Status of Recent Activities by the APEX Materials Group
&
Chemical Compatibility and Radiation Effects Issues in High Temperature Refractory Metals

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Possible Structural Materials for High Wall Loading Concepts

- **Low-activation materials**
  - Vanadium alloys
  - Ferritic/martensitic (8-9%Cr) steels, ODS steels
  - SiC/SiC composites

- **Refractory alloys**
  - Nb-1Zr
  - Nb-18W-8Hf
  - T-111 (Ta-8W-2Hf)
  - TZM (Mo-0.5Ti-0.1Zr-0.02C)
  - Mo-Re
  - W-25Re

- **Ni-based superalloys**

- **Porous-matrix metals and ceramics**

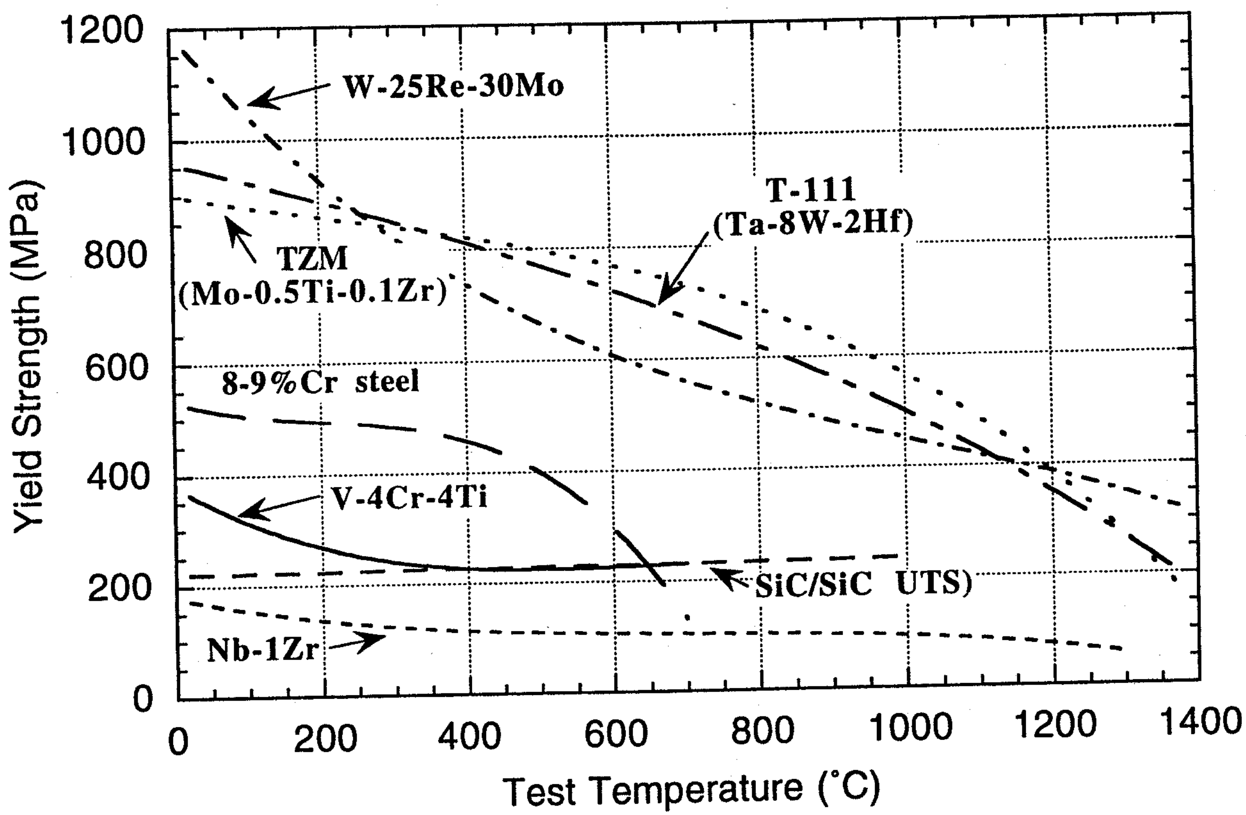
- **Intermetallics**
  - TiAl
  - Fe_3Al

- **Composites**
  - C/C
  - metal matrix composites
  - Cu-graphite
  - Ti_3SiC_2 composites

