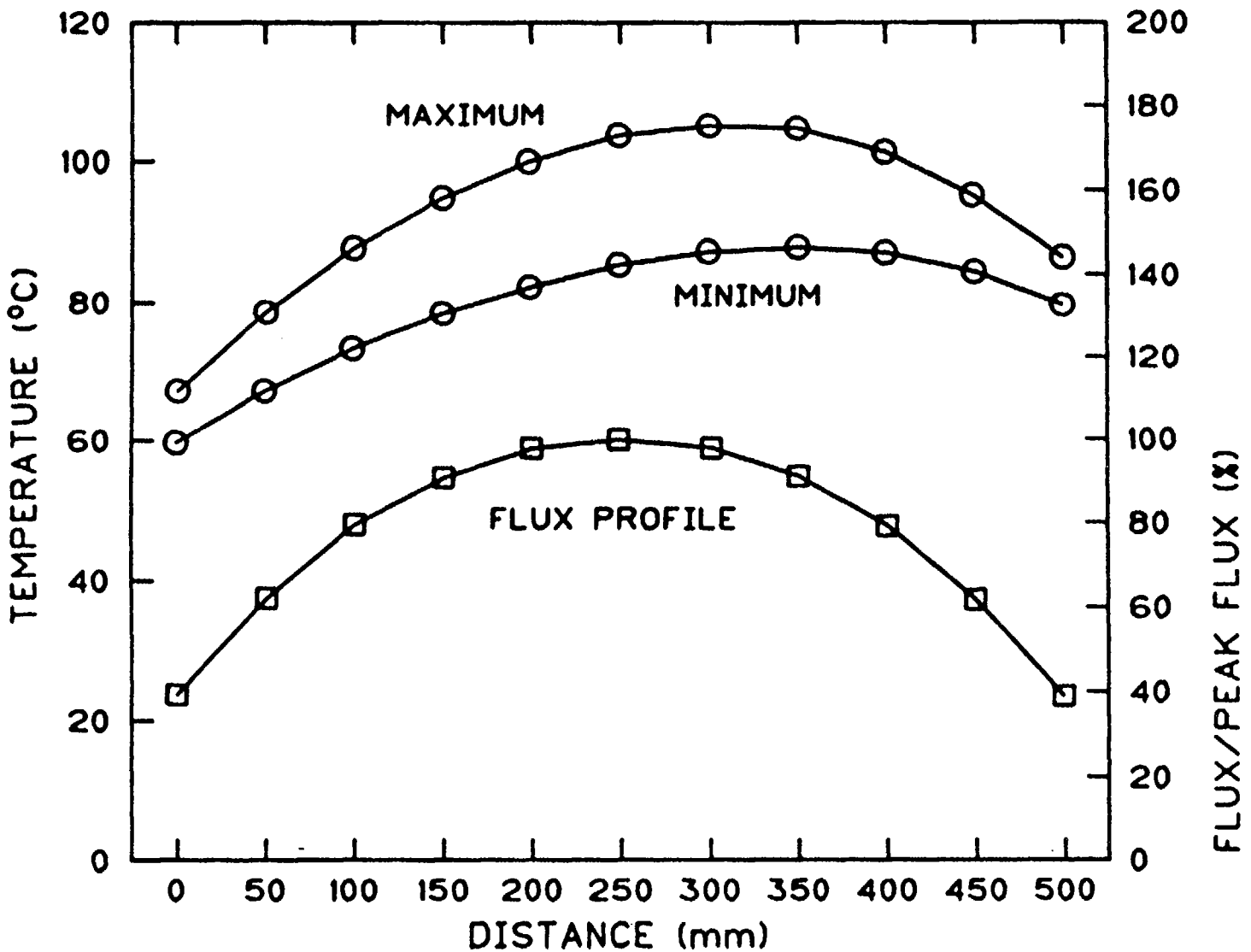
HANSAL-T1 DESIGN

- inserted in HFIR target region
- cluster of four target positions were combined to create a volume large enough for conventional fracture toughness specimens
- 16 compact specimens and 15 flat tensile specimens were arranged in column, with 30 TEM discs and 30 atom probe needles
- irradiation target temperature was 95°C (CPBT operating temperature); specimens were cooled by flowing reactor cooling water, so all openings in specimens were filled to reduce flow perturbations in flow channels
- uninstrumented capsule, but melt wire canisters were inserted in loading holes of some compact specimens, and flux monitors for post-irradiation analysis of flux profile

A new capsule that occupied four target positions was designed.



