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Stress–strain behaviour of nitrogen bearing austenitic stainless steels in the temperature range 298–473 K

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The stress–strain behaviour of three nitrogen-bearing low-nickel austenitic stainless steels has been investigated via a series of tensile tests in the temperature range 298–473 K at an initial strain rate of $1.6 \times 10^{-5}\ s^{-1}$. Experimental stress–strain data were analysed employing Rosenbrock's minimization technique in terms of constitutive equations proposed by Hollomon, Ludwik, Voce and Ludwigson. Ludwigson's equation has been found to describe the flow behaviour accurately, followed by Voce's equation. The resultant strain-hardening parameters were analysed in terms of variations in temperature. A linear relationship between ultimate tensile stress and the Ludwigson parameters has been established. The influence of nitrogen on the Ludwigson modelling parameters has also been explained.

Nomenclature

σ	True stress
ε_t	True strain
ε_f	True fracture strain
$\dot{\varepsilon}$	Strain rate
T	Temperature
K_H, n_H	Hollomon parameters
K_L, n_L	Ludwik parameters
$K_{1L}, K_{2L}, n_{1L}, n_{2L}$	Ludwigson parameters
σ_s, K_V, n_V	Voce parameters
$\varepsilon_{u\ \text{relation}}$	Uniform strain computed from a particular relation
ε_L	Transient strain
σ_0	Flow stress at zero plastic strain (Ludwik)
σ_L	Transient stress
σ_y	Yield stress
σ_u	Ultimate tensile stress

1. Introduction

Austenitic stainless steel is used in the manufacture of a wide variety of formed parts for architectural, automotive, domestic and industrial applications. The methods by which these parts are formed range from relatively uncomplicated stretching and bending operations to the more complex spinning and drawing techniques. In each forming operation the steel reacts to the imposed forming strains by developing progressively greater internal stresses reflecting the increased difficulty of dislocation motion. The stress reaction to the imposed strain characterizes the plastic behaviour of steel. Understanding of the plastic behaviour of different stable or metastable austenitic stainless steels has been the subject of interest for metal-forming technologists [1–10]. Several constitutive relations are available in the literature [11–15] and have been frequently employed for fitting stress–strain data [16–21].

In the present investigations, three grades of nitrogen-bearing austenitic stainless steel, two grades with low nickel and one without nickel, have been considered. The plastic behaviour of these stainless steels has been investigated via a series of tensile tests in the temperature range 298–473 K.

Experimental stress–strain data obtained have been analysed by using a minimization programme employing Rosenbrock's technique [22] based on different constitutive equations proposed by Hollomon [11], Ludwik [12], Voce [14] and Ludwigson [15]. The closeness of the computed stress–strain curve to the actual stress–strain curve and additionally computed plastic uniform strain, were considered to test the validity of the stress–strain relations [17, 18]. The resultant strain-hardening parameters from different stress–strain relations have been analysed in terms of variations in temperature. The strain-induced martensite (α') formed at room temperature (298 K) has been discussed for these steels. The influence of nitrogen on the Ludwigson modelling parameters has also been analysed.

2. Analytical framework

The strain-hardening behaviour of a material is expressed by a simple state equation

$$\sigma = \sigma(\varepsilon, \dot{\varepsilon}, T) \tag{1}$$

TABLE I Computation of plastic uniform strain for different stress–strain relations

Stress–strain relation	Uniform strain, ε_u
Hollomon $\sigma = K_H \varepsilon^{n_H}$	$\varepsilon_{u,H} = n_H$
Ludwik $\sigma = \sigma_0 + K_L \varepsilon^{n_L}$	$\varepsilon_{u,L} = n_L(\sigma_u - \sigma_0)/\sigma_u$
Voce $\sigma = \sigma_s - K_V \exp(n_V \varepsilon)$	$\varepsilon_{u,V} = (1/n_V) \ln[\sigma_s/(1 - n_V) K_V]$
Ludwigson $\sigma = \exp(K_{1L}) \exp(n_{1L} \varepsilon) + K_{2L} \varepsilon^{n_{2L}}$	–

If strain rate and temperature are assumed constant, the plastic state equation can be approximated by the constitutive equations proposed by Hollomon [11], Ludwik [12], Voce [14] and Ludwigson [15] as listed in Table I. The ultimate tensile strength, σ_u, can be calculated by invoking the instability criterion at the onset of necking. The same criterion could also be applied to obtain the value of plastic uniform strain, ε_u. By substituting σ_u for σ and ε_u for ε, the plastic uniform strain can be computed for different stress-strain relations. The calculation of plastic uniform strain, especially for Voce's equation, has been reported earlier [23]. The plastic uniform strain cannot be computed for Ludwigson's equation [15], because as many as four parameters are involved in the equation. The closeness of the computed stress–strain curve to the actual stress-strain curve was considered as a measure to test the validity of Ludwigson's equation.

3. Experimental procedure

The studied steels are two grades of nitrogen-bearing low-nickel and one nickel-free austenitic stainless steel, respectively named A,B and C. The chemical compositions of these steels are given in Table II. These steels were commercially produced and received in the form of 6 mm thick plate. Plates were further processed to nearly 0.6 mm strip using an experimental rolling mill. Strips were solution treated at 1323 K for 300 s and then quenched in water. These steels had austenitic structure and the initial grain sizes of steels A, B and C were 41, 36 and 33 μm, respectively.

Tensile specimens of 25 mm gauge length and 6.25 mm width were machined from solution-treated strips. Room-temperature tensile testing was conducted on a 10 tonne Instron universal testing machine. Tests at elevated temperature were performed using a 10 tonne material test system where a three-zone vertical resistance furnace was attached with the system. Specimens were heated in the above furnace and the temperature was controlled within ± 2 K. The specimens were held at the desired temperature for 900 s prior to commencement of deformation. Tensile tests were performed at an interval of 25 K up to 473 K at an initial strain rate of 1.6×10^{-5} s^{-1}.

TABLE II Chemical composition (wt %) of steels

Steel	C	Cr	Ni	Mn	Si	Cu	N
A	0.06	15.22	4.63	9.85	0.55	–	0.13
B	0.06	16.06	4.10	4.09	0.63	1.61	0.16
C	0.05	12.40	–	18.95	0.48	0.55	0.19

Load–elongation data obtained from the plotter were fed into a Honeywell Bull Computer by points for stress–strain analysis employing Rosenbrock's minimization programme [22] in terms of plastic equations (Table I)

The error in the predicted values of plastic uniform strain has been estimated from the following expression

$$\% \text{ error} = 100(\beta_{ssr} - \beta_{exp})/\beta_{exp} \qquad (2)$$

where β_{ssr} is the value of plastic uniform strain calculated using different constitutive equations and β_{exp} is the value obtained experimentally.

The volume fraction per cent of strain-induced martensite, (α'), at different strains was determined by X-ray technique.

4. Results

Experimental stress–strain curves for steels A, B and C over the entire temperature range of the investigations are shown in Fig. 1a–c, respectively. The yield stress, (σ_y), ultimate tensile stress, (σ_u), and fracture strain, (ε_f) at different temperatures for these three steels are indicated in Fig. 2. Computer analysis of experimental stress–strain curves employing Rosenbrock's minimization programme based on different constitutive equations (Table I) was obtained. The curve fitting of experimental stress–strain curves to computed stress–strain curves in terms of the above equations at 298 and 473 K have been illustrated; Fig. 3a and b correspond to steel A, Fig. 4a and b to steel B and Fig. 5a and b to steel C.

Comparisons of computed stress–strain curves to actual stress–strain curves show that the Ludwigson model has been found unequivocally capable of describing the flow behaviour in the entire range of strain, followed by the Voce relation. The Hollomon and Ludwik relations are inadequate to describe the stress–strain curve especially at lower strains.