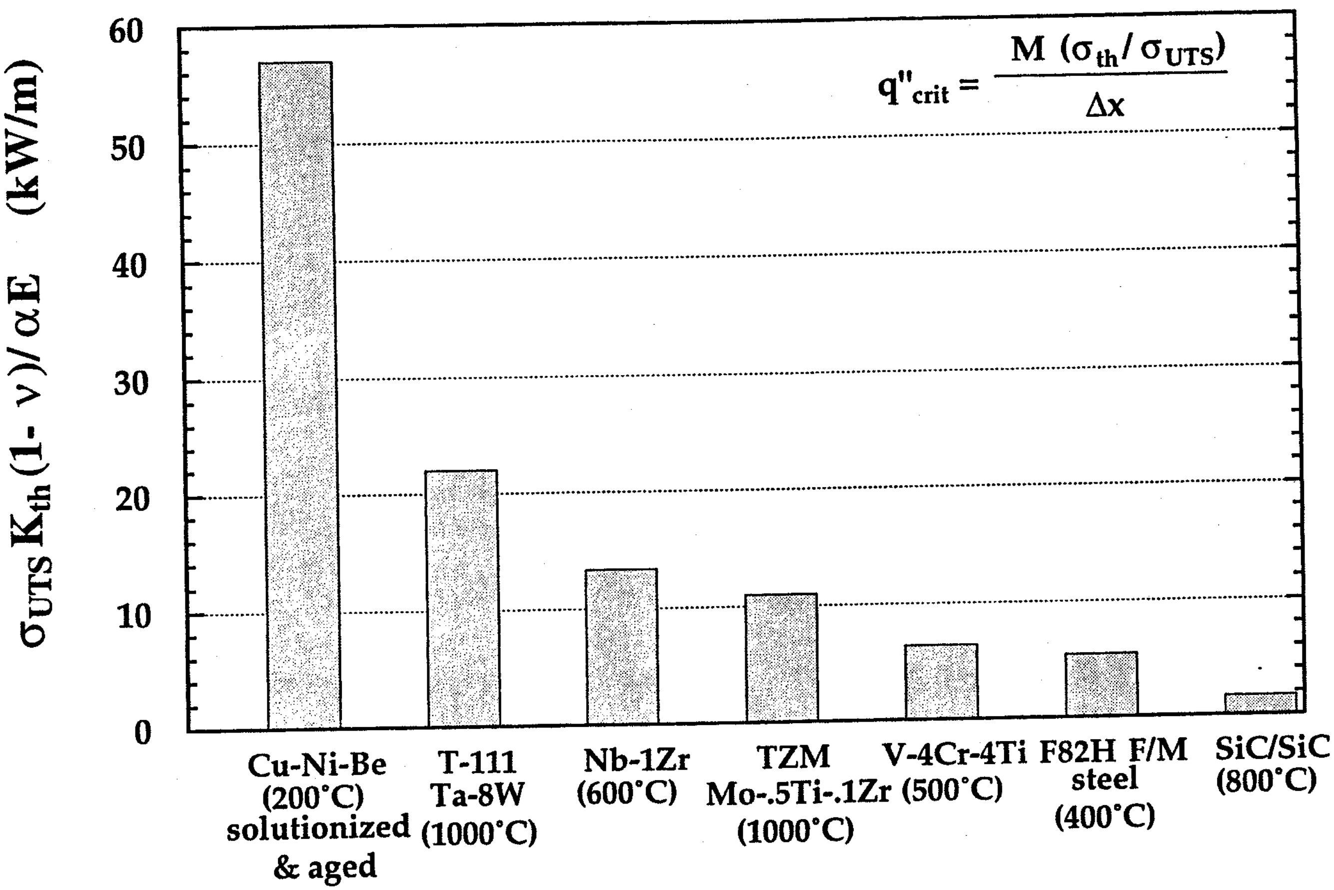
Factors Affecting Selection of Structural Materials

- Unirradiatiated mechanical and thermophysical properties
- Chemical compatibility/corrosion effects
- Materials availability / fabricability / joining technology
- Radiation effects
- Safety aspects (decay heat, induced radioactivity, etc.)

Comparison of the Yield Strengths of Several Materials



COMPARISON OF THERMAL STRESS PARAMETERS



Resources for Structural Materials Database

- Fusion Materials Properties Handbook / ITER Materials Properties Handbook, ed. J.W. Davis (Boeing/St Louis)
  - V alloy chapter is incomplete in present version of IMPH (pub. 4); updated version to be included in IMPH pub. 5, expected summer 1998
  - nothing yet compiled for F/M steels (to be initiated in pub. 5), SiC/SiC
- Aerospace Structural Metals Handbook (1963-1988), ed. W.F. Brown, Jr.
  - mechanical and thermophysical properties of refractory alloys vs. temperature
- Proc. Conf. on Refractory Alloys for Space Nuclear Power Applications, eds. R.H. Cooper, Jr. and E.E. Hoffman, CONF-8308130 (1984)
- Original research publications

Recent Activities by the APEX Materials Group

- Completed assessment reports on properties of unirradiated and irradiated low-activation structural materials
  - V-4Cr-4Ti
  - Fe-8Cr ferritic/martensitic steel
  - SiC/SiC composites (irradiated thermal conductivity is a key issue)

