IRRADIATION CREEP AND SWELLING OF TWO LMR HEATS OF HT9

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OBJECTIVE

The objective of this effort is to determine the creep characteristics of ferritic steels during neutron irradiation at elevated temperatures.

SUMMARY

The irradiation creep and void swelling of two LMR heats of HT9 are analyzed after irradiation at ~400, 495, 550 and 600°C to damage levels ranging from 60 to 174 dpa. Void swelling ceases somewhere between 400 and 495°C. Swelling appears to be somewhat stress-sensitive, however, increasing with stress level. When compared with earlier results on another fusion heat of HT-9, both the swelling and creep appear to be somewhat variable from heat-to-heat. The variability of creep appears to arise from the swelling-enhanced creep component.

At higher temperatures there appears to arise a stress-activated component of strain that increases with temperature. This strain component eventually dominates the strain behavior at the highest temperatures and is probably caused by a combination of stress-activated phase changes and radiation-enhanced primary creep.

PROGRESS AND STATUS

Introduction

Ferritic-martensitic steels are being considered for structural applications in fusion reactors. In order to provide data on the response of such steels to radiation, a series of experiments were conducted in FFTF. One of these experiments involved the simultaneous measurement of irradiation creep and void swelling using gas pressurized tubes.

In an earlier report, the response of the fusion heats of HT9 and 9Cr-1Mo (heats 9607R2 and 30176, respectively) was presented after irradiation at ~400°C to ~208 dpa in FFTF-MOTA[1]. These fusion heats were included as part of a larger LMR (Liquid Metal Reactor) program on irradiation creep.. In an effort to better define the behavior of HT9 over a wider range of temperature and heat-to-heat variations, analysis of the data on the LMR heats 84425 (designated HT9-1) and 91353 (HT9-2) is now in progress. The results attained to date are presented in this report.

EXPERIMENTAL DETAILS

These tubes (2.24 cm long by 0.46 cm diameter) were nominally irradiated at constant temperature. Periodically, they were discharged from the reactor, and prior to reinsertion into the reactor, diameter measurements were made using laser profilometry[2]. The tubes were originally scheduled for insertion into every MOTA vehicle from MOTA-1A through MOTA-1G, but tubes at temperatures higher than 400°C were discarded after MOTA-1D experienced a large temperature excursion that destroyed many tubes. Thus the data presented in this report involve seven measurements vs. dpa level at ~400°C, but only three measurements at 495, 550 and 600°C.

The dpa levels reached at each nominal irradiation temperature are shown in Table 1. Note that there was sometimes a variation in irradiation temperature from one MOTA to the next. The maximum stress levels chosen for this experiment also decrease with temperature. This is a common practice in irradiation creep experiments that avoids testing at unrealistic stresses leading to guaranteed failure.

Table 1. Nominal temperature in °C and dpa level

MOTA	(~400°C)	(~495°C)	(~550°C)	(~600°C)
1A	427, 26.4	494, 25.8	547, 28.4	603, 25.7
1B	401, 38.6	490, 36.1	548, 40.7	600, 39.6
1C	396, 67.2	490, 60.1	550, 76.4	605, 74.1
1D	386, 88.0			
1E	384, 114.1			
1F	386, 145.9			
1G	390, 174.3			

RESULTS

The diametral strains at ~400°C for both HT9-1 and HT9-2 are shown in Figure 1. Note that tubes having hoop stresses of zero develop small but measurable strains that most likely represent one-third of the volumetric swelling rate. HT9-1 swells somewhat less than HT9-2, and both appear to be swelling at relatively constant rates. There may be some small contribution to the strain arising from elemental segregation or phase changes, but these cannot be separated from the void contribution without extensive microscopy measurements.

Figure 2 shows the calculated midwall creep strains at 400°C divided by the hoop stress. The creep strain is calculated by subtracting the stress-free swelling strain from the total strain. This procedure assumes that swelling is not enhanced by stress, an assumption that is known not to be completely correct. Destructive analysis of the tubes from the HT9 fusion heat after irradiation to ~210 dpa at ~400°C showed that stress indeed enhanced the swelling somewhat[1].

It can also be seen in Figure 2, however, that the creep strain per unit stress curves shown in Figure 2 tend to converge toward each other, with the least scatter observed in HT9-2. If one ignores the 200 Mpa hoop stress curve for HT9-1, however, the scatter is least for HT9-1. This convergence indicates that the creep rate is essentially linear with stress (stress-exponent = 1.0), a finding which is especially significant for such large stress levels. Also noteworthy is that, when compared on a basis of the same stress levels, the creep strains are a little larger in HT9-2, consistent with its larger swelling rate at zero stress. There also appears to be some stress-enhancement of swelling-induced creep. This trend can be seen more clearly in Figure 3, where the strain rate for HT9-1 increases considerably at the higher stress levels.

