Material: Ferritic Steel: F82H
Property: Dose (dpa) versus Effective Shear Maximum Strength (MPa)
Condition: Un-irradiated
Data: Experimental

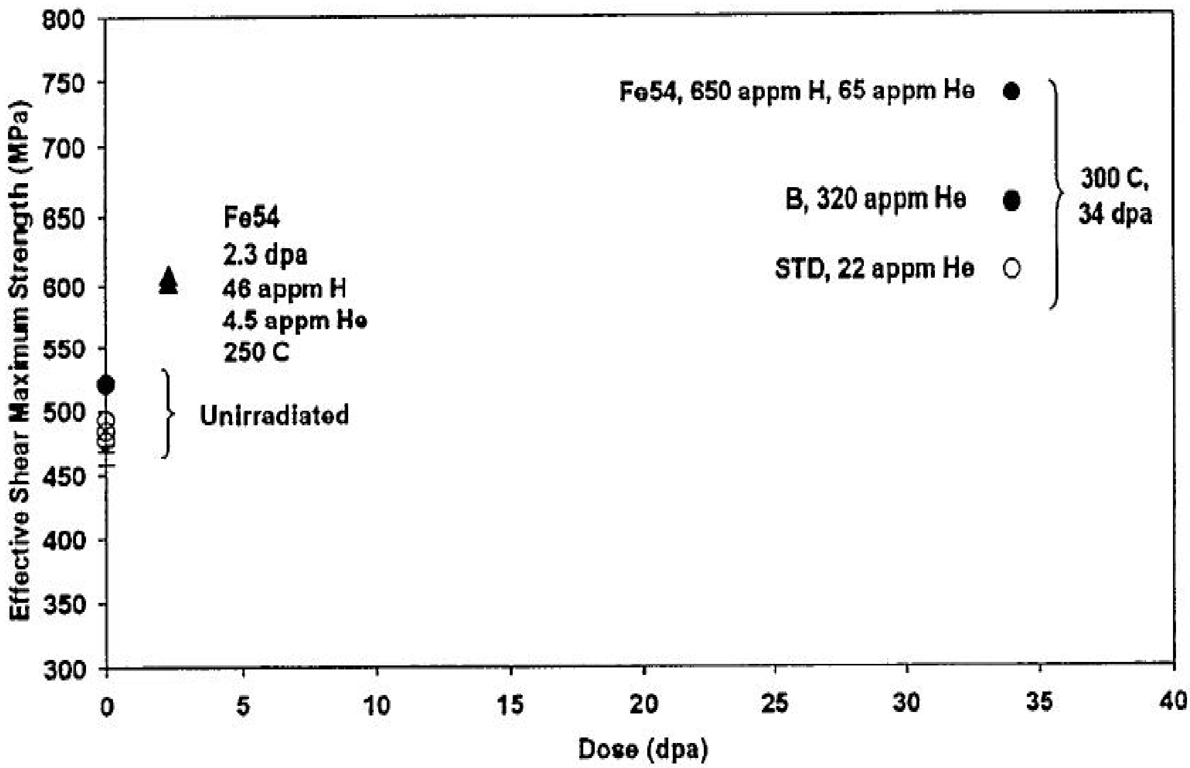


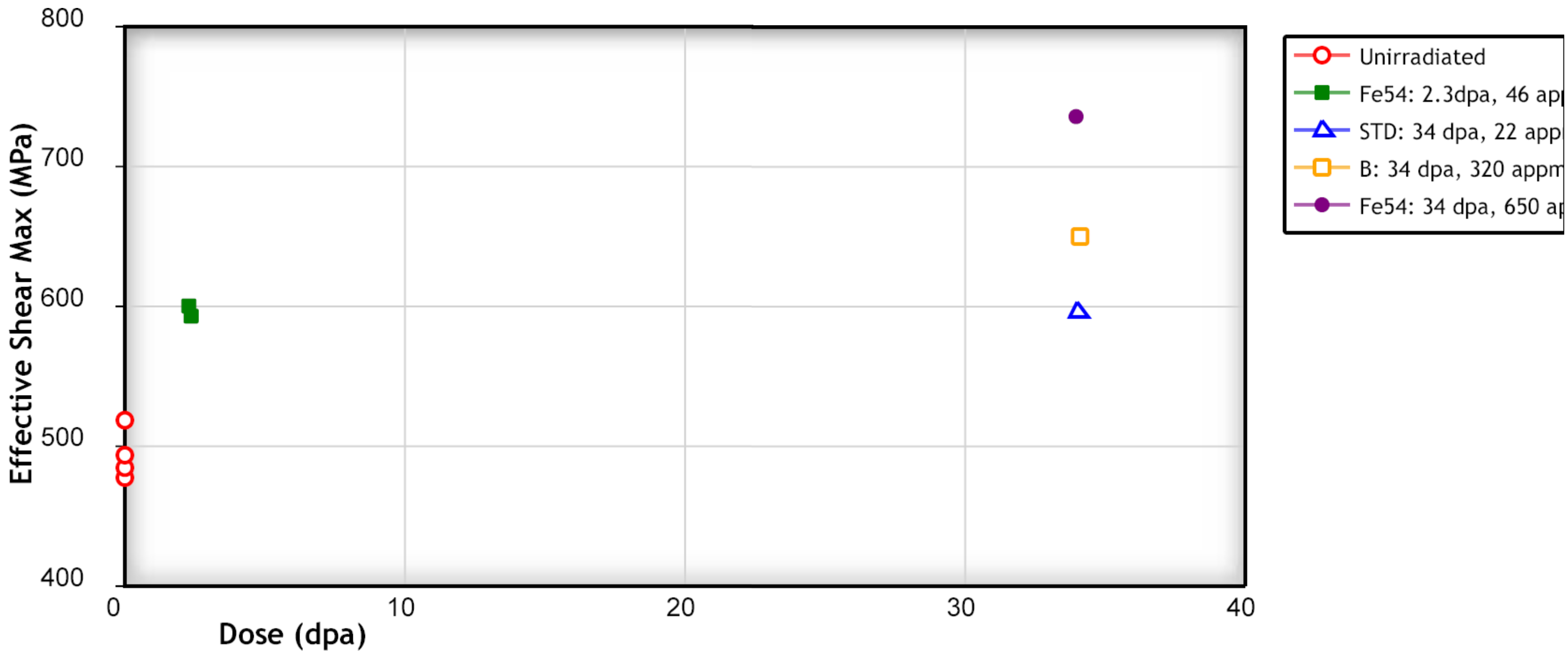
Figure 3. Shear punch test results as a function of dose for (a) effective shear yield strength and (b) effective shear maximum strength. Note that He levels are measured values while H levels are calculated estimates.

Source:
Fusion Materials Semiannual Progress Report, 25, 1998, 136-142

Title of paper (or report) this figure appeared in:
Shear Punch Testing of Irradiated Isotopically Tailored Ferritic/Martensitic Steels

Author of paper or graph:
M.L Hamilton, D.S. Gelles, S. Ohnuki, K. Shiba, Y. Kohno, A. Kohyama

Caption:
Shear Punch test results as a function of dose (dpa) for effective shear yield strength.



Shear Punch test results as a function of dose (dpa) for effective shear maximum strength

Reference:

Author: *M.L Hamilton, D.S. Gelles, S. Ohnuki, K. Shiba, Y. Kohno, A. Kohyama*

Title: *Shear Punch Testing of Irradiated Isotopically Tailored Ferritic/Martensitic Steels*

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Plot Format:

SHEAR PUNCH TESTING OF IRRADIATED ISOTOPICALLY TAILORED FERRITIC/MARTENSITIC STEELS - M. L. Hamilton, D. S. Gelles (Pacific Northwest National Laboratory)*, S. Ohnuki (Hokkaido University), K. Shiba (JAERI), Y. Kohno (University of Tokyo), and A. Kohyama (Kyoto University)

OBJECTIVE

The objective of this effort is to provide an understanding of the effect of hydrogen and helium production during irradiation on post-irradiation mechanical properties in ferritic/martensitic steels for first wall applications in a fusion reactor.

SUMMARY

Single variable experiments are being conducted to study effects of H/He/dpa on properties based on isotopically tailored alloys. ^{54}Fe has been used to prepare an isotopically tailored duplicate of the commercial steel F82H, and a small number of TEM disks have been irradiated in order to study radiation embrittlement. From single disk specimens, mechanical properties were obtained using a shear punch technique that produces a 1 mm blank from the 3 mm disk. Results indicate that shear punch testing can be used successfully to provide mechanical property data from single TEM disks. Little effect of helium on properties was found, either in ^{54}Fe isotopically tailored specimens or in a boron-doped specimen.

