Analysis of deformation induced martensitic transformation in stainless steels

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Many studies monitoring the formation of martensite during the tensile deformation of austenite report data which are, in principle, affected by both the applied stress and the resulting plastic strain. It is not clear in these circumstances whether the transformation is stress induced (i.e. the stress provides a mechanical driving force) or whether the generation of defects during deformation helps nucleate martensite in a scenario better described as strain induced transformation. The authors demonstrate in the present work that a large amount of published data relating the fraction of martensite to plastic strain can in fact be described in terms of the pure thermodynamic effect of applied stress.

Keywords: Austenitic stainless steels, Stress induced transformation, Strain induced transformation, Martensite

Introduction

It is well known that martensitic transformation can be triggered above the martensite start temperature by deformation of the austenite. When the applied stress is below the yield strength of the austenite, the transformation is said to be stress assisted, and the influence of the stress can be described in terms of a mechanical driving force ΔG_{MECH}, which adds to any chemical free energy change due to transformation[1]

$$\Delta G_{\mathrm{MECH}} = \sigma_{\mathrm{N}}\delta + \tau s \qquad (1)$$

where σ_{N} and τ are the normal and shear stresses resolved on the habit plane of martensite, and δ and s are the corresponding dilatational and shear strains accompanying the formation of a plate of martensite.

The applied stress may be sufficiently large to introduce defects such as dislocations and shear bands in the austenite, which then contribute to the nucleation of martensite. Theories for such strain induced transformation are therefore based on the relationship between the number density of nucleating defects as a function of plastic strain in the austenite, for example, Ref. 2. The thermodynamic effect via ΔG_{MECH} is usually not accounted for, or is incorporated using a non-linear nucleation function in order to estimate the rate of transformation.[3–5]

The problem is that, in most experiments, strain induced transformation is studied by applying a sufficiently large stress to the austenite as it transforms. The influence of stress (through ΔG_{MECH}) and strain (via defects) cannot then be isolated. A more controlled experiment would involve the plastic deformation of the austenite at a temperature where martensitic transformation is impossible, followed by the cooling of the austenite which is free from applied stress, to study strain induced martensite. There are few 'prestrain' experiments of this kind.[6,7]

There is increasing evidence that in experiments where deformation induced martensite is studied, the main factor contributing to the formation of martensite is thermodynamic, i.e. a mechanical driving force rather than an enhanced heterogeneous nucleation rate due to defects generated in the austenite. Indeed, the original case for such an interpretation was made in 1982 by Tamura.[8] In more recent work, it has been demonstrated that the crystallographic texture due to martensitic transformation can be predicted for 18/8 austenitic stainless steel tested in tension to a plastic strain of 10%, using the concept of mechanical driving force alone, i.e. assuming stress induced transformation.[9] In the case of plastically deformed transformation induced plasticity assisted steels containing retained austenite, where the transformation is usually said to be strain induced, it has been demonstrated that the same experimental data can be reinterpreted in terms of stress induced martensitic transformation.[10] In a particular study where the austenite in a stainless steel was prestrained and then tested in tension at a temperature where martensite was induced, no evidence could be found to support the role of the prestrain on the kinetics of transformation in the second stage of deformation:[11] the results could in fact be interpreted in terms of the mechanical driving force. Further work on the same alloy supported this conclusion.[12]

There are extensive data on the so called strain induced transformation in austenitic stainless steels where both stress and strain may play a role. The purpose of the present work was to investigate whether these results can be interpreted better in terms of the thermodynamic effect of stress. Such an interpretation

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would be ‘better’ in that it would lead to an easy way of estimating the amount of deformation induced martensite. In contrast, the theory of strain induced transformation requires assumptions, for example, about the dependence of the number density of defects as a function of plastic strain, the nature and potency of the defects.