At ~495°C the total strain rates at the lower stress levels tend to decrease with increasing dpa, as shown in Figure 4. This is usually an indication that some other non-creep component of strain has occurred. Although such behavior is normally ascribed solely to the transition from primary to secondary creep, it is quite likely also due to phase changes which occur relatively early in the irradiation. Note, however, that there are no creep strains in the absence of stress, indicating that the non-creep component is probably stress-activated. There is also a large increase in the creep strain rates between ~100 and ~200 MPa, as shown in Figure 4, a behavior that probably arises from recrystallization assisted by the combined effects of stress, high temperature and irradiation.

Figure 5 shows the irradiation creep rates at 495°C initially are independent of stress (to 65 MPa and 100 MPa in HT9-1 and HT9-2, respectively) and tertiary creep appears to develop at higher stress levels.

As shown in Figure 6, only HT9-2 was irradiated at 550°C, but this figure also shows that the strain rates tend to decrease with increasing dpa and the dependence of creep rate on stress level is to a power greater than 1.0. Note that again there are no strains in the absence of stress.

As shown in Figure 7, the tendency toward saturation of creep strain rate and onset of tertiary creep in HT9-1 at 600°C occurs at even lower stress levels. Once again, there is no strain observed at zero stress.

CONCLUSIONS

Swelling of HT9 occurs in the absence of stress at ~400°C and appears to be small, relatively linear with dpa and somewhat variable from heat-to-heat. Stress-enhancement of swelling also seems to be present. The concurrent irradiation creep at 400°C is relatively linear with both stress and dpa level, with the expected swelling-enhancement of creep rate evident when comparing the relative creep rates of the two heats.

As the temperature increases, swelling decreases to zero somewhere between 400 and 495°C and some stress-activated non-swelling, non-creep component of strain arises. The tendency for this component to dominate the overall strain behavior increases with increasing temperature.

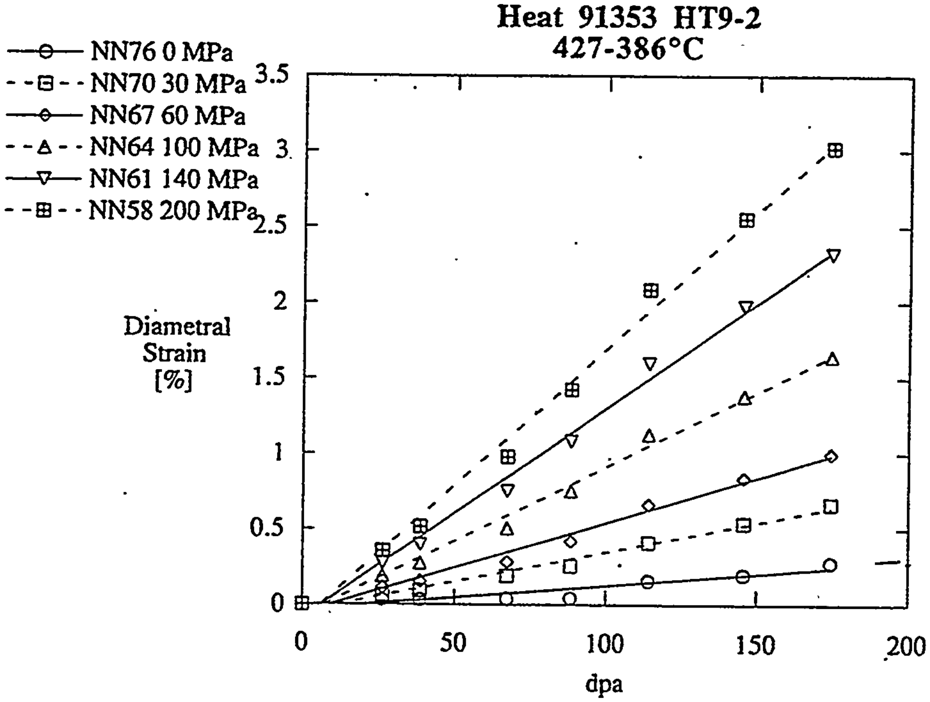
FUTURE WORK

Additional data on these two heats will be collected and analyzed, and then compared with results from the fusion heat of HT9.