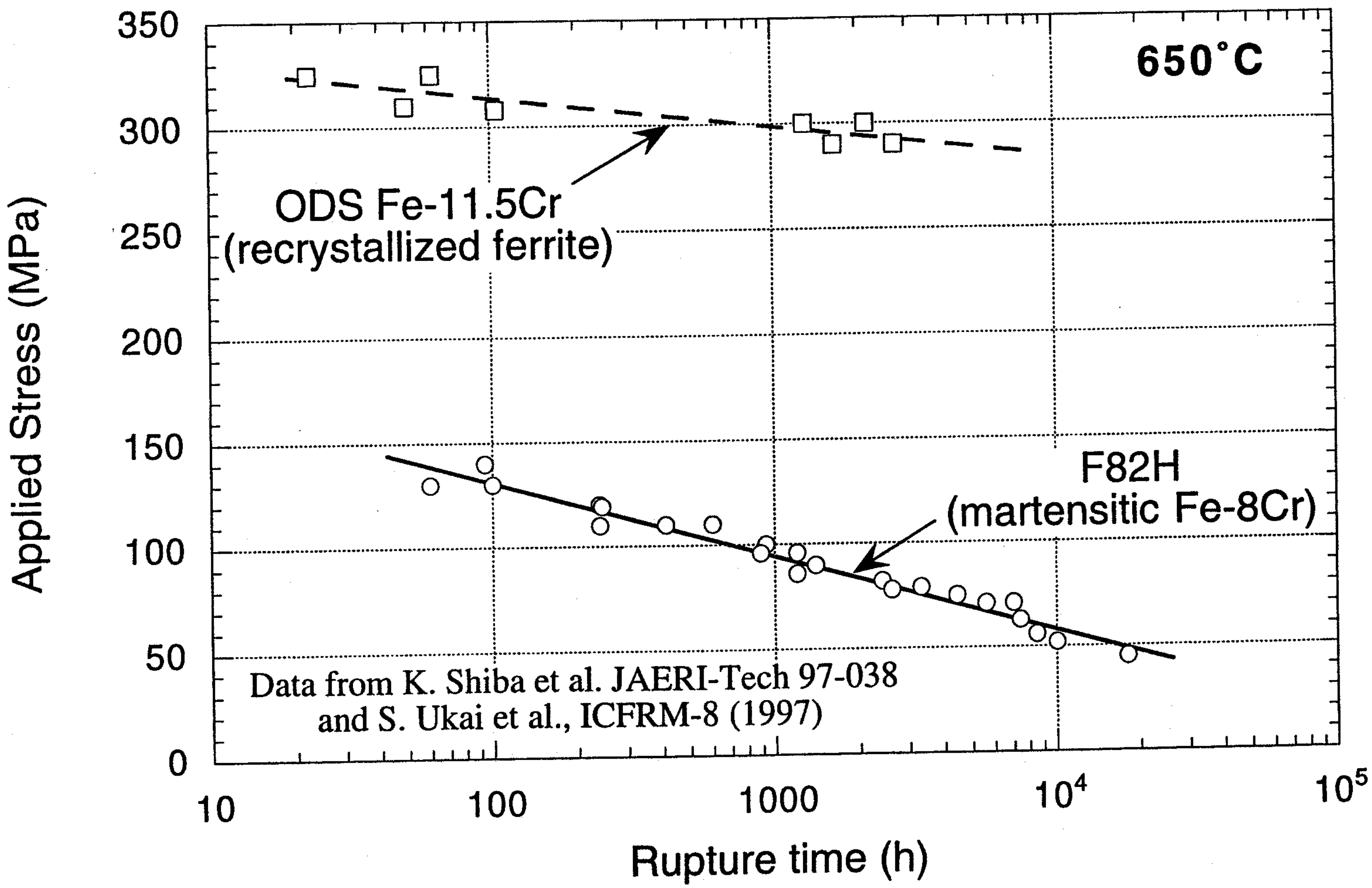
- Information on oxide dispersion strengthened ferritic and martensitic steels is being compiled
  - operation of an ODS ferritic steel up to 650°C or higher appears feasible, based on thermal creep data

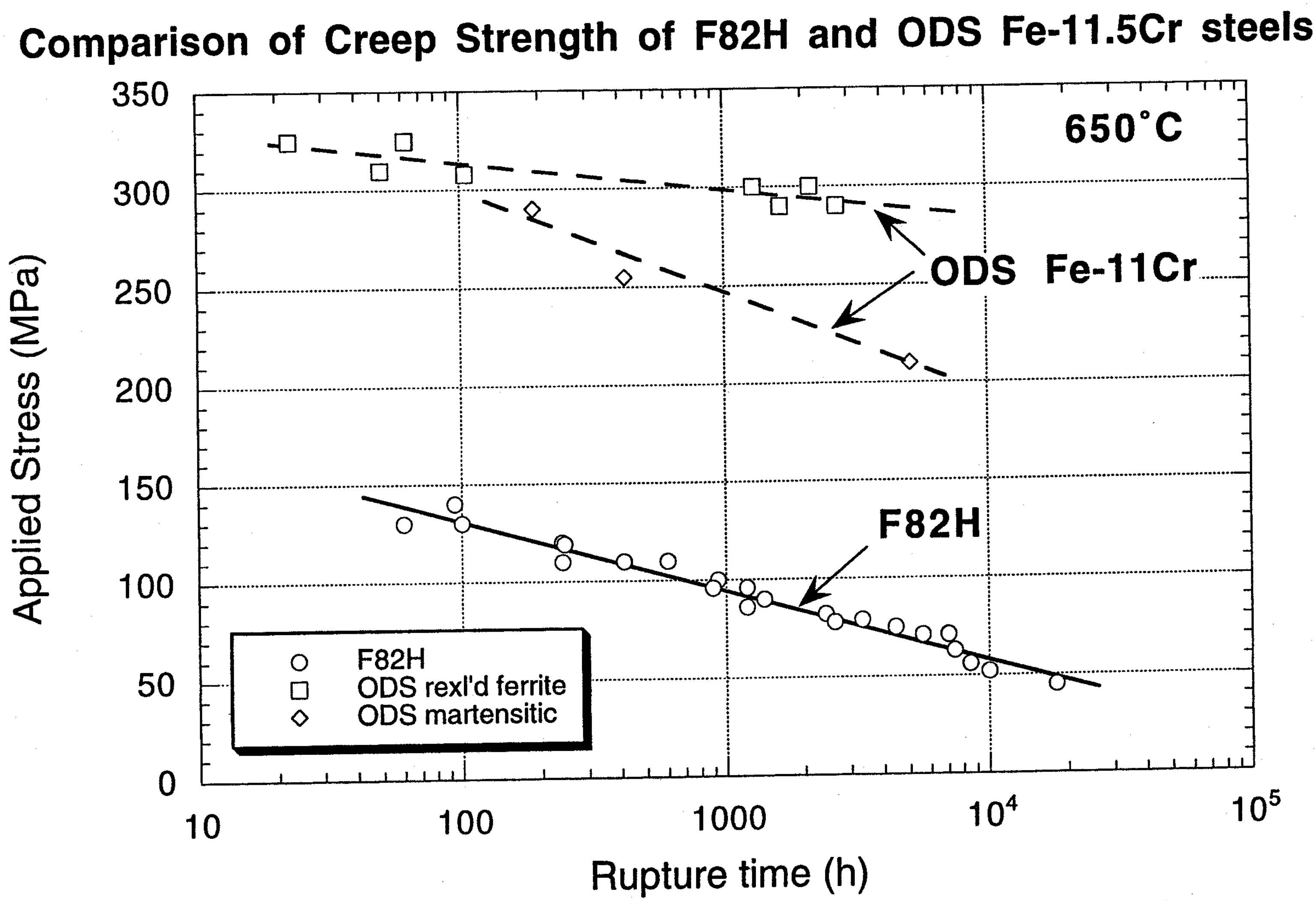
- Assessment reports on high temperature refractory alloys are in progress
  - draft report completed for T-111 (Ta-8W-2Hf)