The temperature and flux varied along the length of the HANSAL-T1 capsule.



TEST TECHNIQUES

Tensile Testing

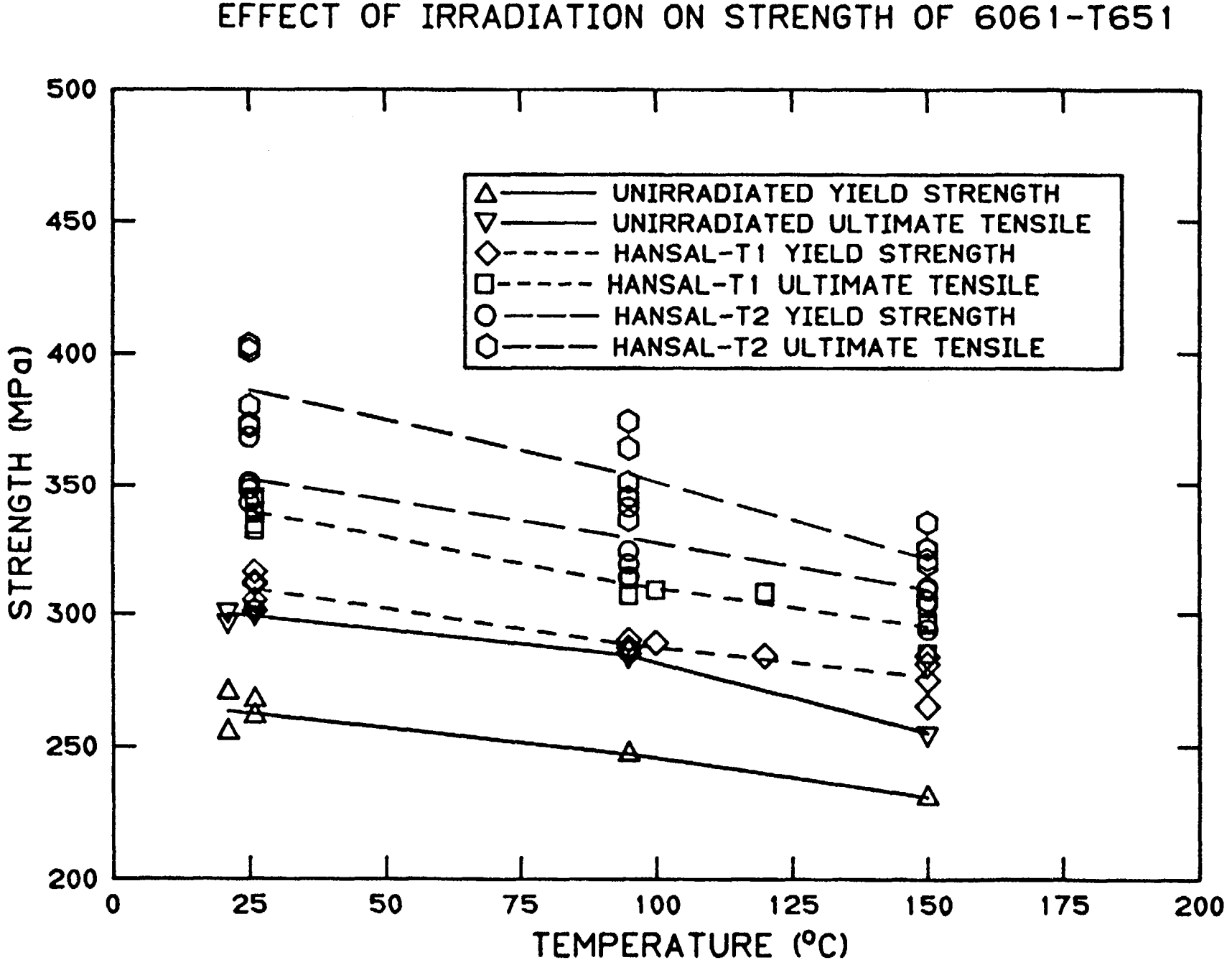
- flat pin-loaded specimens tested with servohydraulic machine in stroke control
- record load and crosshead displacement for analysis
- tests at 25, 95, and 150°C (clip-on thermocouple)

