한국소성가공학회 '94추계학술대회 논문집 pp.74～79

# DETERMINATION OF RUPTURE TIME AND STRAIN RATE IN CREEP BY UNIAXIAL TENSILE TEST

HUNG-KUK OH
Dept. of Mech. Eng. Ajou Univ.
Suwon, 442-749, South Korea

## ABSTRACT

The log-log presentation of stress versus Larson-Miller parameter is obtained by uniaxial tensile test instead of the long time creep test. The used material for example calculations is SUS304 stainless steel. The temperature of the uniaxial tensile test can be determined by the Larson-Miller parameter of the design stress and the 0.1hr' s rupture time of the uniaxial tensile test. The rupture time at the design temperature and stress can be determined by the Larson-Miller parameter of the stress. The average creep rate is the total deformation of the tensile test divided by the rupture time at the design stress and temperature. The linear trend and the order of the data of the average creep rate by this method is almost same as that of experimental results.

## 1. INTRODUCTION

Creep is a limiting design consideration for nearly all metal parts used at elevated temperatures. Since accumulated strain in creep depends on the time under stress, design criteria at elevated temperatures must be based in finite lifetimes. The emphasis in creep analysis is therefore on the prediction of strain rates and time-to-fracture for various conditions of stress and temperature. But the test times raise up engineering problems for economy and time schedules. And also test apparatus and laboratory room are high-priced. It can be imagined, if the creep test is replaced by uniaxial tensile test, how convenient it is. Author found fortunately that the deformation characteristics of any material can by determined by its ultimate tensile strength in case of uniaxial deformation (Ref. 2 and Ref. 3) and the total creep deformation at design temperature and stress is equivalent to the difference between fracture elongation and uniform elongation of the uniaxial tensile test of the same Larson-Miller parameter. The log-log presentation of stress versus Larson-Miller parameter is obtained by uniaxial tensile test with 0.1hr' s test time as metal engineers do. The used material for example calculations is SUS304 stainless steel.

## 2. Log-Log Presentation of Stress Versus Larson-Miller Parameter by Uniaxial Tensile Test

The behavior of a metal under stress at elevated temperatures is quite different from that at ordinary temperatures. Creep, a continuos, slow deformation, may occur. This can take place at a stress below the proportional limit determined by short-time tests. Creep is a thermally activated process which occurs because certain obstacles to deformation exist which can be overcome by the combined action of the applied stress and thermal fluctuations. Testing programs could be further significant if results obtained at one temperature could be correlated with those obtained at another. Unfortunately, metallurgical or microstructural changes which will influence properties may also occur with changes in temperature. By the Larson-Miller parameter, P, temperature and time have been incorporate into one number. Log-Log presentation of stress versus P gives characteristics of the stress-rupture behavior. It is long time and hard job work ,but, for creep design engineers to complete the full curve by creep test. Metal engineers used uniaxial tensile test(test time=0.1hr) instead of long time creep test(Ref. 1) and confirmed its validity for a number of metals. Author takes example by the case of SUS304.

*Table 1 Effect of Temperature on Ultimate Tensile Strength, ksi(MN/m$^2$), of SUS304*

| °C | 24 | 38 | 93 | 149 | 204 | 260 | 316 | 371 |
|---|---|---|---|---|---|---|---|---|
| $\sigma_u$ | 83.9 (578.5) | 81.4 (561.3) | 72.1 (497.1) | 67.1 (462.6) | 65.4 (450.9) | 64.6 (445.4) | 64.6 (445.4) | 64.6 (445.4) |
| $\log\sigma_u$ | 1.92 | 1.91 | 1.86 | 1.83 | 1.82 | 1.81 | 1.81 | 1.81 |
| P | 5643 | 5909 | 6954 | 8018 | 9063 | 10127 | 11191 | 12236 |
| °C | 427 | 482 | 538 | 593 | 649 | 704 | 760 | 816 |
| $\sigma_u$ | 63.8 (439.9) | 62.1 (428.2) | 58.7 (404.7) | 52.9 (364.7) | 46.1 (317.9) | 38.6 (266.1) | 29.4 (202.7) | 21.0 (144.8) |
| $\log\sigma_u$ | 1.80 | 1.79 | 1.77 | 1.72 | 1.66 | 1.59 | 1.47 | 1.32 |
| P | 13300 | 14345 | 15409 | 16454 | 17518 | 18563 | 19627 | 20691 |

Table 1 shows ultimate tensile strength of the SUS304 at various temperatures.