- Chemical compatibility of refractory alloys with liquid metals is being compiled

- Limited database on radiation effects on refractory alloys has been assembled
  - no fracture toughness or Charpy impact tests

Comparison of Creep Strength of F82H and ODS Fe-11.5Cr steels





Comparison of Creep Strength of F82H and ODS Fe-11.5Cr steels
650˚C
ODS Fe-11Cr
F82H
Applied Stress (MPa)
Rupture time (h)
0
50
100
150
200
250
300
350
10
100
1000
10^4
10^5
F82H
ODS rexl'd ferrite
ODS martensitic

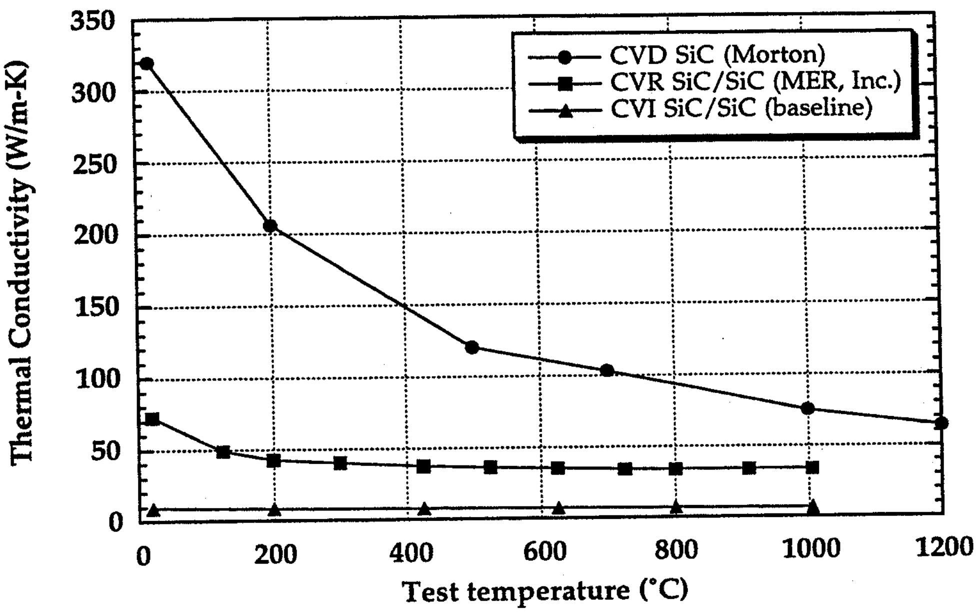


Fig. 1. Comparison of the transverse thermal conductivity of monolithic CVD SiC and two grades of SiC/SiC composites [11,18].