The Hollomon, Ludwik, Voce and Ludwigson parameters are presented in Tables III–VI, respectively, at room temperature (298 K) as an example. The Hollomon parameters, K_H and n_H, obtained for three steels in the temperature range of investigations show that there is a drop in these values with temperature. The Ludwik parameters, σ_0, K_I, and n_L in the Ludwik relation also decrease with increasing temperatures. The relationship of the Voce parameters with temperature show that there is a decrease in the value of strength parameters σ_s and K_v with temperature. The n_v plot has remained practically insensitive to the temperature.

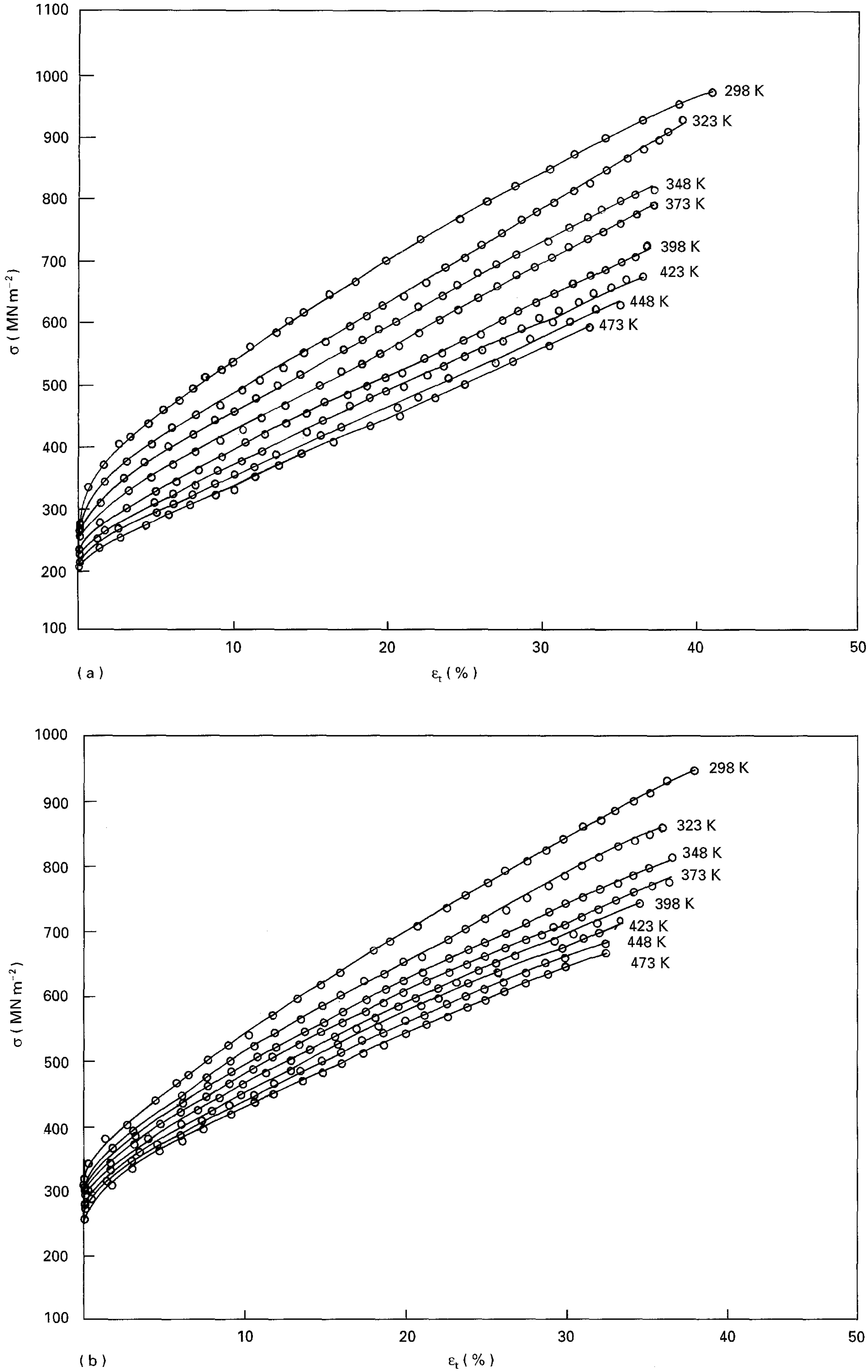

Figure 1 True stress–true strain relations for (a) steel A, (b) steel B, and (c) steel C at different temperatures.

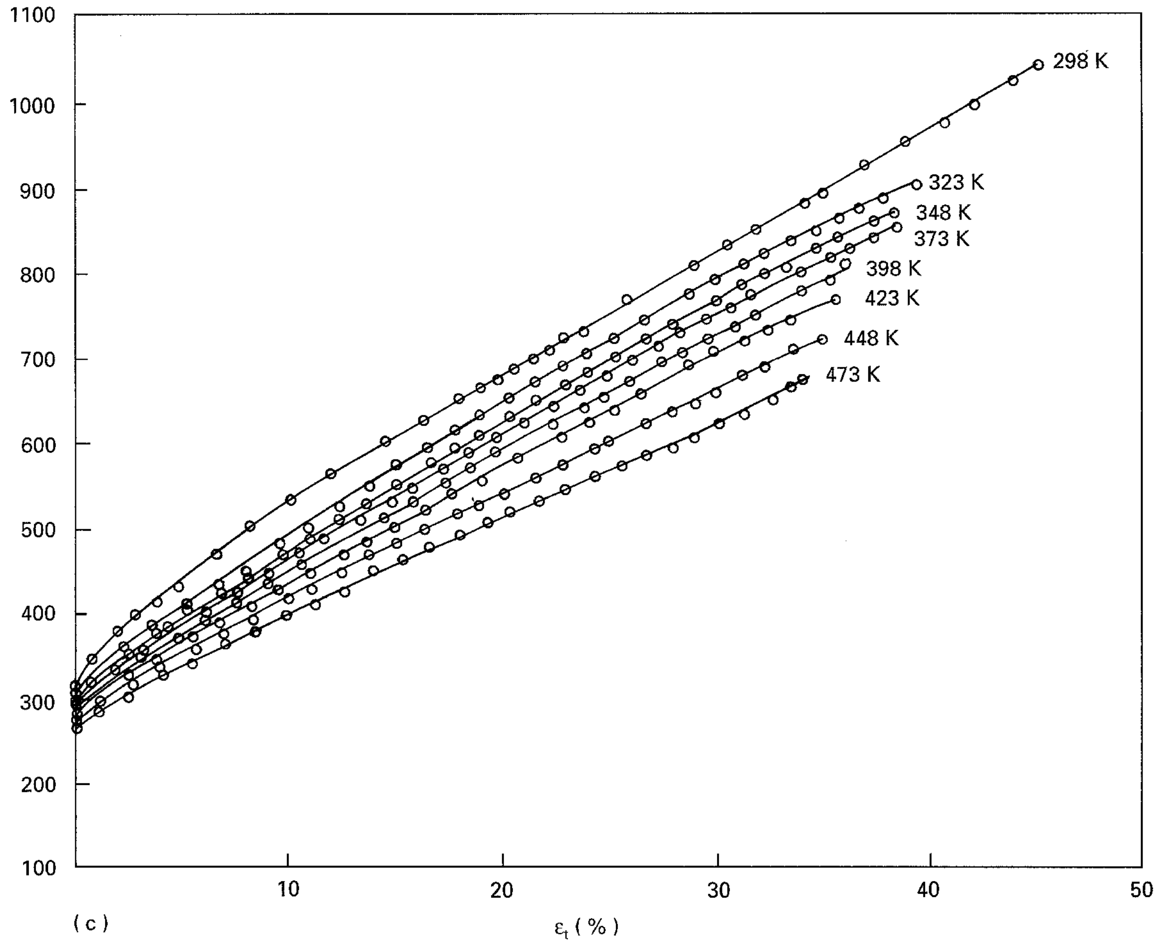

Figure 1 Continued.