PROGRESS AND STATUS

Introduction

A concern in developing structural materials for fusion power systems is the consequences of transmutation-induced helium and hydrogen on material properties. For the advanced ferritic steel fusion materials option, helium (in appm) will be generated at about ten times the dpa rate, and hydrogen will be generated approximately ten times more rapidly. Experiments to define the effect of helium remain controversial[1,2] but severe effects of helium accumulation on fracture toughness have been claimed.[3,4] It is therefore very important to evaluate these transmutation effects in order to establish whether steels can be successfully adapted for fusion applications.

Single variable experiments have been conducted to study effects of H/He/dpa on properties by preparing isotopically tailored alloys. Initially, alloys containing small additions of different nickel isotopes were studied,[5] but the present approach considers alloys made from iron isotopes in order to vary H/He/dpa rates.[6] The controlling reactions are:

^{54}Fe (n,p) ^{54}Mn

^{54}Fe (n,) ^{55}Fe

^{55}Fe (n,) ^{52}Cr or ^{55}Fe (n,p) ^{55}Mn (n,) ^{56}Fe

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^{54}Fe was used to prepare an isotopically tailored duplicate of the commercial steel F82H,[7] and, because of cost and irradiation space limitations, only a small number of TEM disks were irradiated in order to study radiation embrittlement.

Very recently, individual TEM disks were made available for post-irradiation examination. It was possible to obtain mechanical properties from three alloy conditions for which only a single disk was available, and from a fourth condition where several disks were available in order to compare with results on unirradiated controls. Mechanical properties were obtained using a shear punch technique that produces a 1 mm blank from the 3 mm disk.

Experimental Procedure

A 4 g. batch of isotopically tailored F82H martensitic steel was prepared as described previously,[7] and specimens 3 mm in diameter, intended for transmission electron microscopy (TEM), were obtained along with a specimen of standard F82H and a specimen of boron-doped F82H, following irradiation in either the JP17 irradiation experiment to 2.3 dpa at 250°C or the JP22 irradiation experiment to 34 dpa at 300°C in the High Flux Isotope Reactor (HFIR) in Oak Ridge, TN.[8] Also available were unirradiated control specimens of the isotopically tailored alloy, the standard alloy and another heat of the steel, designated the IEA heat.[9] F82H has the approximate composition (in weight %) Fe-7Cr-2W-0.2V-0.1C-.04Ta-0.01N. Composition details are provided in Table 1.

Table 1. Composition of alloys of interest

Alloy	Cr	C	W	V	Ta	B	Mn	N	Si
F82H ^{54}Fe	7.1	0.097	1.8	0.17	0.04	-	0.4	0.007	0.55
F82H STD	7.46	0.097	2.1	0.18	0.03	0.0004	0.07	0.004	0.09
F82H ^{10}B	7.25	0.098	2.1	0.22	0.04	0.0058	0.5	0.002	0.17

Room temperature mechanical properties information was obtained using a shear punch technique that produces 1 mm blanks from 3 mm disks.[10-12] Shear punch testing is essentially a blanking operation which is common to sheet metal forming. A 1 mm diameter punch is driven at a constant rate of 0.127 mm/min. (0.005 in./min.) through a TEM-sized disk (nominally 0.25 mm thick and 2.8 mm in diameter). The load on the punch is measured as a function of punch travel, which is taken to be equivalent to the crosshead displacement. This assumes that the test machine and punch are completely stiff relative to the response of the test specimen.

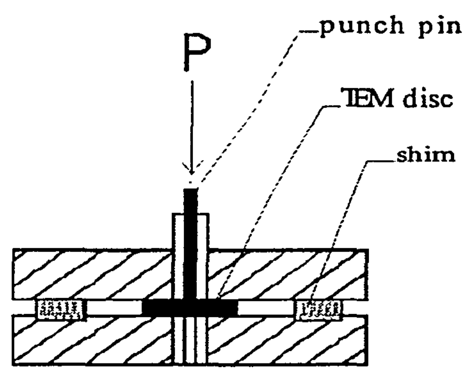


Figure 1. Schematic of shear punch test apparatus.

A plot of punch load versus punch displacement was obtained for each specimen. A diagram of the apparatus that is required is provided in Figure 1.