REFERENCES

1. M. B. Toloczko, F. A. Garner and C. R. Eiholzer, *J. Nucl. Mater.* 212-215 (1994) 604-607.

2. E. R. Gilbert and B. A. Chin, *Proc. Symp. on Effects of Radiation on Materials, 10th Conference, ASTM STP 725* (1981) p. 665.



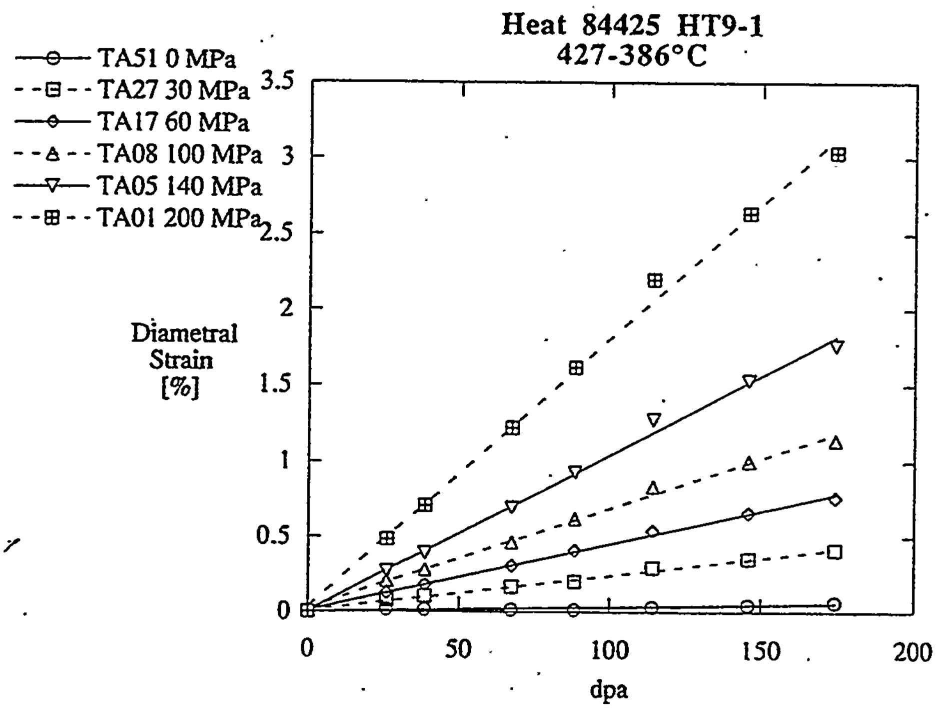
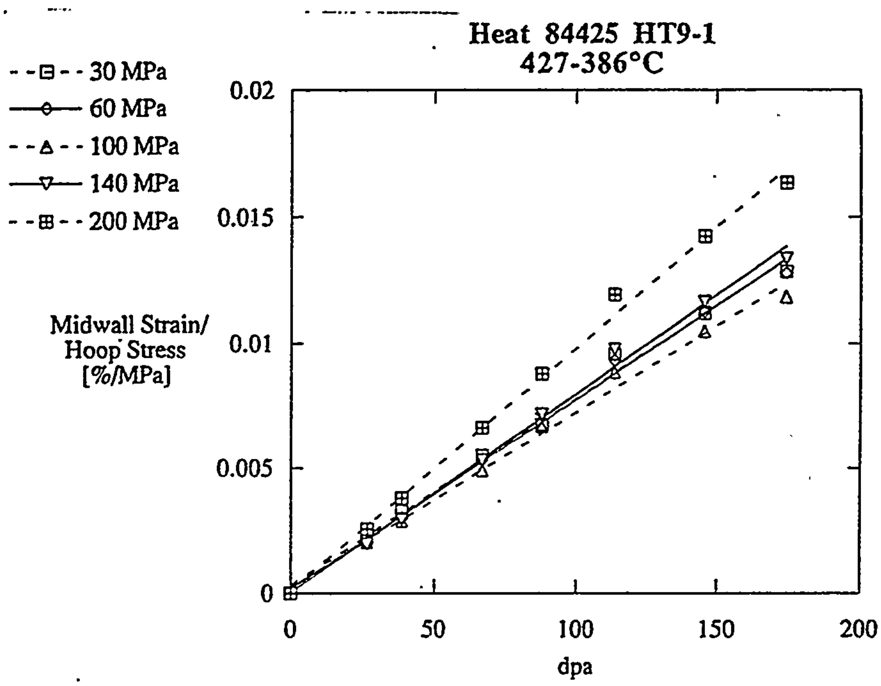


Figure 1. Total diametral strains observed in HT9-1 and HT9-2 at ~400°C. Hoop stresses are used to denote the stress levels.