The relationship of the Hollomon, Ludwik and Voce parameters with temperature is indicated in Fig. 6a–c for steel B as an illustration. The Ludwigson parameters derived for steels A,B and C are plotted against temperature in Fig. 7a–c, respectively. Increase in the test temperature tended to reduce K_{1L}, K_{2L}, and n_{2L}, and to make n_{1L} more negative. Parameters K_H and n_H in the Hollomon, σ_0, K_L, and n_L in the Ludwik, σ_s and K_V in the Voce and K_{1L}, n_{1L}, K_{2L} and n_{2L} in the Ludwigson relations, may be regarded as linearly decreasing functions of temperature. Least square analysis has confirmed the linear relations. These are indicated in Table VII.

The dependence of yield stress, σ_y, ultimate tensile stress, σ_u, and fracture strain, ε_f, on temperature has also been indicated in the form of linear equations. These are shown in Table VIII.

5. Discussion

The Hollomon relation (Table I) is simple because it can be made linear by logarithmic transformation. Accordingly, experimental true stress–true strain points were plotted on double logarithmic coordinates. However, it is observed that the experimental data points can be smoothed by two straight lines (not by a single straight line) with a narrow transient stage near their intercept point. The intercept strain and corresponding flow stress will be termed here the transient strain, ε_L, and transient stress, σ_L, respectively. The resulting stress–strain curve at lower strains is concave upwards and lies at higher stresses than those represented by extrapolation of the Hollomon relation to lower strains. The extent to which the stress–strain data could be described by the Hollomon relation is indicated in Fig. 8 for steel B tested at room temperature (298 K) as an illustration. It is clear that the Hollomon model is inadequate to describe the flow behaviour below the transient strain; however, at strains greater than transient strain, the Hollomon relation represents the data very adequately. The difference between the observed true stress at low strains and the stress represented by the Hollomon relation extended to these low strains is termed Δ. All three steels A,B and C exhibit positive values of Δ under all the testing conditions.

The shape of the stress–strain curve at lower strains indicates that Δ is an exponential function of strain. It is observed that the logarithm of Δ is a linear function of strain. The linear relationship between logarithm of Δ and true strain is shown in Fig. 9 as an example. The significance of Δ and its linear relationship with strain has helped in understanding the Ludwigson model. The underestimation of flow stress at lower strains by the Hollomon equation is also due to the fact that the

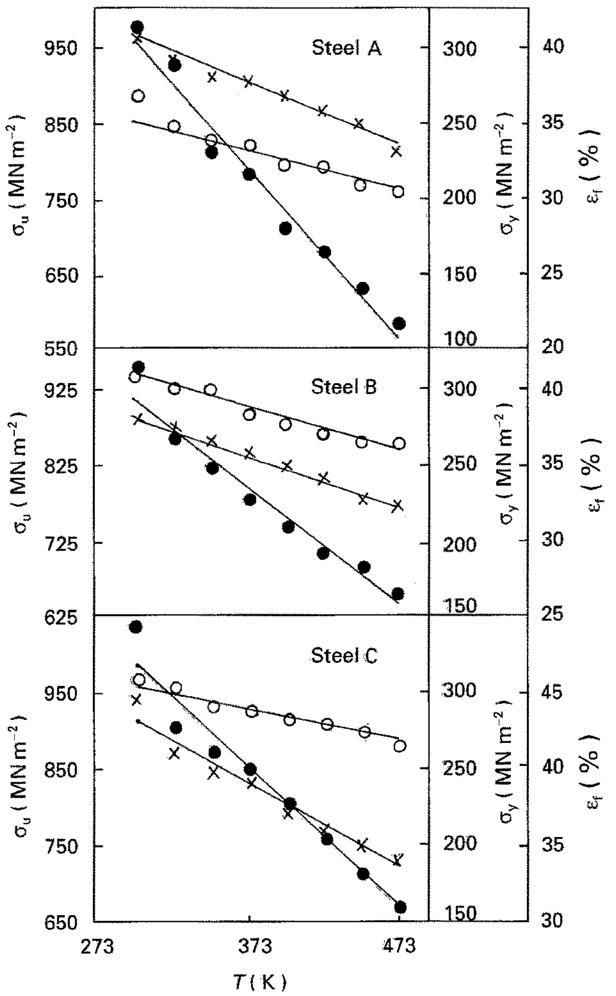

Figure 2 Relationship of (○) yield stress, (●) ultimate tensile stress and (×) fracture strain with temperature for steels A, B and C.

equation implies that at zero plastic strain the flow stress is zero; however, this is not true (Figs 3–5). The equation could not be applied in the region of the yield point. The exhibition of two stages or multiple stages of strain-hardening behaviour and doubts on the validity of the Hollomon equation have been confirmed by many authors [24–32]. The per cent error in estimation of uniform plastic strain by the Hollomon equation is also indicated (Table III). Inadequacy of the Hollomon relation to describe the flow behaviour for AISI 304 and other stable austenitic stainless steels has also been reported [15, 33]; these authors suspected a phase change during straining. In the present investigations the formation of strain-induced martensite, α', has been revealed at room temperature (Table IX), but there is no possibility of α' formation at 473 K; even at this temperature a two-stage hardening behaviour has been observed for all the three steels. So, the phase change during straining could not be the reasons for failure of the Hollomon relation. It is interesting to note that the steel which exhibits the higher value of strain-induced martensite, α', at a particular value of strain also indicates the increased value of flow stress. It is well known that the formation of strain-induced martensite during deformation depends on austenite stability and, in turn, on alloy chemistry. The austenite stability for three steels considering all the elements including copper and nitrogen has been considered in terms of the stability factor [34]. It is seen that the stability factors for steels A, B and C are -1.739, -2.118 and -2.908, repsectively. The higher the value of stability factor, the lesser is the volume fraction of strain-induced martensite at any particular strain; this is true only in the case of