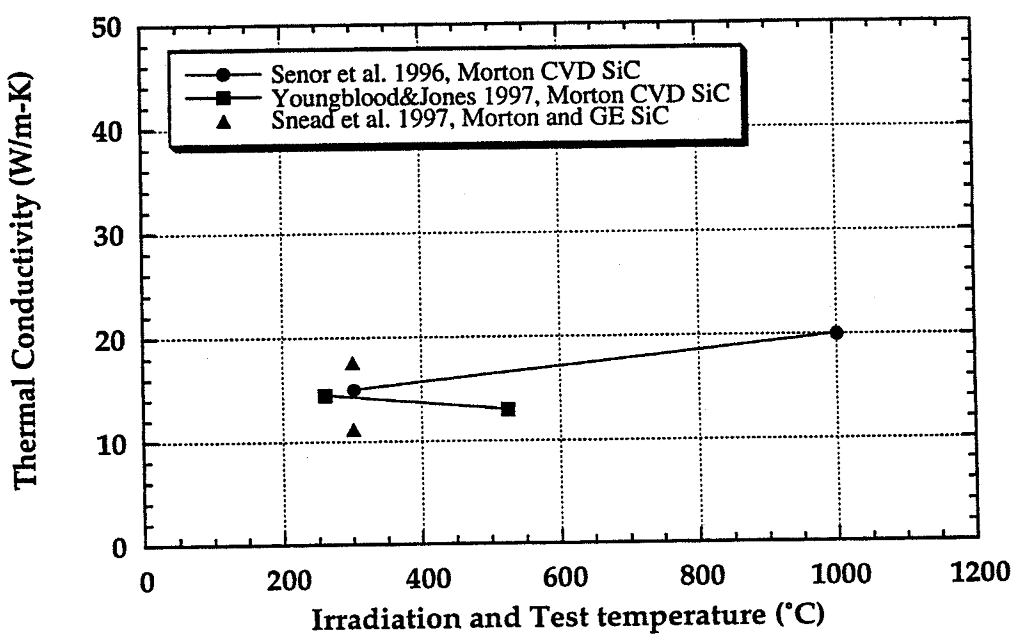
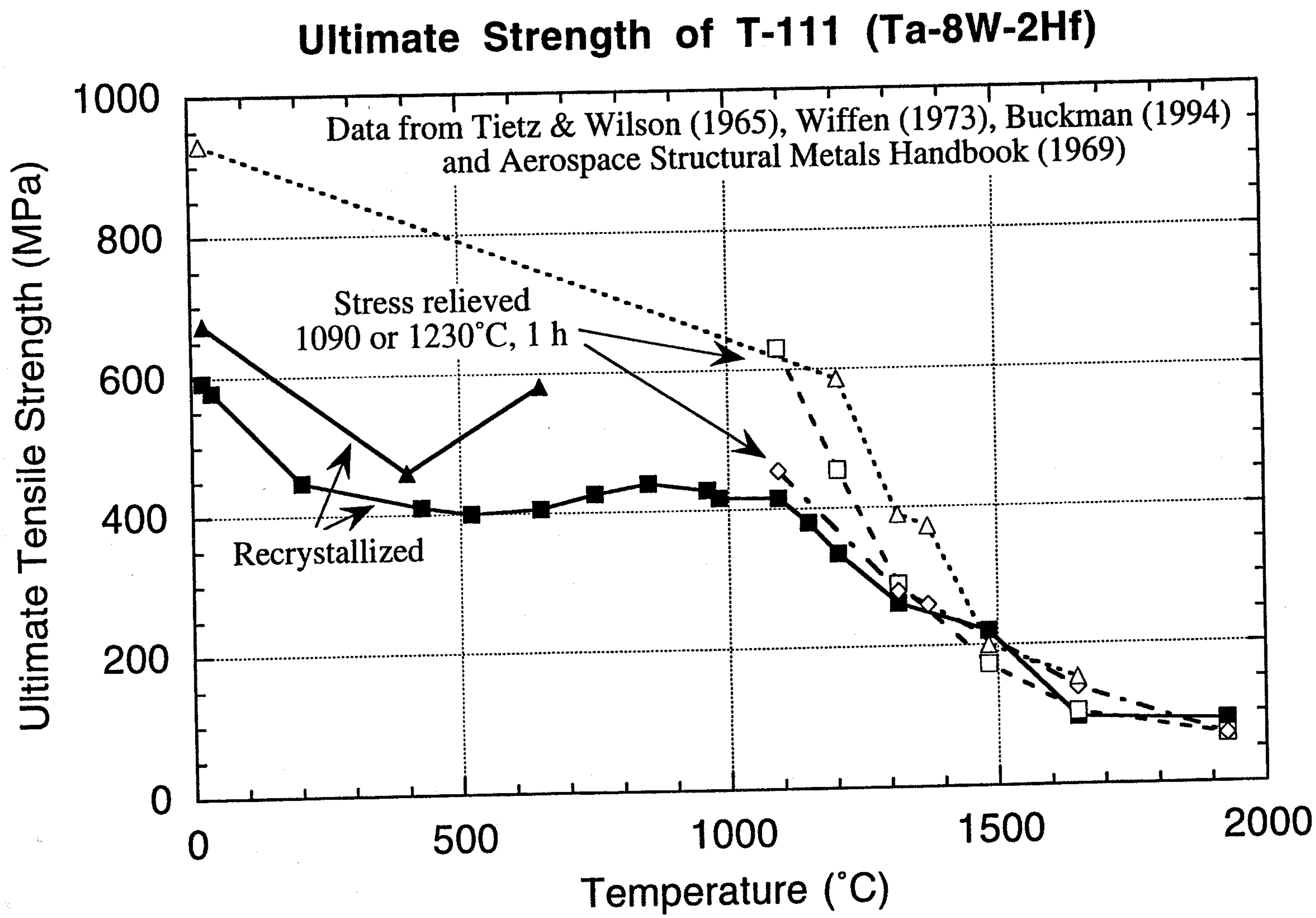
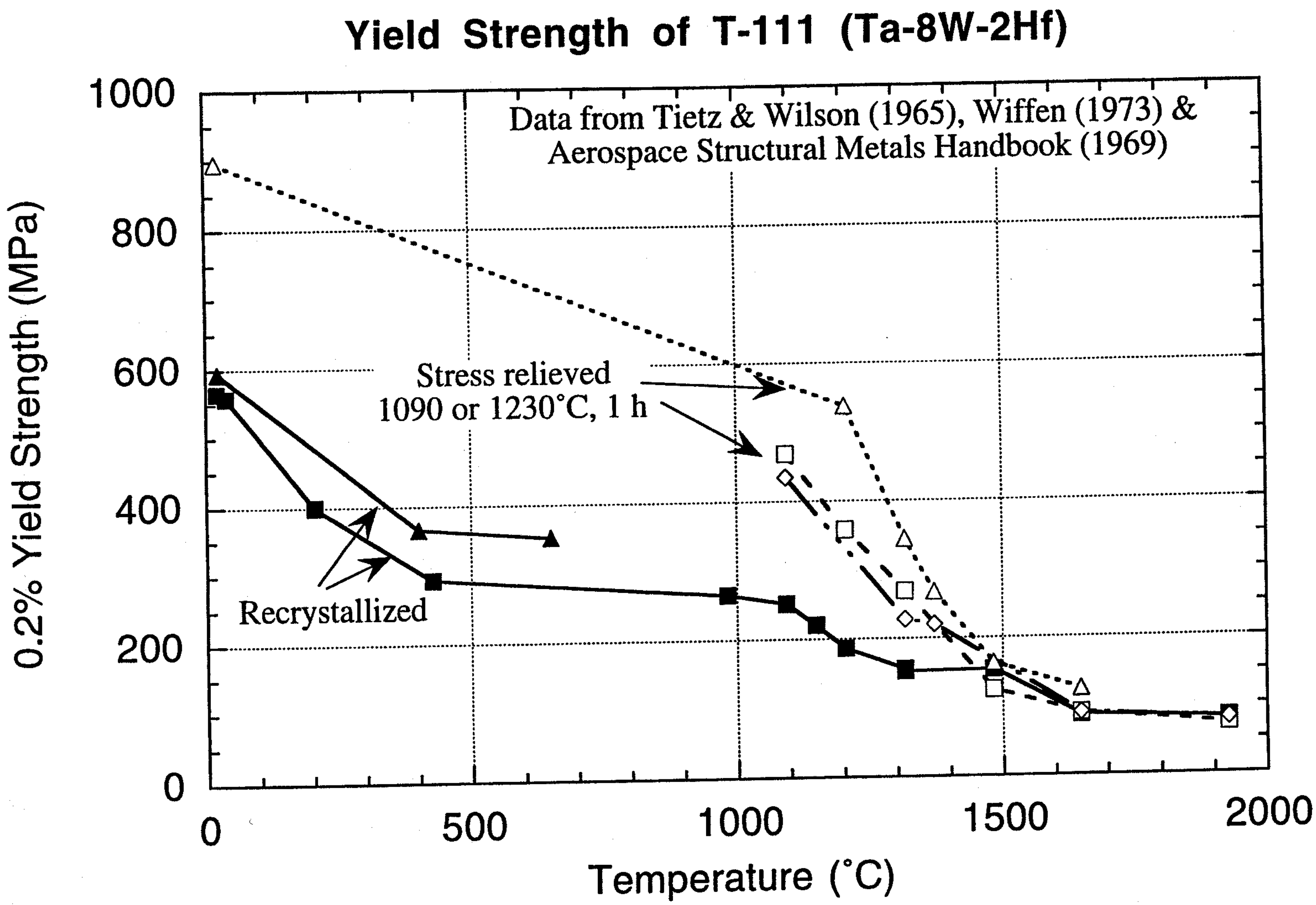