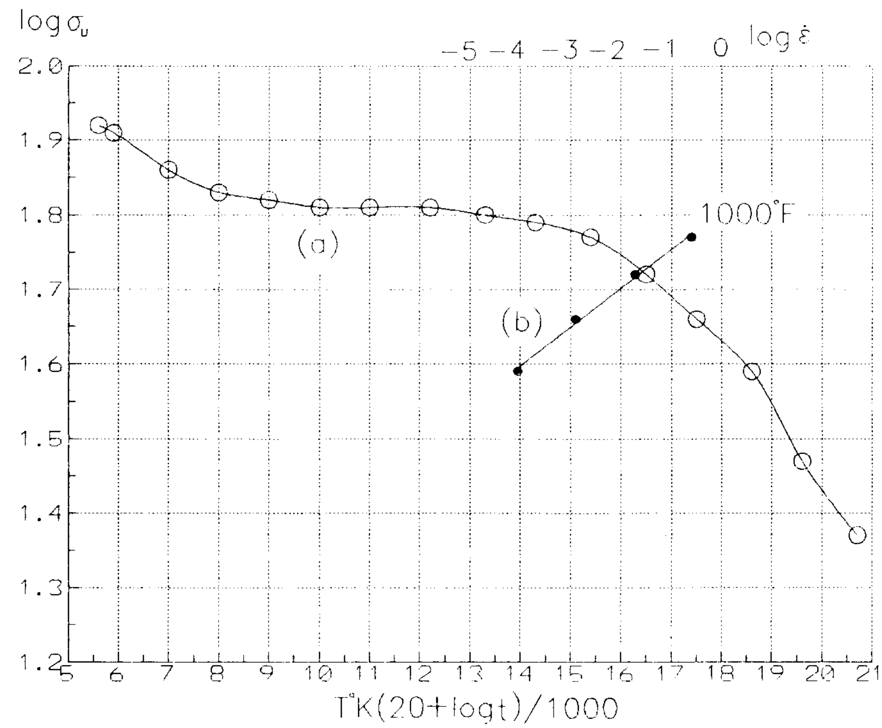


*Fig. 1 Log-Log Presentation of Stress Versus Larson-Miller Parameter(a) and Creep rate(b), SUS304*

Fig. 1 is the log-log presentation of stress versus Larson-Miller parameter and creep rate at 1000°F of SUS304.

### 3. Log-Log Presentation of Stress Versus Creep Rate by Uniaxial Tensile Test

It was verified that the deformation is characterized by the ultimate tensile strength(Ref. 2) (Ref. 3). The ultimate tensile strength has a functional relationship with Larson-Miller Parameter as in Fig. 1. If we want to know the deformation characteristic at any temperature and stress, first look for the Larson-Miller parameter on the stress and second calculate the temperature for uniaxial tensile test with t=0.1hr as follows.

$$T_{UTT}\,^{\circ}C = \frac{P(\sigma)}{19} - 273 \tag{1}$$

The difference between fracture elongation and uniform elongation of the tensile test is the total creep deformation. The average creep rate for the design temperature and stress is the total creep deformation divided by the rupture time at the design temperature. The rupture time at the design temperature and stress is as follows.

$$T_D\,^{\circ}K(20+\log t_D) = P(\sigma) \tag{2}$$

The average creep rate($\dot{\varepsilon}_D$) is

$$\dot{\varepsilon}_D = \frac{\left(\frac{\Delta \ell}{\ell_0}\right)_{u-f}}{t_D} \tag{3}$$

where $\left(\frac{\Delta \ell}{\ell_0}\right)_{u-f}$ is the total creep deformation at the design temperature and stress that is equivalent to the difference between fracture elongation and uniform elongation of the uniaxial tensile test. Author takes example by the case of SUS304. Fig. 2 shows fracture and uniform elongations at various temperatures on SUS304.