Method

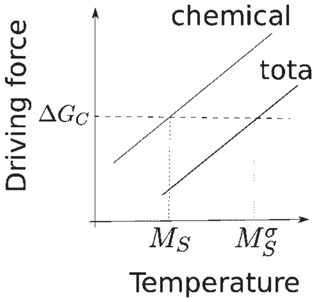
Experimental data were collected from the published literature on strain induced martensitic transformation in a variety of austenitic stainless steels tested in tension.[13–27] The ranges of the various parameters in the dataset are listed in Table 1; the martensite start temperatures M_S in the absence of deformation were in each case calculated as a function of the chemical composition, using an empirical relation published specifically for stainless steels;[28] however, the equation does not include niobium, titanium and cobalt, which therefore had to be neglected in the calculation of the start temperature.

Stress versus plastic strain curves were used to convert strain data in plots of volume fraction of martensite $V^{\alpha'}$ versus plastic strain, into a tensile stress that was then used to estimate the mechanical driving force, which is equal to $-0{\cdot}86$ J mol^{-1} MPa^{-1}.[29] The stress–strain curves were available in the published work on strain induced martensite.[13–27] The total driving force ΔG_T is the sum of the mechanical and chemical terms, where the latter was calculated using the MTDATA thermodynamic software in combination with the TCFE database.[30] Plots of the kind illustrated schematically in Fig. 1 were then used to calculate the stress affected martensite start temperature M_S^σ.

The Koistinen and Marburger equation[31] gives the volume fraction of martensite as a function of undercooling below the martensite start temperature as

$$1 - V^{\alpha'} = \exp\left[-0.011(M_S^\sigma - T_q)\right] \quad \text{provided that} \quad M_S > T_q > -80^\circ\text{C} \tag{2}$$

where M_S^σ has been substituted for M_S to deal with stress induced transformation, and T_q refers to the lowest temperature at which the martensite was generated. It was thus possible to calculate the volume fraction of martensite expected for any steel, applied stress and temperature.



1 Martensite is triggered when free energy change $G^{\alpha'} - G^{\gamma} = \Delta G_C$ (M_S^σ is therefore higher than M_S)

Results and discussion

Thermodynamic analysis

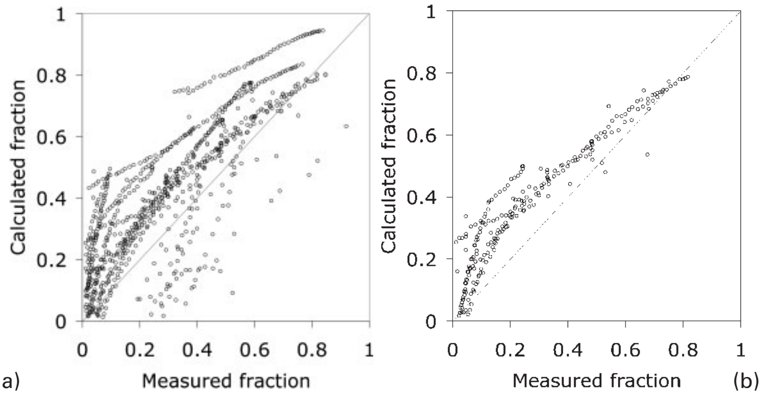
The results are illustrated in Fig. 2*a*; there is some scatter about the line of perfect agreement between the calculated and measured fractions, with a tendency for the calculations to overestimate the amount of martensite for intermediate values of plastic strain. The most accurate data are likely to be those measured using X-ray diffraction, since this is a technique that, unlike magnetic methods, does not require calibration. The results using just X-ray determinations are illustrated in Fig. 2*b*, where the same general trend is visible although with somewhat reduced scatter.

The agreement with theory is best at low ($<0{\cdot}1$) and high ($>0{\cdot}7$) values of strains. It is likely that the early stages of transformation are dominated by stress effects, since the defect density due to plastic strain will then be small. At very large strains, workhardening allows greater stresses to be applied, thus again emphasising the role of stress. As an example, 304L stainless steel workhardens from a true proof strength of ~360 MPa to a true ultimate tensile strength of 1200 MPa (corresponding to engineering stress values of 300 and 755 MPa respectively).[26]