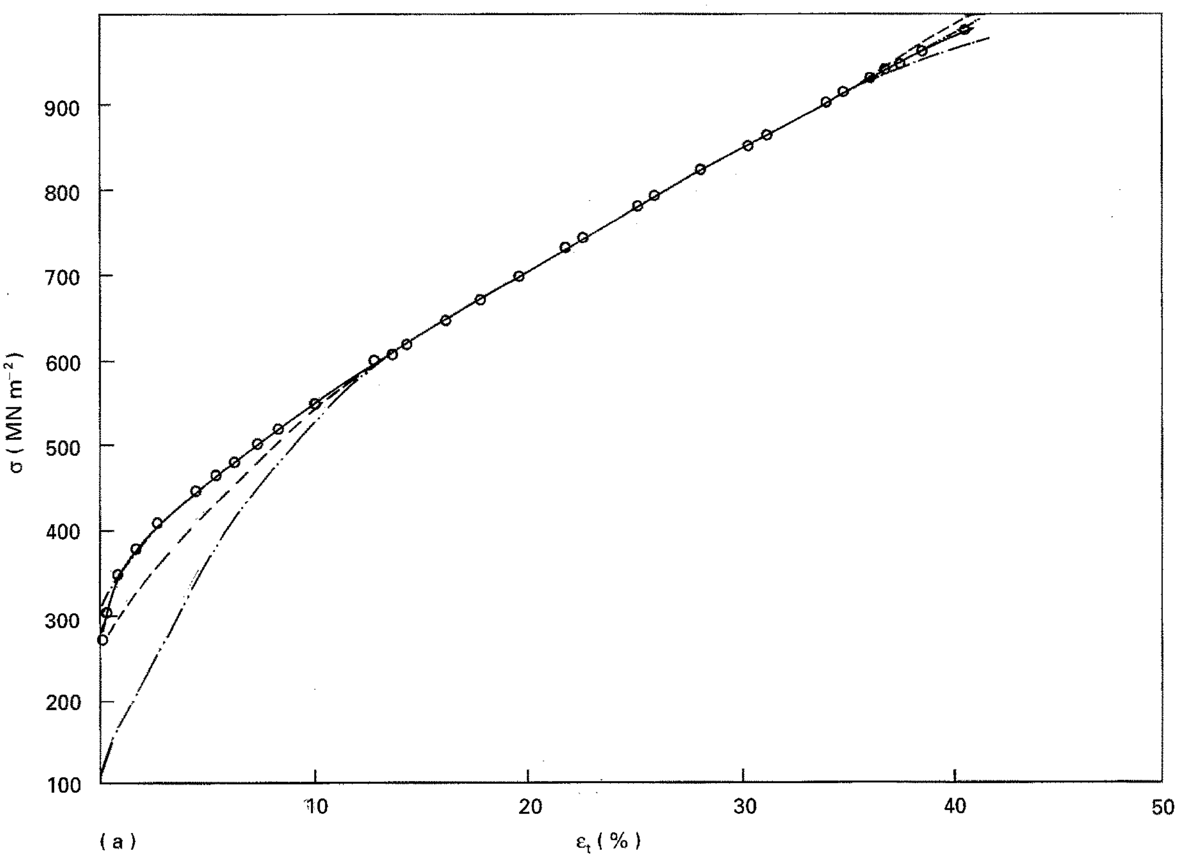

Figure 3 Analysis of true stress-true strain curve using four different relations for steel A at (a) 298 K and (b) 473 K. (—··—) Holloman, (– – –) Ludwig, (—·—) Voce, (—) Ludwigson, (○) experimental.

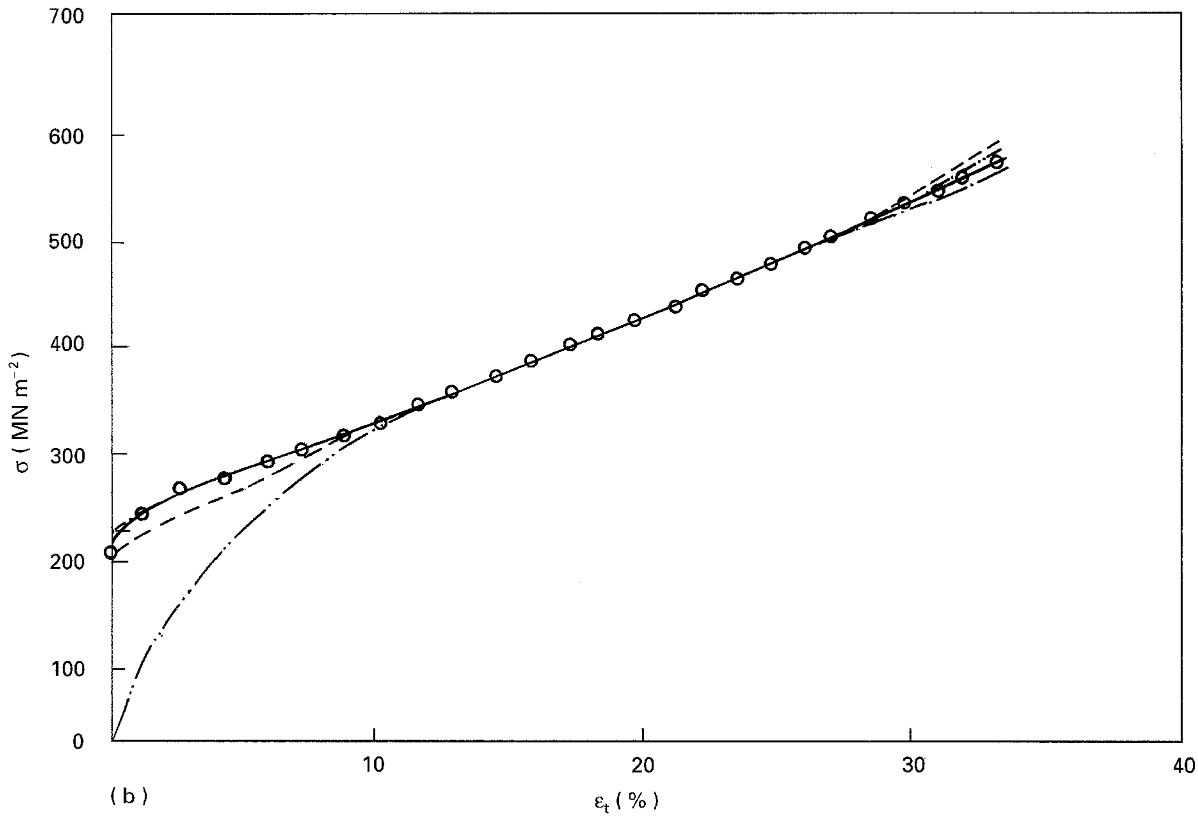

Figure 3 Continued.

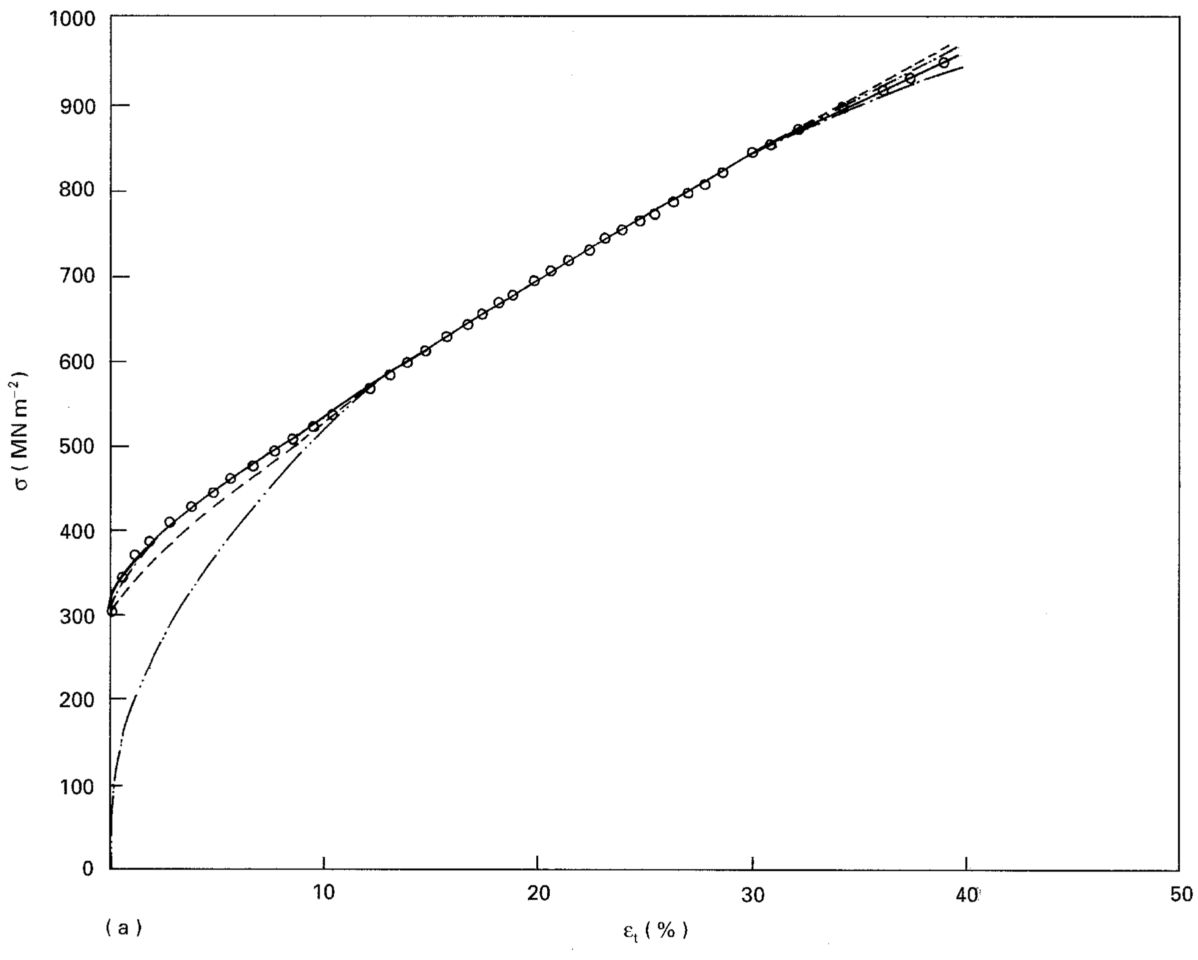

Figure 4 Analysis of true stress–true strain curve using four different relations for steel B at (a) 298 K and (b) 473 K. For key, see Fig. 3.