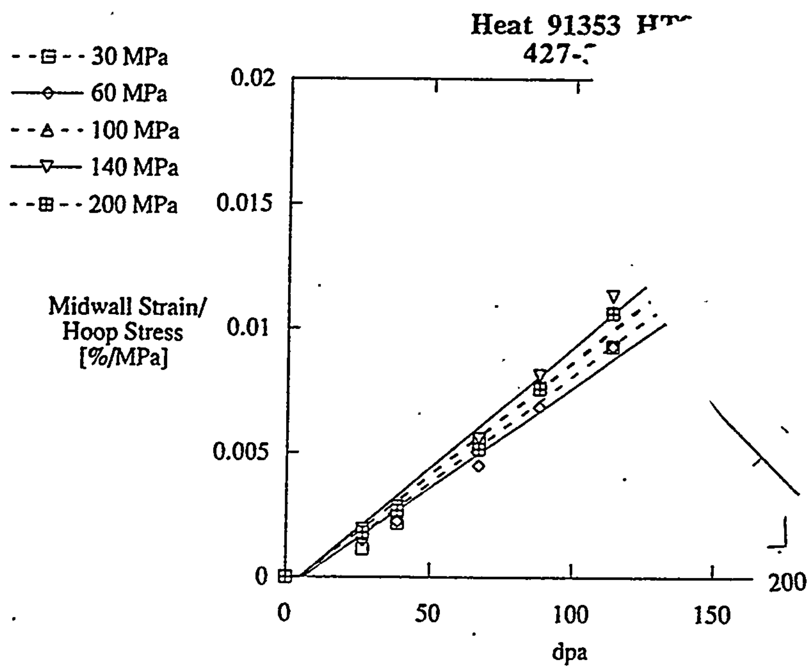


Figure 2. Midwall creep strains per unit hoop stress for HT9-1 and HT9-2 at ~400°C