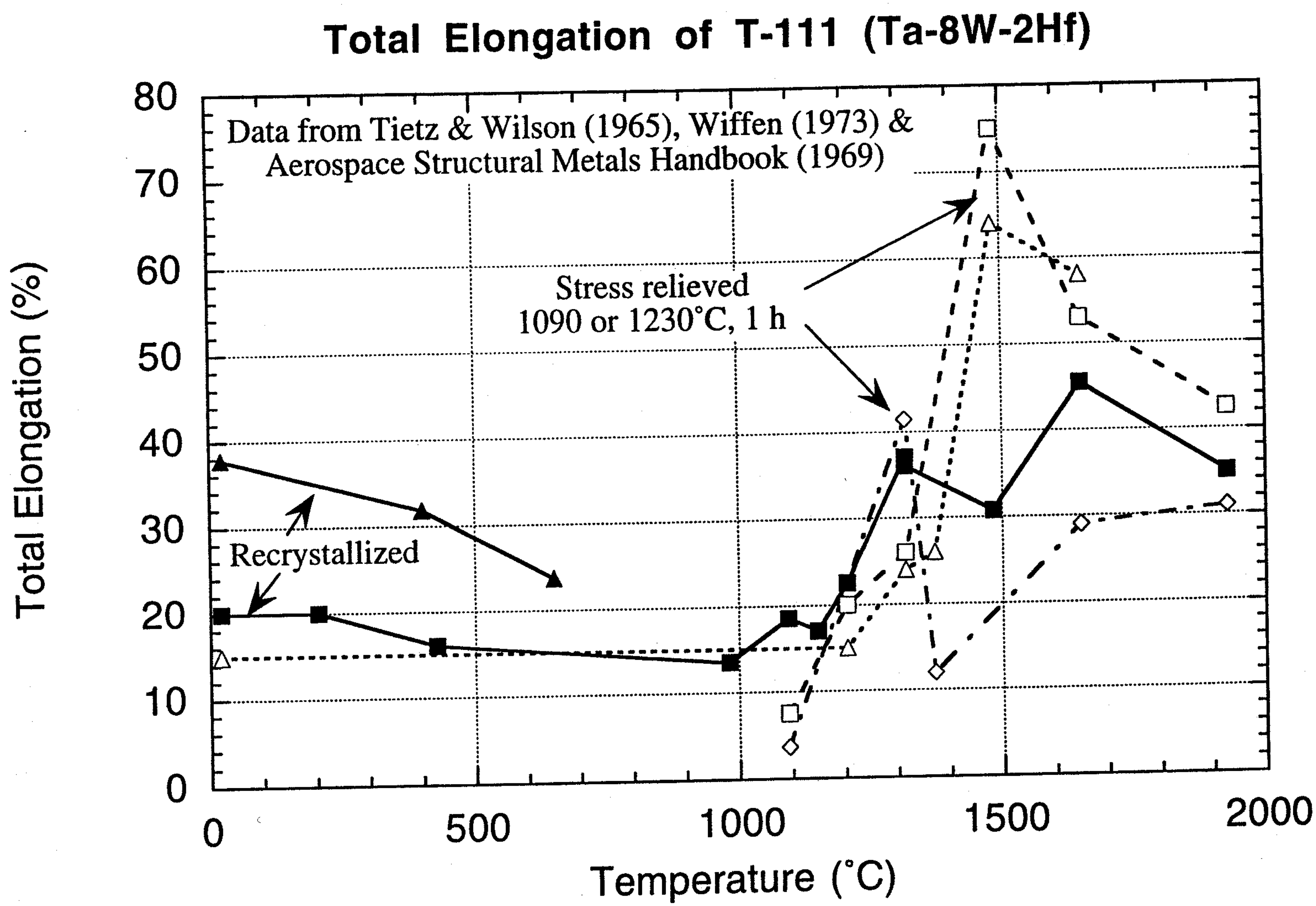
Fig. 2. Effect of low-temperature neutron irradiation on the thermal conductivity of SiC [9,19,20]. The studies by Senor et al. and Youngblood and Jones were performed on samples irradiated to 33-43 dpa, whereas the data by Snead et al. were obtained on samples irradiated to 0.1 dpa.