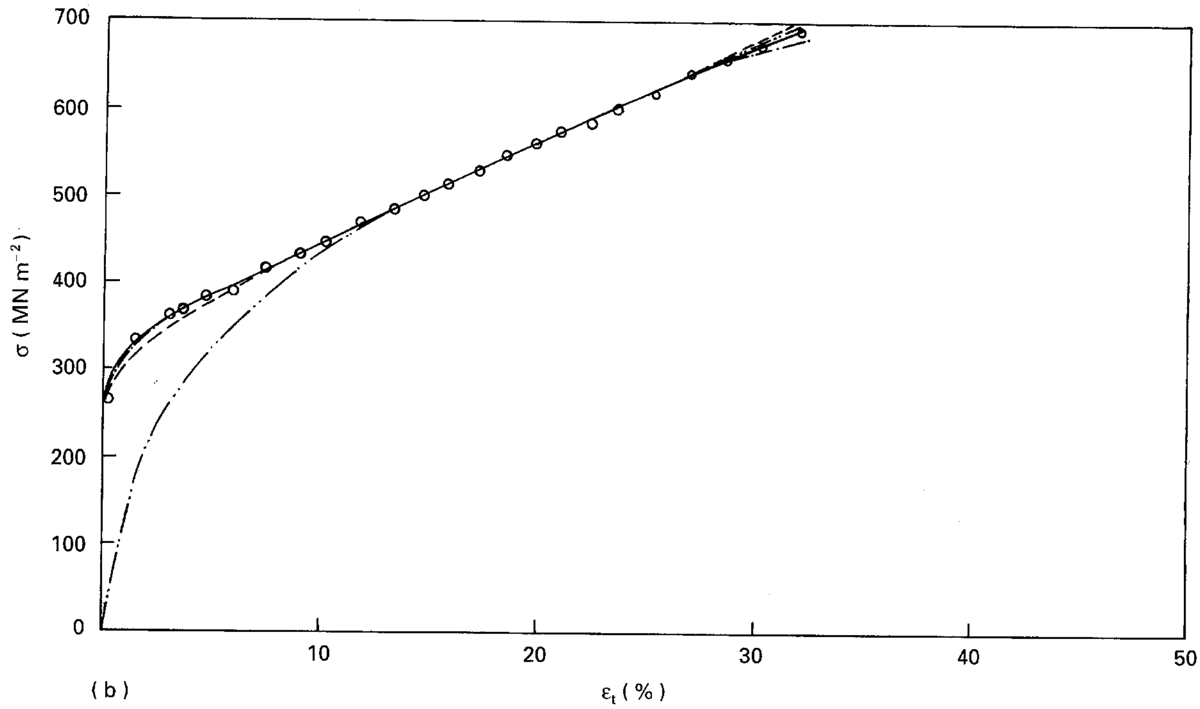

Figure 4 Continued.

TABLE III Hollomon constants for different steels ($T = 298$ K, $\dot{\varepsilon} = 1.6 \times 10^{-5}\,s^{-1}$)

Steel grade	K_H (MPa)	n_H	ε_u	% error in ε_u
A	1380	0.43	0.43	6.0
B	1435	0.44	0.44	17.33
C	1560	0.525	0.525	15.20

TABLE IV Ludwik constants for different steels ($T = 298$ K, $\dot{\varepsilon} = 1.6 \times 10^{-5}\,s^{-1}$)

Steel grade	σ_0 (MPa)	K_L (MPa)	n_L	ε_u	% error in ε_u
A	275	1372	0.728	0.525	29.37
B	260	1360	0.665	0.485	29.33
C	310	1440	0.840	0.5918	29.69

TABLE V Voce constants for different steels ($T = 298$ K, $\dot{\varepsilon} = 1.6 \times 10^{-5}\,s^{-1}$)

Steel grade	σ_s (MPa)	K_V (MPa)	n_V	ε_u	% error in ε_u
A	1400	1050	− 2.20	0.41	0.97
B	1390	1040	− 2.185	0.38	1.32
C	1400	1190	− 2.20	0.46	0.93

TABLE VI Ludwigson constants for different steels ($T = 298$ K, $\dot{\varepsilon} = 1.6 \times 10^{-5}\,s^{-1}$)

Steel grade	K_{1L} (MPa)	$-n_{1L}$	K_{2L} (MPa)	n_{2L}
A	5.495	42.0	1380	0.43
B	5.620	35.0	1435	0.44
C	5.74	20.0	1560	0.525

steels A and B. It is not true for steel C. The validity of the expression for determining the stability factor is doubted for steel C, because nickel-free stainless steel has not been considered in their studies [34].

The Ludwik relation has also not found total favour in the present investigations. Of the two equations, Hollomon and Ludwik, the Ludwik equation seems more logical because it includes a term σ_0. The deviation of the experimental stress–strain curve from the computed stress–strain curve is reduced remarkably in the initial stages of straining compared to the Hollomon relation. In the later stages of straining the relation also represents the data adequately. The Ludwik relation also indicates the higher per cent error in the estimation of plastic uniform strain (Table IV). Doubts on the validity of the Ludwik relation have also been raised by other investigators [16, 17, 22, 35].

The relations presented by Hollomon and Ludwik predict monotonic unbounded increase in flow stress as straining progresses, whereas the Voce equation, due to the presence of an exponential term, presumes the existence of saturation stress at large strain values. Saturation in flow stress may occur upon concurrent hardening and softening due to recovery [36]. From Figs 3a, b, 4a, b and 5a, b it is clear that the Voce relation is able to describe the flow behaviour well compared to the Hollomon and Ludwik relations. The per cent error furnished in the estimation of plastic uniform strain is also the least and within acceptable limits