The curve obtained from a shear punch test is of a similar form to that obtained from a tensile test. Initially a linear relationship exists between load and punch displacement during which no plastic deformation occurs. This is followed by a deviation from linearity or yield point when permanent penetration of the punch into the specimen occurs. Beyond the yield point, further deformation forms a shear process zone between the die and punch. Work hardening compensates for thinning until a maximum load is achieved. The points of interest on the curve were the yield load and maximum load. Effective shear yield strength (τ_{sy}) and an effective maximum shear strength (τ_{sm}) can be evaluated from these values, respectively, by the following equation:[10]

$$\tau_{sy,sm} = P/(2\pi rt)$$

Where P is the appropriate load, r is the average of bore and punch radii and t is the specimen thickness. Previous work has shown that an empirical relationship can be developed between data from shear punch testing and that from tensile testing.[10-12] In this instance, however, no tensile data were available and the shear punch test was used only as a tool to identify trends in the mechanical properties that might occur as a result of differing helium and hydrogen levels as has successfully been done before.[5]

Results

Fourteen shear punch tests were performed in this study, comprising nine control tests and five tests on irradiated samples. The results of shear punch testing are provided in Table 1 and examples of test curves are provided in Figures 2a and b. Table 2 includes irradiation conditions and calculated values of effective shear yield strength, τ_{sy}, and effective shear maximum strength, τ_{ms} for each of the specimens tested. Figure 2a shows test curves for all ^{54}Fe isotopically tailored samples tested and Figure 2b compares response for the three specimens that were tested following irradiation to highest dose. It is apparent from the test traces shown in Figure 2, that shear punch tests are well behaved and that materials differences are evidenced as differences in yield and maximum strength, whereas differences in ductility are modest, being inversely proportional to strength changes.

The results of Table 2 are plotted as a function of dose in Figure 3 to demonstrate the fluence dependence of hardening. Figure 3a provides comparison of all conditions as a function of effective shear yield strength and Figure 3b gives similar results for effective shear maximum strength. Strength values for unirradiated controls are restricted to a narrow range whereas irradiation of the isotopically tailored alloy to 2.3 dpa at 250°C increased strength and irradiation to 34 dpa at 300°C increased strength further. In comparison, other conditions of F82H have lower strengths, particularly following irradiation to 34 dpa. The response is complex, as comparison of relative strengths for yield differ from those for maximum strength. This complex response may be an indication of inadequate statistics.

Discussion

This work demonstrates that it is possible to obtain mechanical property information on very limited quantities of material: TEM samples weigh about 0.1 gm and the 1 mm blank about 0.01 gm. The techniques described above not only allow for experiments where material is very limited, very expensive or very difficult to obtain in the desired treatment or irradiation condition, but it also allows sampling of complex conditions. For example, in irradiation creep experiments