The discrepancy at intermediate strains is interesting. The calculation overestimates the fraction of martensite, whereas if strain adds to the number density of nucleation sites, then one might expect a theory based on the mechanical driving force alone to underestimate the fraction of martensite. Martensite grows by the conservative displacement of a glissile interface. A sufficiently large density of defects in the austenite can hinder the progress of martensitic transformation

Table 1 Range of data obtained from published literature as described in text

	Maximum	Minimum	Mean	Standard deviation
Carbon, wt-%	0·10	0·02	0·06	0·03
Manganese, wt-%	6·46	0·42	1·32	0·43
Chromium, wt-%	18·58	16·19	18·05	0·37
Nickel, wt-%	11·84	4·12	8·17	0·61
Molybdenum, wt-%	2·03	0	0·18	0·17
Nitrogen, wt-%	0·17	0	0·04	0·03
Copper, wt-%	0·46	0	0·18	0·12
Strain rate, s^{-1}	200	0·0001	6·02	33
T_q, °C	100	−80	−1·25	37·7
Grain size, μm	180	5·9	28	22
True stress, MPa	1728	322	949	237
True strain	0·65	0·02	0·30	0·13
M_S, °C	0·2	−175	−79	36
$V^{\alpha'}$	0·92	0·01	0·31	0·22



2 ***a* comparison between measured and calculated martensite fractions for 301, 304L, 304, 305 and 316L stainless steels (experimental techniques used to measure $V^{\alpha'}$ included X-ray diffraction and magnetic methods) and *b* same but only plotting data from X-ray determinations**

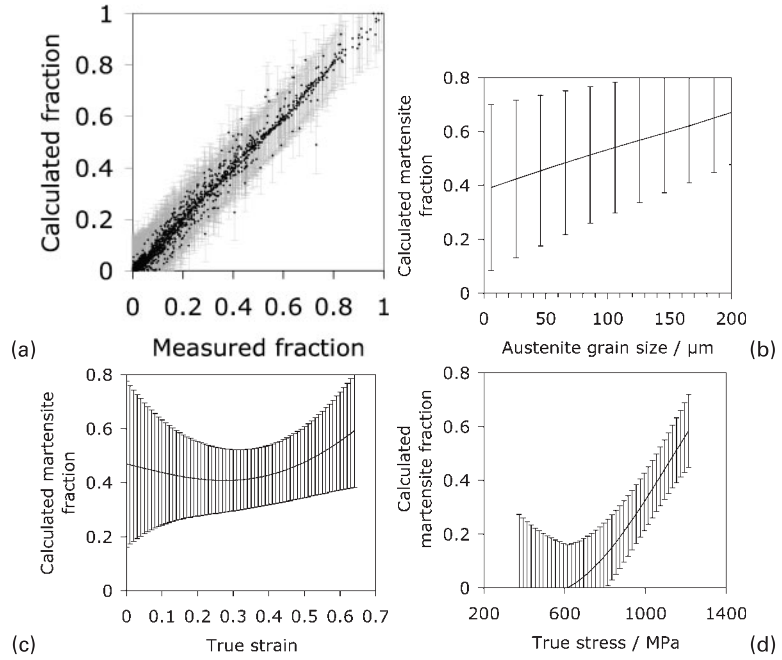
because of mechanical stabilisation.[32–40] If mechanical stabilisation does indeed contribute to the results, then the calculated fraction of martensite will be an overestimate of that obtained in reality, as observed here for intermediate values of strain.

It is possible in some austenitic steels for body centred cubic α' martensite to be preceded by the hexagonal close packed ε-martensite. This path has been neglected here and could, in principle, complicate the interpretation. On the other hand, it has been shown recently that the α' transformation texture in such cases can nevertheless be predicted using variant selection based on the mechanical driving force, without taking into account any intermediate transformation.

Notice that the austenite grain size range listed in Table 1 is likely to have an intrinsic influence on the M_S temperature by about 30°C,[41] which is not accounted for in the estimation of the martensite start temperature. As will be seen later (Fig. 3*b*), given an average austenite grain size of 29 ± 28 μm (Table 1), the error in the predicted fraction of martensite resulting from this neglect would be about $\pm 0{\cdot}09$. Nevertheless, the method based on mechanical free energy, M_S^{σ} and equation (2) permits $V^{\alpha'}$ to be estimated to the accuracy illustrated without the use of any fitting parameters.