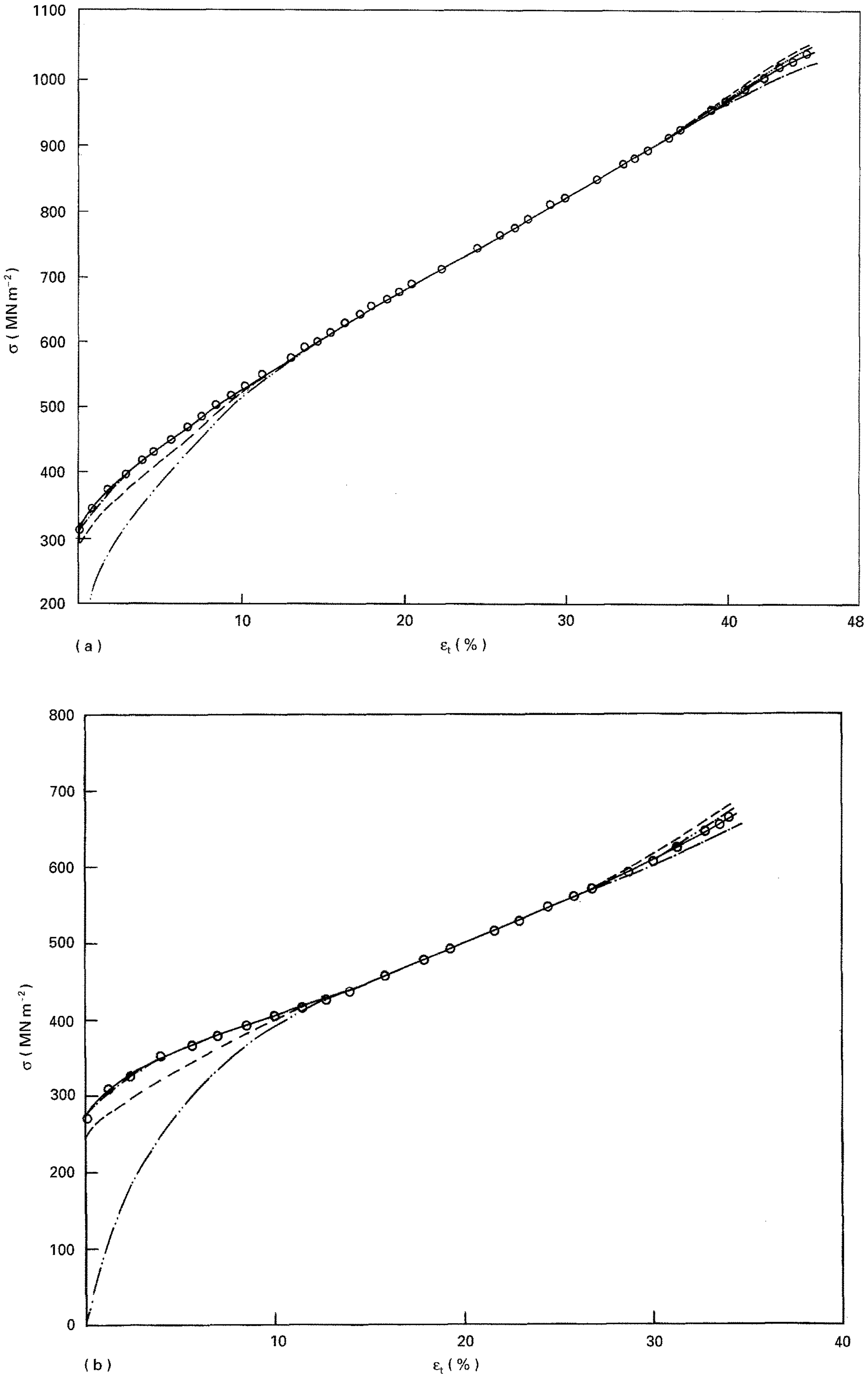

Figure 5 Analysis of true stress–true strain curve using four different relations for steel C at (a) 298 K and (b) 473 K. For key, see Fig. 3.

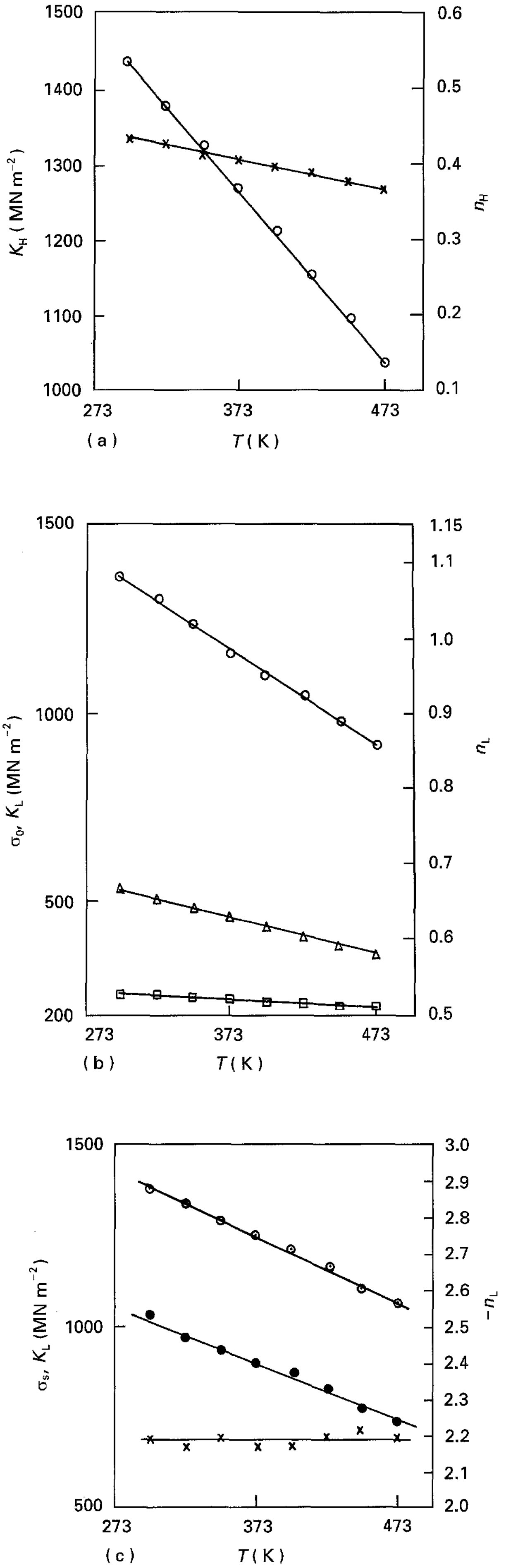

Figure 6 Relationship of (a) Hollomon parameters, (b) Ludwik parameters, and (c) Voce parameters with temperature (steel B). (○) K_H, K_L, σ_s, (×) n_H, n_V, (□) σ_0, (△) n_L, (●) K_V.

(Table V). Towards the end of straining, the Voce relation shows a divergence from experimental points. The presumption of saturation stress in the Voce relation at large strain values could be the possible reasons for such a divergence.

The values of n_V have been variously associated with rate-controlling mechanisms [37, 38]. It is suggested that at low and medium temperatures where cross-slip is dominant, n_V will have a lower value. In our investigations the values of n_V are also lower (Table V) and the Voce relation is able to describe the flow behaviour well; it may be advocated that the Voce equation is valid in cases where the dominant mechanism of recovery is cross-slip. However, in the present investigations, the flow behaviour at higher temperatures has not been discussed. The dependence of the Voce parameters on temperature and strain rate has also been discussed by Mattiazze *et al.* [19] for AISI 316H stainless steel. The Ludwigson model, which is considered as essentially a modification of the

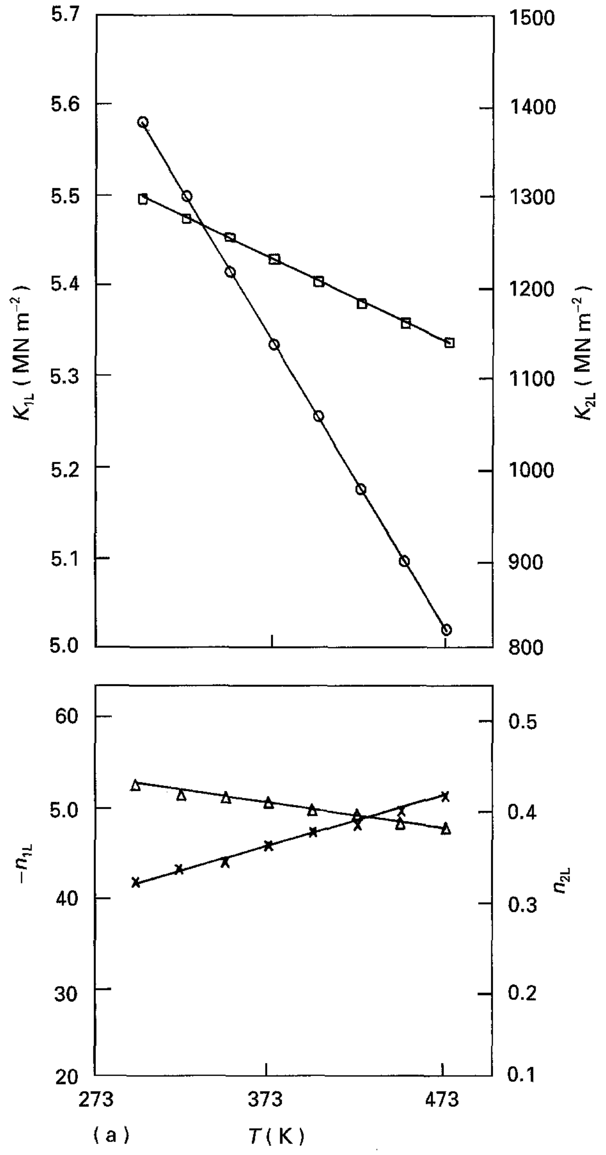

Figure 7 Relationship of Ludwigson parameters with temperature for (a) steel A, (b) (steel B) and (c) (steel C). (□) K_{1L}, (○) K_{2L}, (×) n_{1L}, (△) n_{2L}.