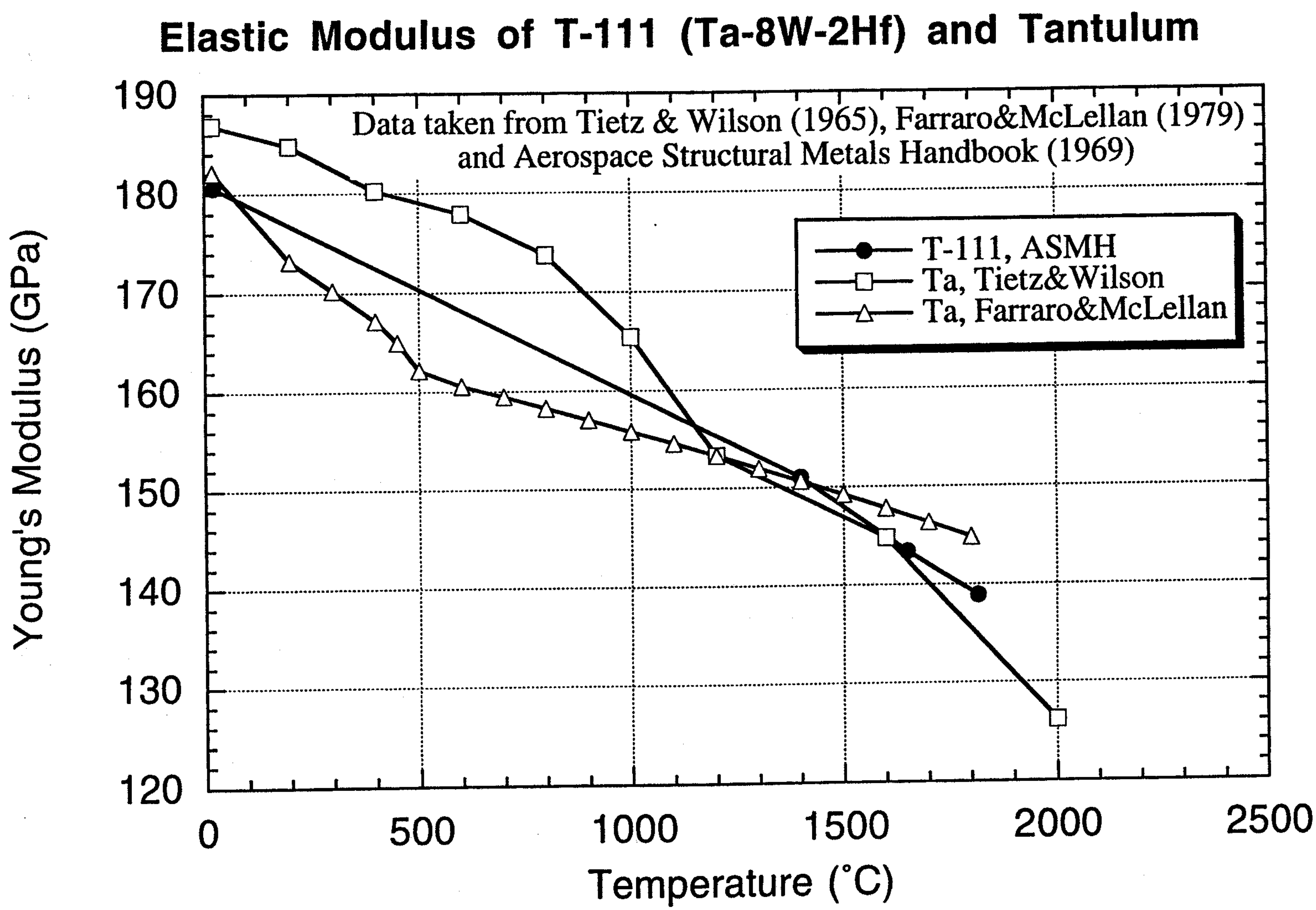


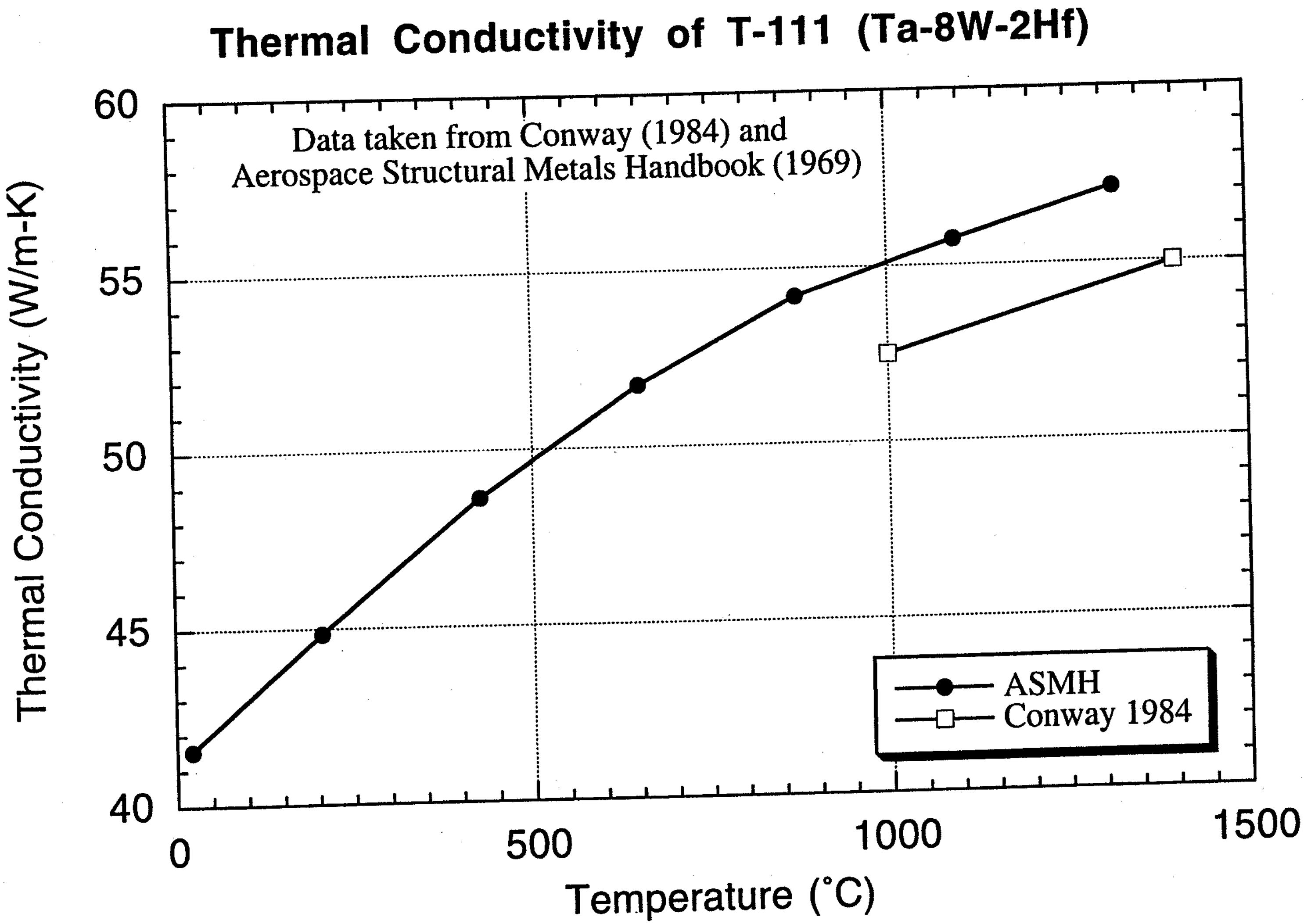
Ultimate Strength of T-111 (Ta-8W-2Hf)
Data from Tietz & Wilson (1965), Wiffen (1973), Buckman (1994)
and Aerospace Structural Metals Handbook (1969)
Stress relieved
1090 or 1230°C, 1 h
Recrystallized
Ultimate Tensile Strength (MPa)
Temperature (°C)
0
200
400
600
800
1000
500
1000
1500
2000



Yield Strength of T-111 (Ta-8W-2Hf)
Data from Tietz & Wilson (1965), Wiffen (1973) &
Aerospace Structural Metals Handbook (1969)
Stress relieved
1090 or 1230°C, 1 h
Recrystallized
0.2% Yield Strength (MPa)
Temperature (°C)
0
200
400
600
800
1000
0
500
1000
1500
2000


Total Elongation of T-111 (Ta-8W-2Hf)
Data from Tietz & Wilson (1965), Wiffen (1973) &
Aerospace Structural Metals Handbook (1969)
Stress relieved
1090 or 1230°C, 1 h
Recrystallized
Total Elongation (%)
Temperature (°C)
0
10
20
30
40
50
60
70
80
0
500
1000
1500
2000


Elastic Modulus of T-111 (Ta-8W-2Hf) and Tantulum
Data taken from Tietz & Wilson (1965), Farraro&McLellan (1979) and Aerospace Structural Metals Handbook (1969)
T-111, ASMH
Ta, Tietz&Wilson
Ta, Farraro&McLellan
Young's Modulus (GPa)
Temperature (˚C)
190
180
170
160
150
140
130
120
0
500
1000
1500
2000
2500



Thermal Conductivity of T-111 (Ta-8W-2Hf)
Data taken from Conway (1984) and
Aerospace Structural Metals Handbook (1969)
Thermal Conductivity (W/m-K)
60
55
50
45
40
0
500
1000
1500
Temperature (˚C)
ASMH
Conway 1984

Chemical Compatibility of High Temperature Refractory Alloys with Liquid Metals

- In general, the refractory alloys have very good compatibility with the liquid metals of interest for fusion applications