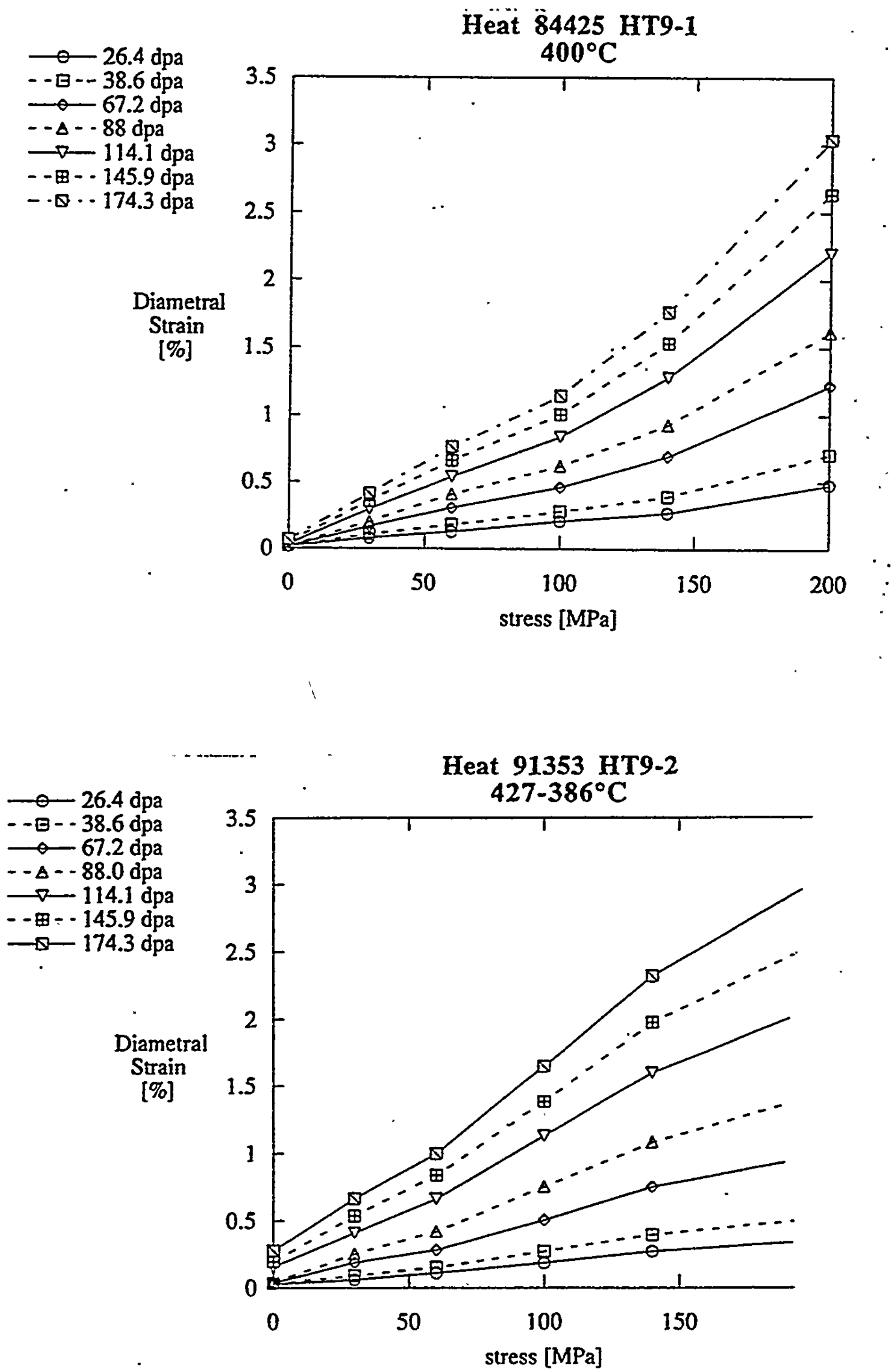
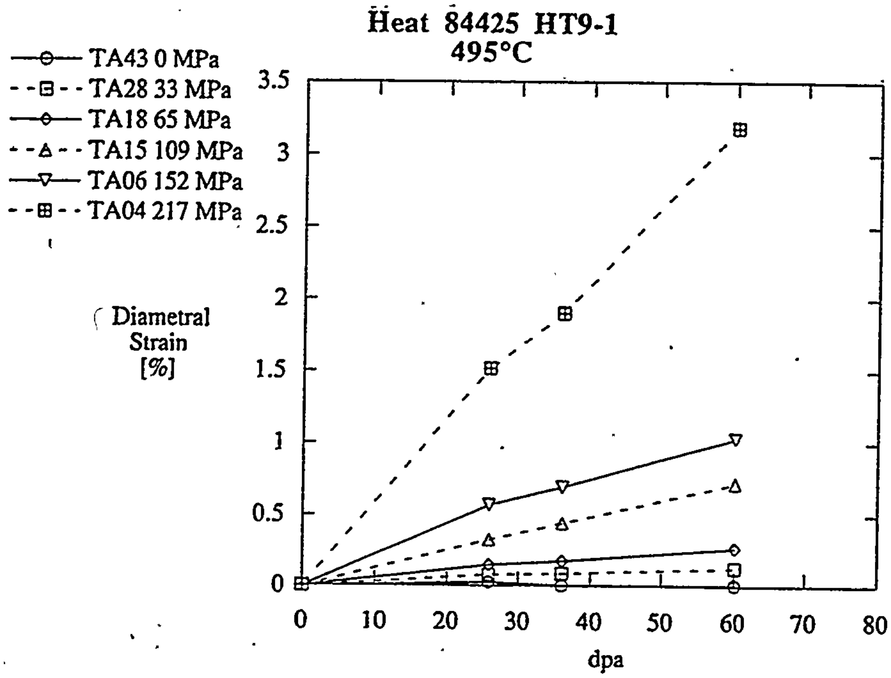


Figure 3. Diametral strains vs. hoop stress level, showing greater tendency toward stress-enhancement of total strain in HT9-1 at ~400°C.