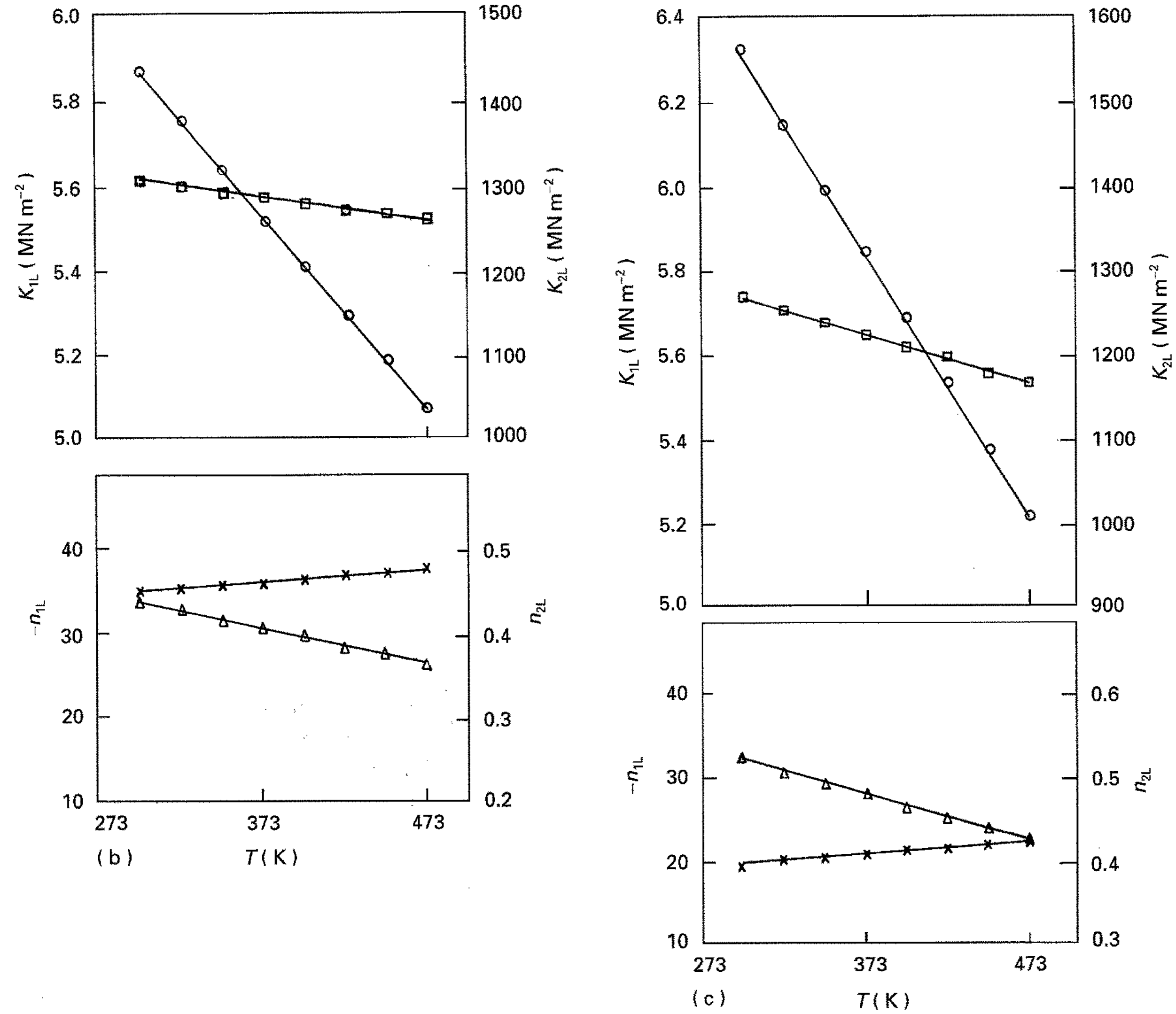

Figure 7 Continued.

TABLE VII Relationship between parameters of different constitutive equations and temperature

Steel grade	Equation	Correlation
A	$k_H = 2320 - 3.164T$	0.9996
	$n_H = 0.511 - 0.00028T$	0.9965
	$\sigma_0 = 424.6 - 0.504T$	0.9982
	$K_L = 2500 - 3.80T$	0.9998
	$n_L = 0.90 - 0.000598T$	0.9988
	$\sigma_s = 2140 - 2.45T$	0.9843
	$K_V = 1370 - 1.02T$	0.9774
	$K_{1L} = 5.77 - 0.000905T$	0.9988
	$-n_{1L} = 24.90 + 0.057T$	0.9975
	$K_{2L} = 2320 - 3.164T$	0.9996
	$n_{2L} = 0.511 - 0.00028T$	0.9965
B	$K_H = 2105 - 2.25T$	0.9998
	$n_H = 0.558 - 0.0004T$	0.9977
	$\sigma_0 = 321.7 - 0.22T$	0.9883
	$K_L = 2118 - 2.54T$	0.9985
	$n_L = 0.82 - 0.00051T$	0.9985
	$\sigma_s = 1940 - 1.82T$	0.9891
	$K_V = 1500 - 1.56T$	0.9601
	$K_{1L} = 5.77 - 0.0005143T$	0.9918
	$-n_{1L} = 30.01 + 0.017T$	0.9929
	$K_{2L} = 2105 - 2.25T$	0.9998
	$n_{2L} = 0.5585 - 0.0004T$	0.9977

TABLE VII Continued

Steel grade	Equation	Correlation
C	$K_H = 2486.4 - 3.12T$	0.9998
	$n_H = 0.687 - 0.000548T$	0.9980
	$\sigma_0 = 391 - 0.282T$	0.9870
	$K_L = 2628 - 3.97T$	0.9998
	$n_L = 1.128 - 0.000962T$	0.9995
	$\sigma_s = 2040 - 2.23T$	0.9173
	$K_V = 1930 - 2.69T$	0.9049
	$K_{1L} = 6.089 - 0.001176T$	0.9980
	$-n_{1L} = 15.71 + 0.0145T$	0.9898
	$K_{2L} = 2486 - 3.1214T$	0.9998
	$n_{1L} = 0.6873 - 0.000548T$	0.9980

Hollomon model, takes into account the positive deviation Δ which appears below a transient strain, ε_L, at low strain levels.

It has been observed that the Ludwigson model has been found unequivocally capable of describing the flow behaviour in the entire range of strain and temperatures for steels A,B and C (Figs 3a, b, 4a, b and 5a, b). This is mainly due to the fact that the Ludwigson equation takes into account the positive deviation which occurs below the transient strain in the Hollomon model.