Empirical analysis

The entire data were subjected to neural network analysis as another method of deciphering the independent roles of stress and strain in stimulating martensitic transformation when both are applied simultaneously in experiments. The method used here is in a Bayesian framework and has been comprehensively described[42,43] and reviewed[44–46] so it is not introduced here. Suffice it to say that it is the ultimate tool for non-linear regression, and its predictions are associated not only



a illustrating accuracy with which model replicates all of available measured martensite fractions; *b* isolated effect of true plastic strain on calculated fraction of martensite for specific set of inputs; *c* isolated effect of true stress on calculated fraction of martensite for same specific set of inputs

3 Neural network analysis for estimation of stress or strain induced martensite for data listed in Table 2: error bars represent $\pm 1\sigma$ modelling uncertainties

Table 2 Range of data used in empirical analysis*

	Maximum	Minimum	Mean	Standard deviation	Example
Carbon, wt-%	0·10	0·007	0·05	0·03	0·028
Manganese, wt-%	8·92	0·42	1·76	1·61	1·32
Chromium, wt-%	18·58	15·40	17·78	0·68	18·13
Nickel, wt-%	13·53	2·75	8·03	1·59	8·32
Molybdenum, wt-%	2·53	0	0·31	0·53	0·15
Nitrogen, wt-%	0·24	0	0·05	0·05	0·044
Copper, wt-%	0·70	0	0·16	0·15	0·26
Niobium, wt-%	0·11	0	0·006	0·016	0·015
Titanium, wt-%	0·67	0	0·01	0·08	0·01
Cobalt, wt-%	0·20	0	0·04	0·07	0·1
Strain rate, s^{-1}	200	0·0001	6·44	35	$1{\cdot}25\times10^{-4}$
T_q, °C	200	−196	−1·5	67	24
Grain size, μm	200	5·9	29	28	24
True stress, MPa	1951	14	848	283	
True strain	0·65	0·0	0·25	0·14	
$V^{\alpha'}$	1·00	0·00	0·22	0·24	

*The column marked ‘Example’ is a specific case used to generate Fig. 3*b* and *c*.

with an average measure of scatter (reflecting uncontrolled variables) but, more importantly in the present context, also a modelling uncertainty which describes the ambiguity with which different empirical models can express the same data.

The dataset used to create the model was more extensive (~1600 rows)[13–27,47–57] than in the thermodynamic analysis. This is because many of the data do not satisfy the condition listed in equation (2) that $M_S>T_q>-80^\circ C$. Since the calculated martensite start temperature is not used in the neural network model, a much larger set becomes available.

The neural network model was created as a function of all the variables listed in Table 2, with the exception of the volume fraction of martensite, which was its output. Figure 3*a* shows that the model created is able to reasonably estimate the martensite fraction for all the available data.

Figure 3*b* and *c* shows predictions made for a specific 304 stainless steel. The remarkable result is that the role of stress is convincingly revealed, whereas the independent effect of strain is seen to be minor and more uncertain. These results confirm the earlier conclusion that in experiments where martensite is stimulated during a tensile test, it is the mechanical driving force which plays a dominant role rather than strain induced transformation.

Conclusions

It appears that the major part of the variation in martensite fraction during the tensile deformation of austenitic stainless steels can be attributed to the fact that the stress adds to the driving force for martensitic transformation. An empirical analysis of a wide range of data supports the predominant role of stress over plastic strain.

A simple model based on classical theory[1,31] can be used to estimate quantitatively the fraction of martensite as long as the stress versus plastic strain relationship, the M_S temperature and the dependence of chemical free energy on temperature are known. This can be done without using any fitting parameters. The influence of strain rate is implicitly included through its effect on the stress–strain relationship and provided that the temperature is maintained constant during the course of deformation.