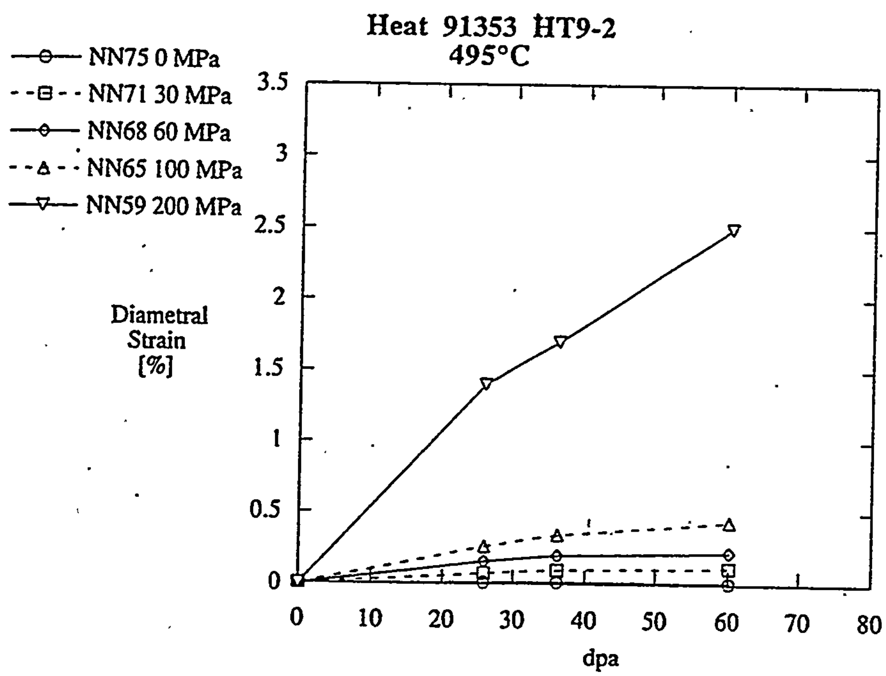


Figure 4. Total diametral strains observed at ~495°C.