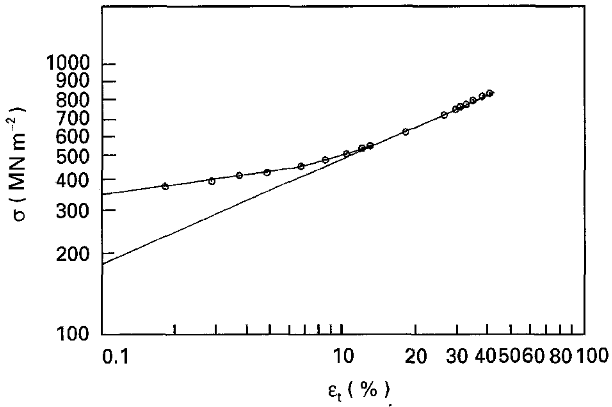

Figure 8 True stress–true strain relationship (steel B) on logarithmic coordinates at 298 K.

TABLE VIII Equations relating yield stress, ultimate tensile stress, fracture strain and temperature

Steel grade	Equation	Correlation
A	$\sigma_y = 325 - 0.25T$	0.9183
	$\sigma_u = 1616.7 - 2.22T$	0.9763
	$\varepsilon_f(\%) = 52.08 - 0.039T$	0.9596
B	$\sigma_y = 394 - 0.28T$	0.9367
	$\sigma_u = 1369.2 - 1.538T$	0.9511
	$\varepsilon_f(\%) = 48.13 - 0.0335T$	0.9871
C	$\sigma_y = 350 - 0.17T$	0.9918
	$\sigma_u = 1527.5 - 1.819T$	0.9396
	$\varepsilon_f(\%) = 58.74 - 0.053T$	0.8945

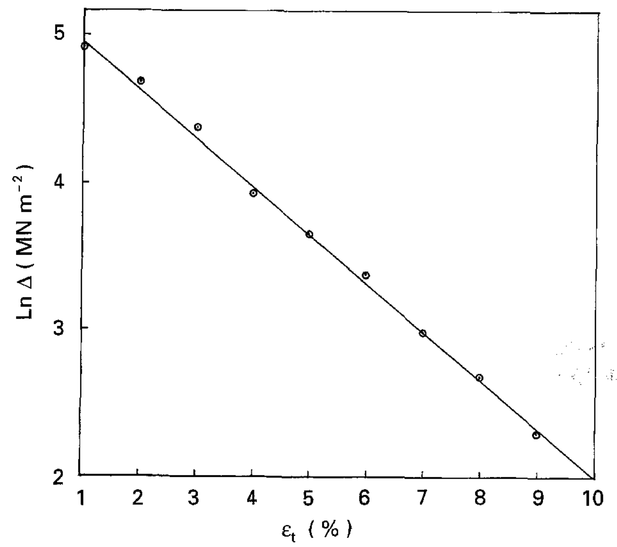

Figure 9 Relationship between logarithimic Δ and true strain (steel A) at 298 K.

It is observed that there is an increase in the values of transient strain, ε_L, transient stress σ_L, and the Ludwigson parameters with increasing nitrogen content at room temperature. The transient strain, ε_L, has increased from 0.10 to 0.15 as the nitrogen content increases from 0.13 wt % to 0.19 wt % for steels A and C, respectively, at room temperature. The corresponding change in transient stress, σ_L, value is from 550 to 605 MPa. It has been confirmed [39–41] that nitrogen alloying promotes the planar dislocation slip in austenitic stainless steel by delaying the multislip and cross-slip onset to a higher strain. It favours the planar slip by decreasing the stacking fault energy and creating short-range order resulting from its affinity with substitutional solute atoms like chromium, manganese, etc. [42–46].

The parameter K_{1L} also has an increasing tendency with increasing nitrogen content. The exponent n_{1L}, which is negative, expresses the rate at which the ratio between the short-range stresses and the long-range stresses decreases with increasing plastic strain. It has been obeserved that the term $-n_{1L}$ decreases with the increase in nitrogen content (Table VI). This is valid with the idea that the short-range stresses act up to higher strains with increasing nitrogen content.

The Ludwigson parameter, K_{2L}, has increased with increasing nitrogen content (Table VI). The increase in K_{2L} may be explained by the fact that it expresses the ability of the austenite to be strengthened by deformation. The strengthening elements carbon and nitrogen have a strong effect on such an ability. They create short-range stresses acting on the dislocations which become less mobile. In order to accommodate the deformation, the multiplication of dislocations is necessary which leads to an increase in the flow stress or K_{2L}. The increase in K_{2L} is also related to an increase of frictional and internal stresses with increasing nitrogen content [47–49].

The exponent n_{2L} is considered essentially independent of the nitrogen content, because it expresses the ability of the strain-hardening phenomenon at high strain levels. This is due to the fact that at high strain levels the strain hardening depends essentially on the long-range stresses acting on the dislocations, while the interstitials like nitrogen create essentially short-range stresses. In the present study, n_{2L} has increased with increasing nitrogen content (Table VI). The increase in n_{2L} may be due to elements such as chromium, manganese, copper, etc., other than nitrogen (Table II).

The above behaviour of the Ludwigson parameters with nitrogen at a temperature other than room temperature, is not clearly understood at this stage. It is very interesting to note that the Ludwigson parameters K_{1L}, n_{1L}, K_{2L} and n_{2L} are linked to the ultimate tensile stress, σ_u, by a linear relationship. These are indicated in Table X.

TABLE IX Strain-induced martensite formation, α′, at 298 K at a true strain shown

Steel grade	α′ % at						
	9.5%	18.23%	26.24%	33.65%	39.4%	41.5%	45.6%
A	1.0	3.0	5.3	6.25	–	8.5	–
B	1.6	4.25	8.0	9.25	12.50	–	–
C	0.6	2.50	4.0	5.25	–	–	8.0

TABLE X Relationship between different parameters of the Ludwigson equation and ultimate tensile stress

Steel grade	Equation	Correlation
A	$K_{1L} = 5.1146 + 0.000\,398\ \sigma_u$	0.9742
	$-n_{1L} = 63.740 - 0.0250\ \sigma_u$	0.9750
	$K_{2L} = 39.40 + 1.3941\ \sigma_u$	0.9787
	$n_{2L} = 0.3118 + 0.000\,122\ \sigma_u$	0.9737
B	$K_{1L} = 5.3277 + 0.000\,3186\ \sigma_u$	0.9467
	$-n_{1L} = 44.37 - 0.0102\ \sigma_u$	0.9276
	$K_{2L} = 153.84 + 1.394\ \sigma_u$	0.9531
	$n_{2L} = 0.2114 + 0.000\,2486\ \sigma_u$	0.9586
C	$K_{1L} = 5.1340 + 0.000\,6078\ \sigma_u$	0.9604
	$-n_{1L} = 27.55 - 0.007\,55\ \sigma_u$	0.9475
	$K_{2L} = -52.23 + 1.6161\ \sigma_u$	0.9682
	$n_{2L} = 0.2415 + 0.000\,284\ \sigma_u$	0.9643

6. Conclusions

A series of tensile tests was performed to describe the stress–strain behaviour of three nitrogen-bearing austenitic stainless steels in the temperature range 298–473 K. The studies led to the following conclusions.

1. The Ludwigson equation has been found to be the most accurate to describe the flow behaviour under the temperature and strain range involved.

2. The Voce relation also gives a good fit for the flow behaviour over the range of temperature and strain examined.

3. The Hollomon equation failed to describe the stress–strain behaviour especially at lower strains for these materials.

4. The Ludwik equation, however, gives a better fit to the flow curve compared to the Hollomon relation.

5. The variation in flow stress could be explained in terms of variations in different strain-hardening parameters with temperature.

6. A linear relationship between the ultimate tensile stress and the Ludwigson parameters has been established.

7. The influence of nitrogen on the Ludwigson parameters has been explained in terms of the fact that nitrogen favours planar dislocation slip in the austenitic stainless steels.

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