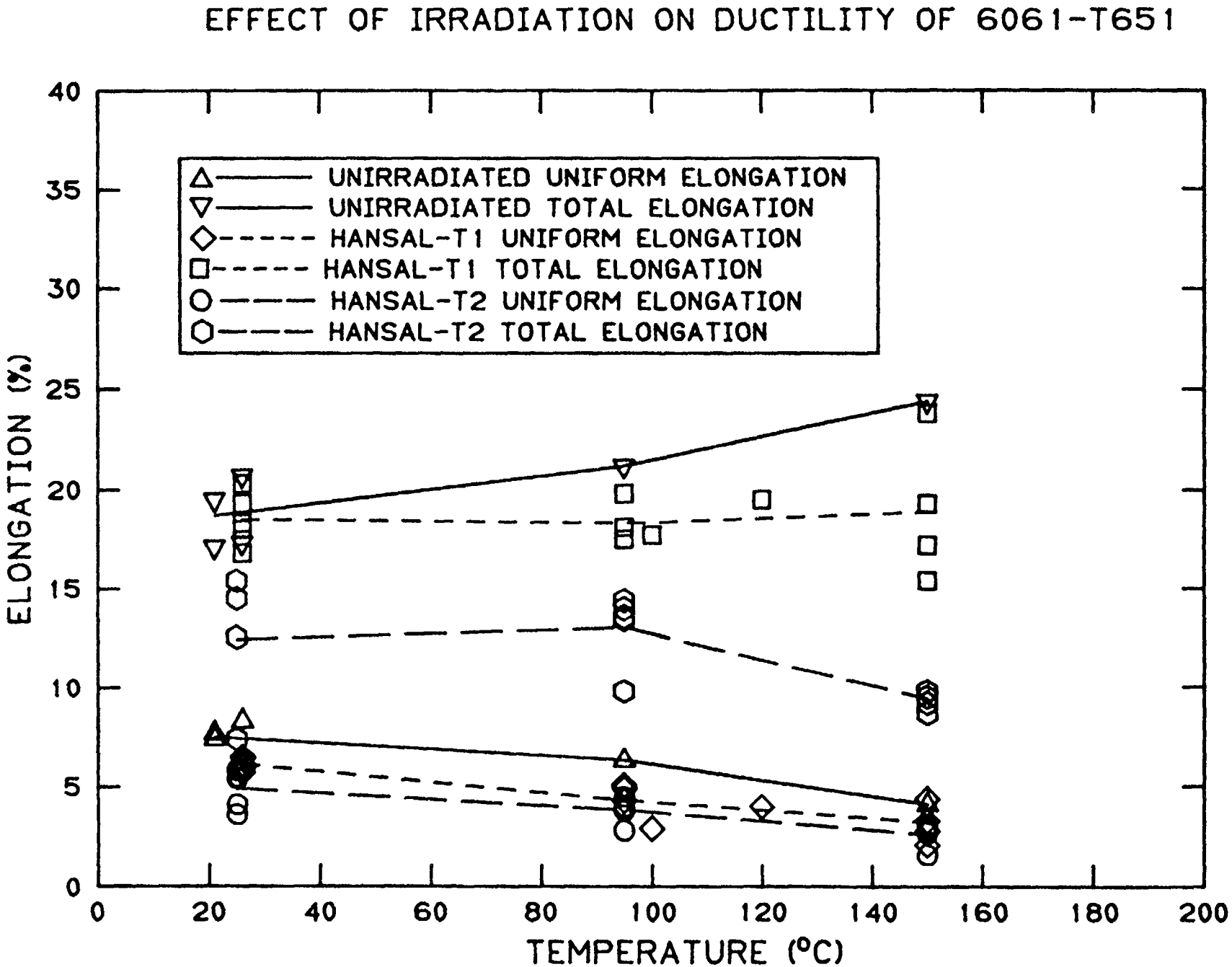
Fracture Toughness Testing

- 0.45 T compact specimens precracked at room temperature and then sidegrooved 20% prior to irradiation
- unloading compliance measured from outboard clip gage on loadline used to monitor crack extension
- tests at 25, 95, and 150°C (clip-on thermocouple)
- final crack extension marked by cyclic loading
- photographs of surface used to measure crack lengths

TENSILE TESTING

- yield and ultimate strengths were increased significantly by irradiation, as expected
- uniform and total elongation are reduced, as expected, although total elongations are still fairly high after irradiation
- results are similar to literature data