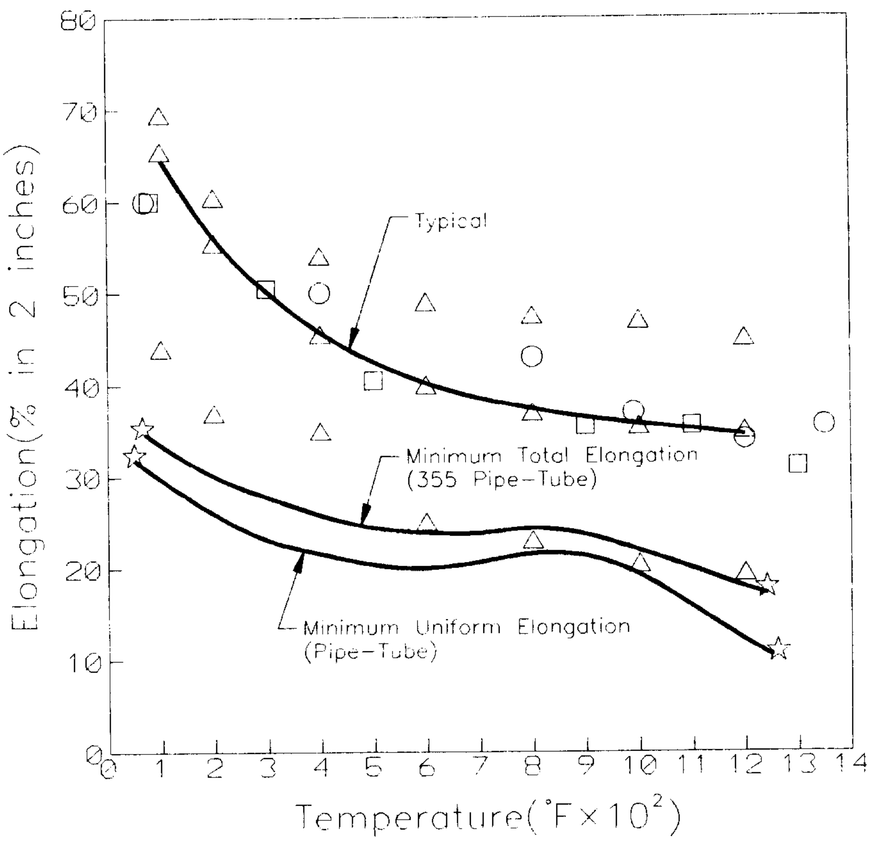


*Fig. 2 Total fracture elongations and uniform elongations at various temperatures, SUS304*

As a matter of convenience, we take in Fig. 2 the difference between minimum total elongation and minimum uniform elongation. And also the design temperature is taken, 538°C. Table 3 shows the calculations of the rupture time, uniaxial tensile test temperature and creep rate at various design stresses and the design temperature (538°C). The creep rate is graphed in Fig. 1(b). The linear trend and the order of the data are almost same as of Fig. 2 in (Ref. 4). This is not very bad result.

*Table 2 Calculations of the rupture time, uniaxial tensile test temperature and creep rate at various design stresses and the design temperature (538°C)*

| | | | | | | |
|---|---|---|---|---|---|---|
| $\sigma_u$(ksi) | 58.7 | 52 | 46.1 | 38.6 | 29.4 | 21.0 |
| log $\sigma_u$ | 1.77 | 1.72 | 1.66 | 1.59 | 1.47 | 1.32 |
| P | 15409 | 16454 | 17518 | 18563 | 19627 | 20691 |
| log $t_D$ | -1.00 | 0.289 | 1.60 | 2.89 | 4.20 | 5.51 |
| $t_D$(hr) | 0.10 | 1.95 | 39.8 | 776 | 15849 | 323594 |
| $T_{UTT}$ °C (°F) | 538 (1000) | 593 (1100) | 649 (1200) | 704 (1300) | 760 (1400) | 816 (1500) |
| $\left(\frac{\Delta \ell}{\ell}\right)_{u-f}$ in Fig. 2 | 0.025 | 0.035 | 0.05 | 0.075 | | |
| $\dot{\varepsilon}$ | $2.5 \times 10^{-1}$ | $1.79 \times 10^{-2}$ | $1.26 \times 10^{-3}$ | $9.66 \times 10^{-5}$ | | |
| log $\dot{\varepsilon}$ | 0.40–1.00 | 0.25–2.00 | 0.10–3.00 | 0.98–5.00 | | |

## 4. CONCLUSION

1. The log-log presentation of stress versus Larson-Miller parameter can be obtained by uniaxial tensile test instead of the long time creep test as metal engineers do.
2. The deformation characteristics of any material can be determined by its ultimate tensile strength in case of uniaxial deformation.
3. The log-log presentation of stress versus creep rate can be obtained by uniaxial tensile test.
4. The temperature of the uniaxial tensile test can be determined by the Larson-Miller parameter of the design stress and the 0.1hr's rupture time of the uniaxial tensile test.
5. The rupture time at the design temperature and stress can be determined by the Larson-Miller parameter of the stress.
6. The total creep deformation at design temperature and stress is equivalent to the difference between fracture elongation and uniform elongation of the uniaxial tensile test.
7. The average creep rate is the total deformation of the tensile test divided by the rupture time at the design stress and temperature.
8. The linear trend and the order of the data of the average creep rate by this method is almost same as that of experimental results.

## REFERENCE


1. TAYLOR LYMAN, METALS HANDBOOK, Vol. 1, properties and selection of metals, American Society for Metals, 1961, Page 492~495
2. HUNG-KUK OH, DETERMINATION OF FRACTURE TOUGHNESS BY UNIAXIAL TENSILE TEST, Submitted in J. of Materials Processing Technology, Dec. 1993
3. HUNG-KUK OH, DETERMINATION OF DUCTILE FRACTURE(DUCTILITY) AT ANY STRESS STATE BY UNIAXIAL TENSILE TEST, Submitted in J. of Materials Processing Technology, Feb. 1994
4. DONALD PECKNER, HANDBOOK OF STAINLESS STEELS, McGraw-Hill Book Company, 1987, page 21~23