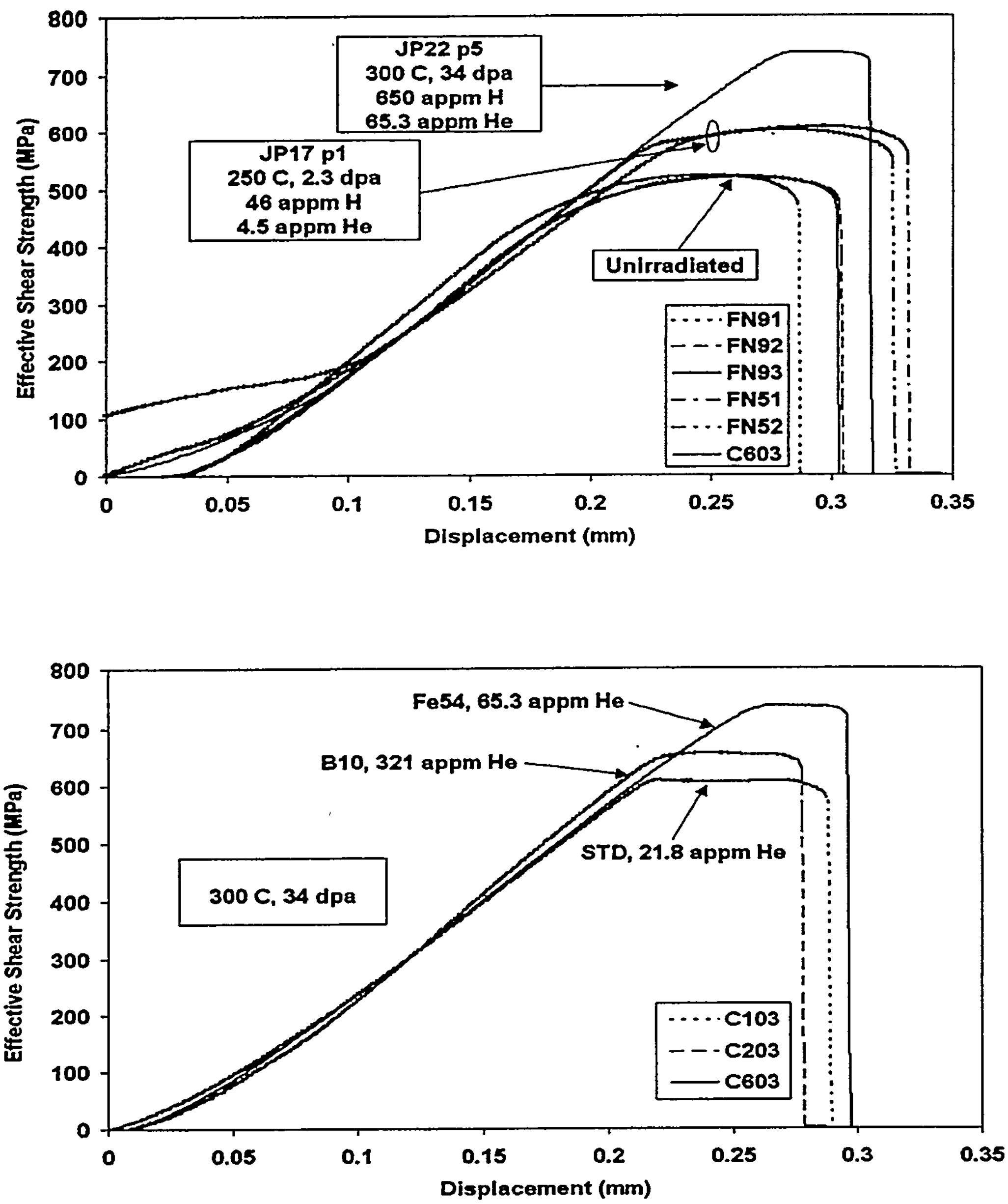
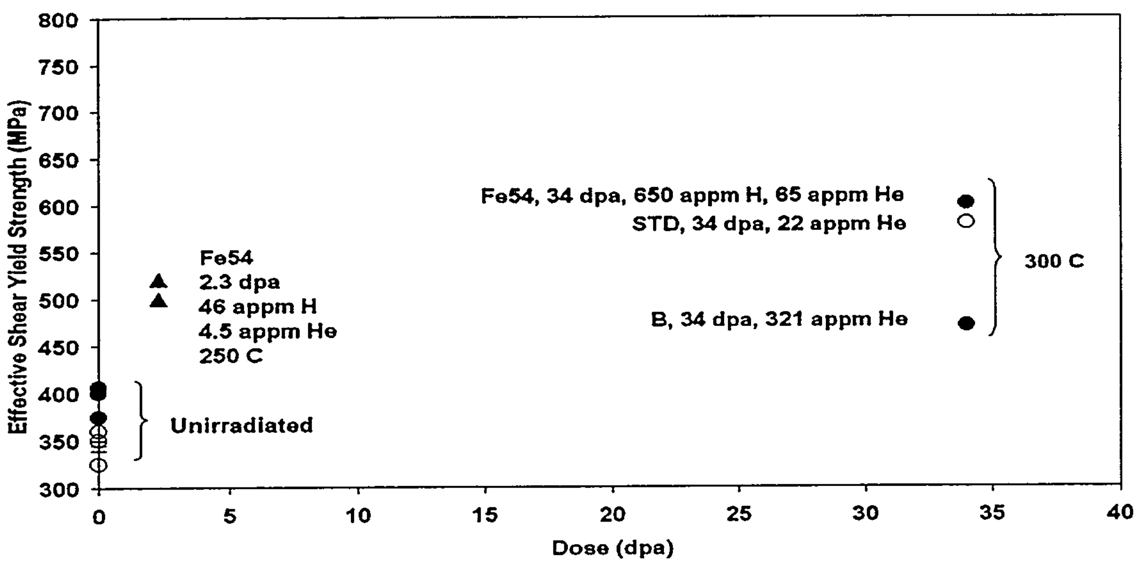


Figure 2. Shear punch test traces for (a) isotopically tailored specimens and (b) high dose specimens. Note that He levels are measured values while H levels are calculated estimates.