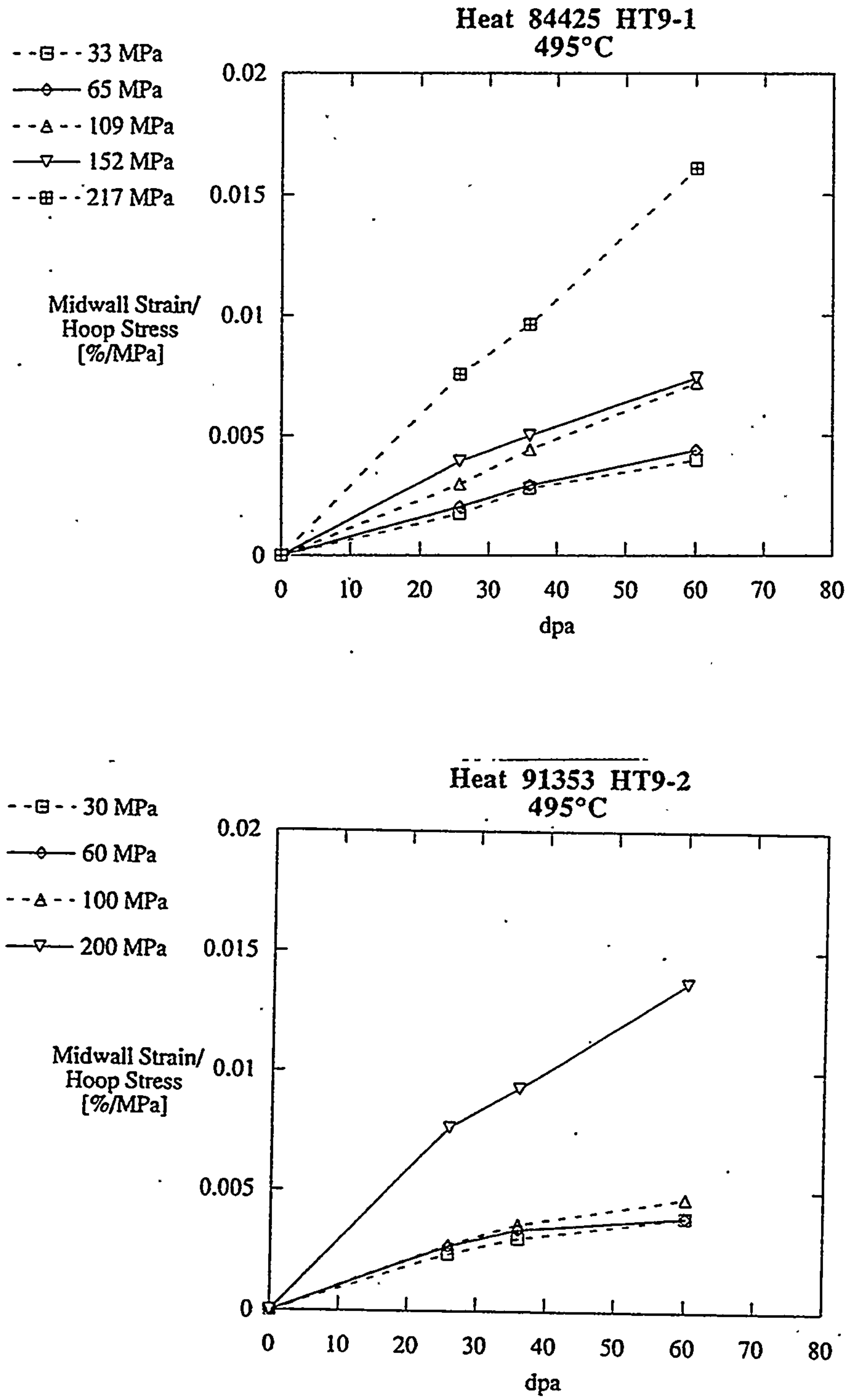
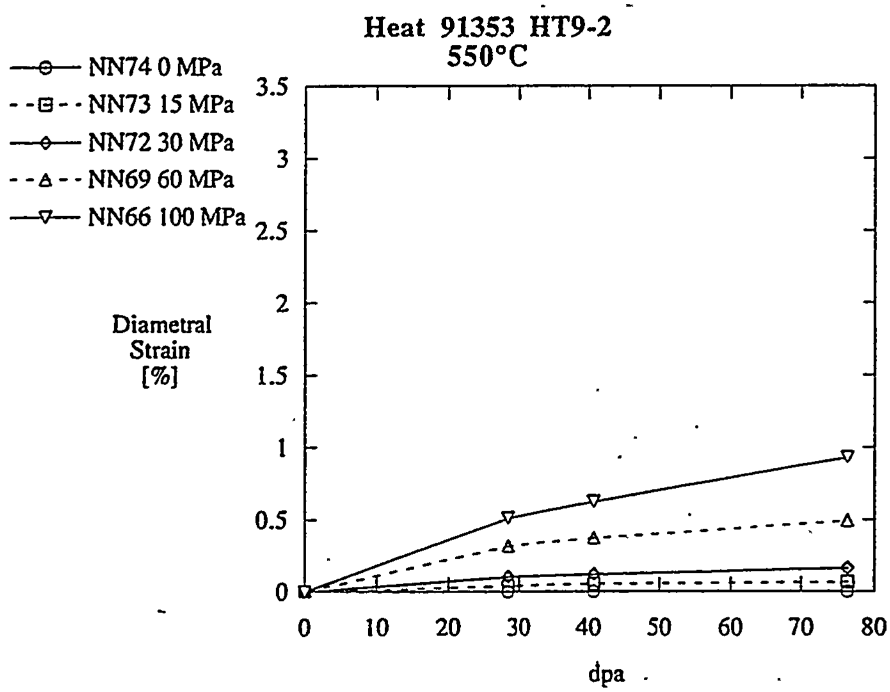