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References

1. J. R. Patel and M. Cohen: ‘Criterion for the action of applied stress in the martensitic transformation’, *Acta Metall.*, 1953, **1**, 531–538.
2. G. B. Olson and M. Cohen: ‘Kinetics of strain-induced martensitic transformation’, *Metall. Trans. A*, 1975, **6A**, 791–795.
3. G. B. Olson: ‘Transformation plasticity and the stability of plastic flow’, in ‘Deformation, processing and structure’, 390–424; 1982, Metals Park, OH, American Society for Metals.
4. H. K. D. H. Bhadeshia: ‘An aspect of the nucleation of “burst” martensite in steels’, *J. Mater. Sci.*, 1982, **17**, 383–386.
5. M. Mukherjee, S. B. Singh and O. N. Mohanty: ‘Deformation-induced transformation of retained austenite in transformation induced plasticity-aided steels: a thermodynamic model’, *Metall. Mater. Trans. A*, 2008, **39A**, 2319–2328.
6. J. C. Bokros and E. R. Parker: ‘The mechanism of the martensite burst transformation in Fe–Ni single crystals’, *Acta Metall.*, 1963, **11**, 1291–1301.
7. A. A. Shirzadi, H. Abreu, L. Pocock, D. Klobcar, P. J. Withers and H. K. D. H. Bhadeshia: ‘Bainite orientation in plastically deformed austenite’, *Int. J. Mater. Res.*, 2009, **100**, 40–45.
8. I. Tamura: ‘Deformation induced martensitic transformation and transformation-induced plasticity in steels’, *Met. Sci.*, 1982, **16**, 245–254.
9. S. Kundu and H. K. D. H. Bhadeshia: ‘Transformation texture in deformed stainless steel’, *Scr. Mater.*, 2006, **55**, 779–781.
10. S. Chatterjee and H. K. D. H. Bhadeshia: ‘TRIP-assisted steels: stress or strain-affected martensitic transformation’, *Mater. Sci. Technol.*, 2007, **23**, 1101–1104.
11. E. S. Perdahcioğlu, H. J. M. Geijselaers and M. Groen: ‘Influence of plastic strain on deformation-induced martensitic transformations’, *Scr. Mater.*, 2008, **58**, 947–950.
12. H. J. M. Geijselaers and E. S. Perdahcioglu: ‘Mechanically induced martensitic transformation as a stress-driven process’, *Scr. Mater.*, 2009, **60**, 29–31.
13. T. Angel: ‘Formation of martensite in austenitic stainless steel’, *J. Iron Steel Inst.*, 1954, **181**, 165–174.
14. S. S. Hecker, M. G. Stout, K. P. Staudhammer and J. L. Smith: ‘Effects of strain state and strain rate on deformation-induced transformation in 304 stainless steel. Part I – magnetic measurements and mechanical behaviour’, *Metall. Mater. Trans. A*, 1982, **13A**, 619–626.
15. S. K. Varma, J. Kalyanam, L. E. Murr and V. Srinivas: ‘Effect of grain size on deformation-induced martensite formation in 304 and

316 stainless steels during room temperature tensile testing', *J. Mater. Sci. Lett.*, 1994, **13**, 107–111.