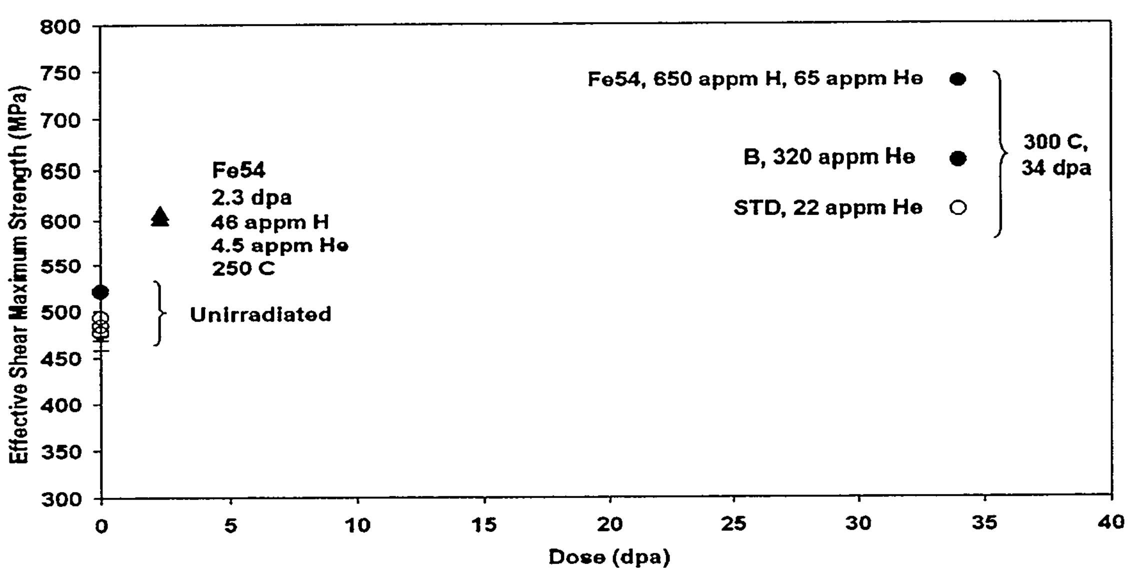


Figure 3. Shear punch test results as a function of dose for (a) effective shear yield strength and (b) effective shear maximum strength. Note that He levels are measured values while H levels are calculated estimates.

where strong gradients exist in temperature or flux, it may now be possible to provide understanding of property and microstructural variation over distances of one or two mm. The added advantages of effectively smaller TEM sample volumes that reduce radioactivity or magnetic interactions are also of benefit.

Table 2. Results of shear punch testing at room temperature.

ID	MATERIAL	CONDITION*	τ_{sy}	τ_{ms}
A943-5	F82H IEA	Unirradiated	340, 345, 350	458, 469, 473
F191-3	F82H STD	Unirradiated	325, 350, 360	476, 482, 492
C103	F82H STD	300°C, 34 dpa, 21.8 appm He	580	609
FN91-3	F82H ^{54}Fe	Unirradiated	390, 400, 406	519, 520, 522
FN51-2	F82H ^{54}Fe	250°C, 2.3 dpa,6 appm H,4.5 appm He	500, 520	602, 608
C603	F82H ^{54}Fe	300°C, 34 dpa,650 appm H,65.3 appm He	600	738
C203	F82H ^{10}B	300 C, 34 dpa, 321 appm He	470	656

* H values are predicted, but He values are measured.[14]

The intent of isotopic tailoring experiments is to assess the effect of hydrogen and helium production during irradiation on properties and microstructure. Because mechanical properties for the different alloys following irradiation at 300°C are very similar, the present results do not demonstrate a significant effect of helium on mechanical properties, and any effect of hydrogen is probably small, although hydrogen production levels are not completely understood. However, it should be noted that concerns about a large effect of helium on ductile brittle transition behavior are centered on irradiation temperatures in the 400°C range. Therefore, the present results are probably not pertinent to that issue.

CONCLUSIONS

Isotopic tailoring is being used to study effects of transmutation on mechanical properties. Shear punch tests can provide mechanical properties information with limited numbers of TEM samples.

ACKNOWLEDGMENTS

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FUTURE WORK

This work will be continued within the confines of funding and specimen availability.

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