Figure 5. Midwall creep strains per unit hoop stress at ~495°C.



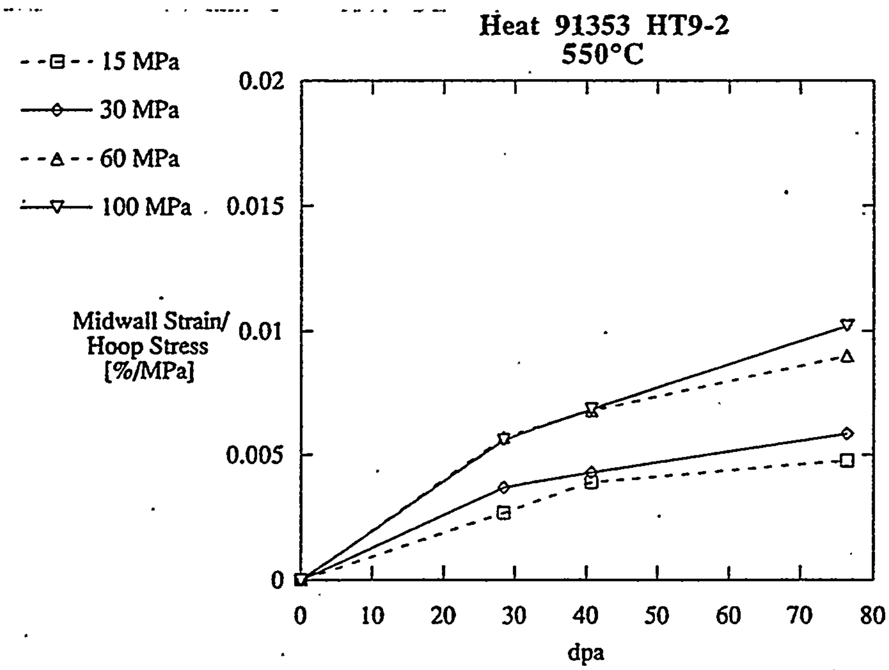
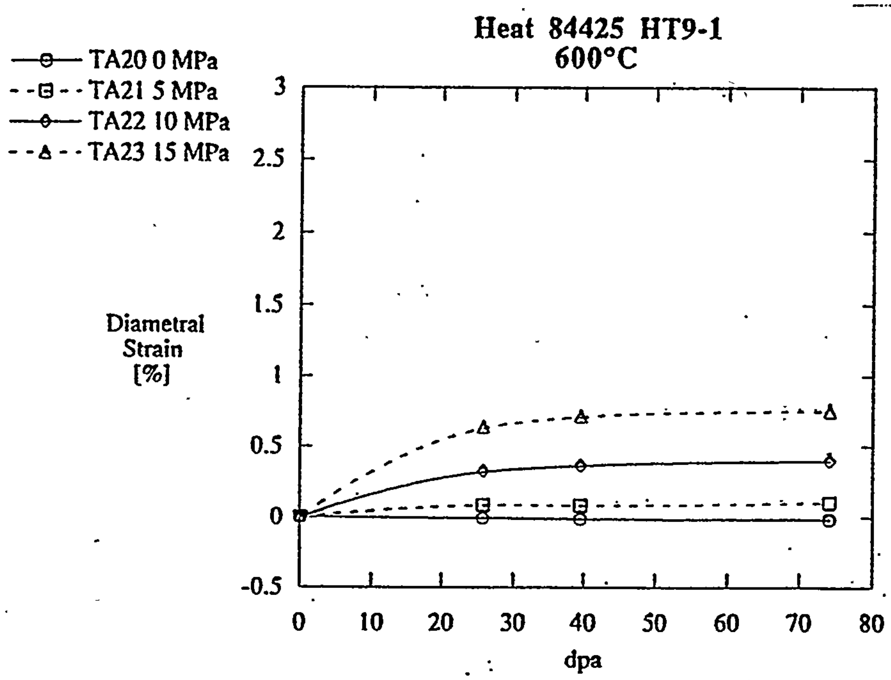


Figure 6. Total strains and midwall creep strain rates observed in HT9-2 at ~550°C.



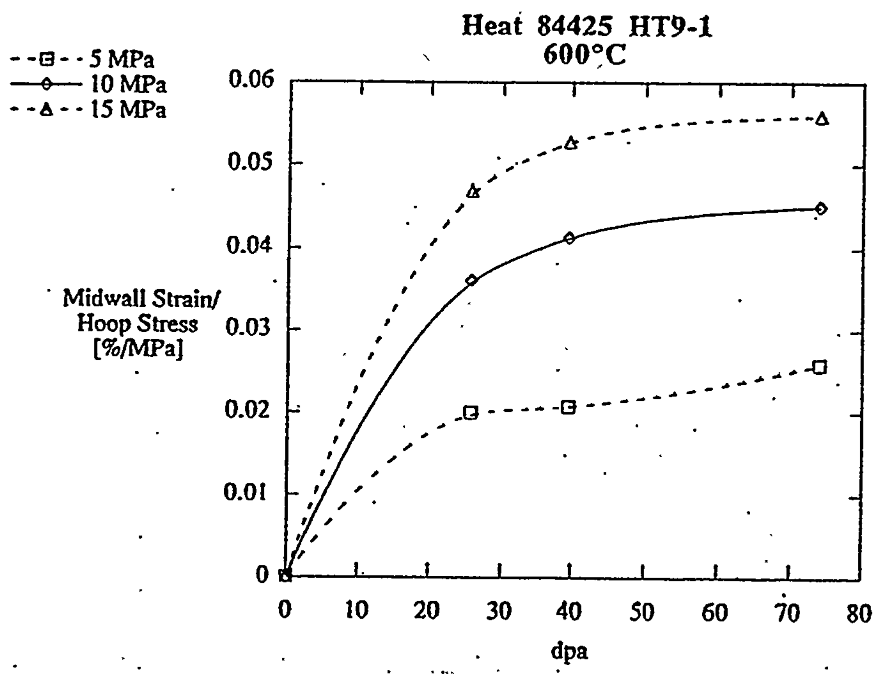


Figure 7. Total strains and midwall creep strains observed in HT9-1 at ~600°C.