  - impurity pickup is the key engineering issue

- Li chemical compatibility data base:

  T-111 (Ta-8W-2Hf) data up to 1370°C (good compatibility; static and circulating loops)

  Nb-1Zr data up to 1000°C (good compatibility; static and circulating loops)

  W alloys up to 1370°C (attack observed at ≥1540°C)

  Mo alloys (TZM) up to 1370°C (attack observed at ≥1540°C)

Overview of Radiation Effects in Refractory Metals

- Void swelling is not anticipated to be a lifetime-limiting issue due to the BCC structure of the high-temperature refractory alloys
  - existing fission reactor data base indicate low swelling (<2%) for doses up to 50 dpa or higher
  - effects of fusion-relevant He generation on swelling is uncertain
  - swelling regimes are ~600 to 1000°C for all 4 classes of refractory alloys

- The Group Va alloys (Nb, Ta) exhibit better ductility before and after irradiation
  - very limited mechanical properties data base on irradiated Nb, Ta alloys
  - extensive mechanical properties data base on irradiated Mo, W alloys

- Very limited or no fracture toughness/Charpy impact data on irradiated high temperature refractory alloys

  - "tensile DBTT" of Mo, W alloys increases to very high values even for low dose irradiations at moderate temperatures (e.g., 600°C after ~1 dpa irradiation at 300 C for W, W-10Re)

- Refractory alloys are generally designed for use in stress-relieved condition (rather than recrystallized) in order to achieve of higher strength
  - radiation-enhanced recrystallization and/or radiation creep effects need to be investigated (designs should use recrystallized strengths to be conservative)