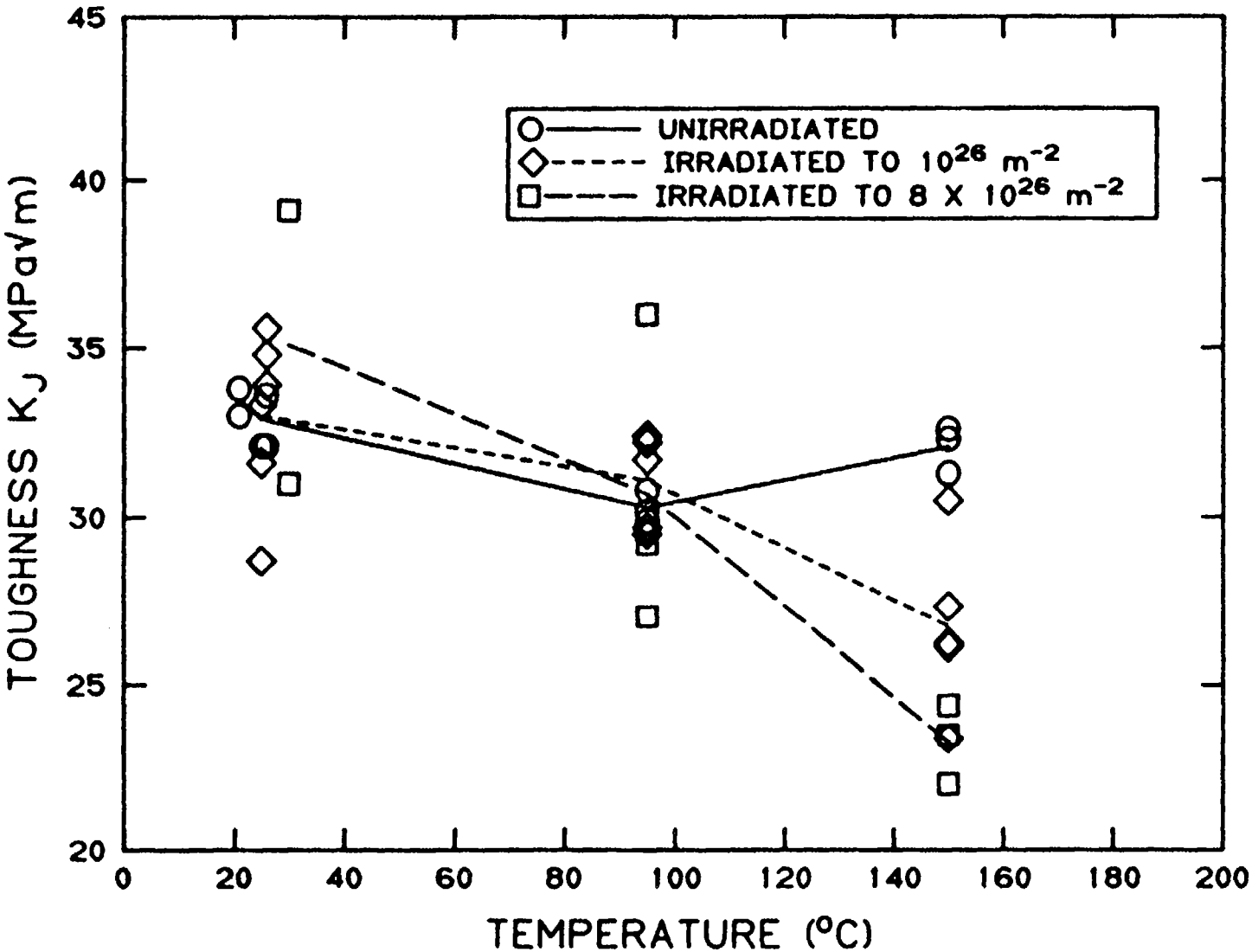

EFFECT OF IRRADIATION ON STRENGTH OF 6061-T651
UNIRRADIATED YIELD STRENGTH
UNIRRADIATED ULTIMATE TENSILE
HANSAL-T1 YIELD STRENGTH
HANSAL-T1 ULTIMATE TENSILE
HANSAL-T2 YIELD STRENGTH
HANSAL-T2 ULTIMATE TENSILE
STRENGTH (MPa)
500
450
400
350
300
250
200
0
25
50
75
100
125
150
175
200
TEMPERATURE (°C)


EFFECT OF IRRADIATION ON DUCTILITY OF 6061-T651
UNIRRADIATED UNIFORM ELONGATION
UNIRRADIATED TOTAL ELONGATION
HANSAL-T1 UNIFORM ELONGATION
HANSAL-T1 TOTAL ELONGATION
HANSAL-T2 UNIFORM ELONGATION
HANSAL-T2 TOTAL ELONGATION
ELONGATION (%)
TEMPERATURE (°C)
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100
120
140
160
180
200

FRACTURE TOUGHNESS TESTING

- the fracture toughness at 25 and 95°C is not significantly affected by irradiation, but does decrease at 150°C
- alloy shows tendency for sudden, rapid crack extension
- tearing modulus of unirradiated material is low, and is reduced to extremely low value after irradiation
- poor agreement between measured and predicted final crack lengths

EFFECT OF IRRADIATION ON FRACTURE TOUGHNESS



IRRADIATION EMBRITTLEMENT OF ALUMINUM

- irradiation with thermal neutrons results in the transmutation of Al to Si
- fast neutrons generate point defects in the lattice which enhances the diffusion of Si
  - this allows Si precipitates to form throughout the material
- precipitate formation accounts for the increase in the strength and the decrease in ductility following irradiation

The HANSAL-T3 capsule has been irradiated for 6 cycles and removed from HFIR for cooldown.

- contains fracture toughness and tensile specimens from weldments

Arrangements are being made for the shipping and disassembly of this capsule.

CONCLUSIONS

The first two capsules for the ANS Irradiation Effects program have been successfully irradiated to 10^{26} and 8×10^{26} m^{-2} (thermal), respectively, at a nominal irradiation temperature of 95°C. The testing of the specimens of 6061-T651 aluminum has shown:

1. The yield and ultimate tensile strengths are increased by irradiation.

2. The uniform and total elongations are reduced, but useful ductility remains, even at the higher irradiation level.

3. The fracture toughness at 25 and 95°C is unaffected by irradiation, but at 150°C, it decreases with an increase in irradiation.

4. The tearing modulus of 6061-T651 is low in the unirradiated condition, and is reduced to very low values by irradiation. This alloy also shows a tendency for sudden unstable crack extension.