16. A. K. Raj and K. A. Padmanabhan: 'Room-temperature plastic flow and strain-induced martensitic transformation in 1·2 wt-%Ni metastable austenitic stainless steel sheets', *J. Mater. Sci. Lett.*, 1997, **16**, 1920–1924.
17. S. F. Peterson, M. C. Mataya and D. K. Matlock: 'The formability of austenitic stainless steels', *J. Miner. Met. Mater.*, 1997, **49**, 54–58.
18. R. H. Wagoner and J. K. Lee: 'Formability of stainless steel', *Metall. Mater. Trans. A*, 1998, **29A**, 2161–2172.
19. J. Talonen, P. Nenonen, G. Pape and H. Hanninen: 'Effect of strain rate on the strain-induced martensite transformation and mechanical properties of austenitic stainless steels', *Metall. Mater. Trans. A*, 2005, **36A**, 421–432.
20. A. K. De, D. C. Murdock, M. C. Mataya, J. G. Speer and D. Matlock: 'Quantitative measurement of deformation-induced martensite in 304 stainless steel by X-ray diffraction', *Scr. Mater.*, 2004, **12**, 1445–1449.
21. A. K. De, J. G. Speer, D. Matlock, D. C. Murdock, M. C. Mataya and R. J. Comstock, Jr: 'Deformation-induced phase transformation and strain hardening in type 304 austenitic stainless steel', *Metall. Mater. Trans. A*, 2006, **37A**, 1875–1886.
22. J. Talonen: 'Effect of strain-induced α'-martensite transformation on mechanical properties of metastable austenitic stainless steels', PhD thesis, Helsinki University of Technology, Espoo, Finland, 2007.
23. C. Muller-Bollenhagen, M. Zimmermann and H.-J. Christ: 'Very high cycle fatigue behaviour of austenitic stainless steel and the effect of strain-induced martensite', *Int. J. Fatigue*, 2010, **32**, 936–942.
24. P. Hedström: 'Deformation induced martensitic transformation of metastable stainless steel', PhD thesis, Lulea University of Technology, Lulea, Sweden, 2005.
25. L. Zhang, S. Takahashi, Y. Kamada, H. Kikuchi, K. Ara, M. Sato and T. Tsukada: 'Magnetic properties of SUS 304 austenitic stainless steel after tensile deformation at elevated temperatures', *J. Mater. Sci. Lett.*, 2005, **40**, 2709–2711.
26. J. A. Lichtenfeld, M. C. Mataya and C. J. Van Tyne: 'Effect of strain rate on stress–strain behaviour of alloy 309 and 304l austenitic stainless steel', *Metall. Mater. Trans. A*, 2006, **37A**, 147–161.
27. P. Hedstrom, L. E. Lindgren, J. Almer, U. Lienert, J. Bernier, M. Terner and M. Oden: 'Load partitioning and strain-induced martensite formation during tensile loading of a metastable austenitic stainless steel', *Metall. Mater. Trans. A*, 2009, **40A**, 1039–1048.
28. F. B. Pickering: 'Physical metallurgical development of stainless steels', in 'Stainless steels', 2–28; 1985, London, The Institute of Metals.
29. S. Denis, E. Gautier, A. Simon and G. Beck: 'Stress-phase-transformation interactions – basic principles, modelling and calculation of internal stresses', *Mater. Sci. Technol.*, 1985, **1**, 805–814.
30. NPL: MTDATA Software, National Physical Laboratory, Teddington, UK, 2006.
31. D. P. Koistinen and R. E. Marburger: 'A general equation prescribing the extent of the austenite–martensite transformation in pure iron–carbon alloys and plain carbon steels', *Acta Metall.*, 1959, **7**, 59–60.
32. E. S. Machlin and M. Cohen: 'Burst phenomenon in the martensitic transformation', *Trans. Metall. Soc. AIME*, 1951, **191**, 746–754.
33. H. C. Fiedler, B. L. Averbach and M. Cohen: 'The effect of deformation on the martensitic transformation', *Trans. Am. Soc. Met.*, 1955, **47**, 267–290.
34. W. C. Leslie and R. L. Miller: 'The stabilization of austenite by closely spaced boundaries', *ASM Trans. Q.*, 1964, **57**, 972–979.
35. J. R. Strife, M. J. Carr, and G. S. Ansell: 'Effect of austenite prestrain above the M_d temperature on the M_s temperature in Fe–Ni–Cr–C alloys', *Metall. Trans. A*, 1977, **8A**, 1471–1484.
36. K. Tsuzaki, S. Fukasaku, Y. Tomota and T. Maki: 'Effect of prior deformation of austenite on the gamma–epsilon martensitic transformation in Fe–Mn alloys', *Trans. JIM*, 1991, **32**, 222–228.
37. V. Raghavan: 'Kinetics of martensitic transformations', 197–226; 1992, Metals, OH, ASM International.
38. H. K. D. H. Bhadeshia: 'The bainite transformation: Unresolved issues', *Mater. Sci. Eng. A*, 1999, **A273–A275**, 58–66.
39. S. Chatterjee, H. S. Wang, J. R. Yang and H. K. D. H. Bhadeshia: 'Mechanical stabilisation of austenite', *Mater. Sci. Technol.*, 2006, **22**, 641–644.
40. M. Maalekian, E. Kozeschnik, S. Chatterjee and H. K. D. H. Bhadeshia: 'Mechanical stabilisation of eutectoid steel', *Mater. Sci. Technol.*, 2007, **23**, 610–612.
41. H. S. Yang and H. K. D. H. Bhadeshia: 'Austenite grain size and the martensite-start temperature', *Scr. Mater.*, 2009, **60**, 493–495.
42. D. J. C. MacKay: 'Practical Bayesian framework of backpropagation networks', *Neural Comput.*, 1992, **4**, 448–472.
43. D. J. C. MacKay: 'Bayesian interpolation', *Neural Comput.*, 1992, **4**, 415–447.
44. D. J. C. MacKay: 'Bayesian non-linear modelling for the energy prediction competition', *ASHRAE Trans.*, 1994, **100**, 1053–1062.
45. H. K. D. H. Bhadeshia: 'Some phase transformations in steels', *Mater. Sci. Technol.*, 1999, **15**, 22–29.
46. H. K. D. H. Bhadeshia: 'Neural networks and information in materials science', *Stat. Anal. Data Min.*, 2009, **1**, 296–305.
47. V. Seetharaman and R. Krishnan: 'Influence of the martensitic transformation on the deformation behaviour of an AISI 316 stainless steel at low temperatures', *J. Mater. Sci.*, 1981, **16**, 523–530.
48. M. Botshekan, S. Degallaix, Y. Desplanques and J. Polak: 'Tensile and LCF properties of AISI 316LN SS at 300 and 77 K', *Fatigue Fract. Eng. Mater. Struct.*, 1998, **21**, 651–660.
49. A. A. Lebedev and V. V. Kosarchuk: 'Influence of phase transformations on the mechanical properties of austenitic stainless steels', *Int. J. Plast.*, 2000, **16**, 749–767.
50. V. Talyan, R. H. Wagoner and J. K. Lee: 'Formability of stainless steel', *Metall. Mater. Trans. A*, 1998, **29A**, 2161–2172.
51. E. Nagy, V. Mertinger, F. Tranta and J. Solyom: 'Deformation induced martensitic transformation in stainless steels', *Mater. Sci. Eng. A*, 2004, **A378**, 308–313.
52. K. Spencer, J. D. Embury, K. T. Conlon, M. Veron and Y. Brechet: 'Strengthening via the formation of strain-induced martensite in stainless steels', *Mater. Sci. Eng. A*, 2004, **A387**–A**389**, 873–881.
53. H. N. Han, C. G. Lee, C.-S. Oh, T.-H. Lee and S.-J. Kim: 'A model for deformation behaviour and mechanically induced martensitic transformation of metastable austenitic steel', *Acta Mater.*, 2004, **52**, 5203–5214.
54. X. Chen, Y. Wang, M. Gong and Y. Xia: 'Dynamic behavior of SUS304 stainless steel at elevated temperatures', *J. Mater. Sci.*, 2004, **39**, 4869–4875.
55. B. Petit, N. Gey, M. Cherkaoui, B. Bolle and M. Humbert: 'Deformation behavior and microstructure/texture evolution of an annealed 304 AISI stainless steel sheet', *Int. J. Plast.*, 2007, **23**, 323–341.
56. V. Mertinger, E. Nagy, F. Tranta and J. Solyom: 'Strain-induced martensitic transformation in textured austenitic stainless steels', *Mater. Sci. Eng. A*, 2008, **A481–A482**, 718–722.
57. S. Nanga, A. Pineau, B. Tanguy and P.-O. Santacreu: 'Strain induced martensitic transformations in two austenitic stainless steels: macro–micro behaviour', Proc. 17th Eur. Conf. on 'Fracture', (ed. J. Pokluda and P. Lucaš); 2008, Brno, Brno University of Technology.