Journal of Scientific Research & Reports
5(7): 517-523, 2015; Article no.JSRR.2015.118
ISSN: 2320-0227

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Effect of Plastic Strain on Anisotropic Behaviour of AISI202

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Authors' contributions

This work was carried out in collaboration between all authors. Author VG designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author PKT managed the literature searches, contributed in manuscript writing, analyses of the study and performed the experimental analysis and author RS managed the spectroscopy process. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2015/14466
Editor(s):
(1) Ming-Jyh Chern, Department of Mechanical Engineering, National Taiwan University of Science and Technology, Taiwan.
(2) Luigi Rodino, Dipartimento di Matematica, Università di Torino, Italy.
Reviewers:
(1) D.M. Neto, Department of Mechanical Engineering, University of Coimbra, Portugal.
(2) Fariborz Forouhandeh, Department of Engineering, Islamic Azad university, Iran.
(3) Anonymous, Japan.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=753&id=22&aid=7829

Original Research Article

Received 30th September 2014
Accepted 24th December 2014
Published 21st January 2015

ABSTRACT

Aims: In the present study an attempt has been made to determine the effect of plastic strain on the anisotropic parameters of AISI202 series.
Study Design: The parameter commonly used to characterize the anisotropy of sheet metal is the plastic strain ratio i.e. the ratio of true width-strain to thickness-strain. Accurate determination of plastic strain ratio is difficult as it is influenced by percentage elongation given to the specimen during uniaxial tension test. Moreover, AISI202 shows approximately 60% of uniform strain during tension test and no necking is observed at all, which adds to the problem in accurate determination of anisotropic parameter.
Place and Duration of Study: Samples were tested at Plasticity and Metal Forming Laboratory, Department of Mechanical Engineering, Delhi Technological University (DTU), New Delhi, between January 2014 and April 2014.
Methodology: Tensile specimens were laser cut from 0.8mm thick sheet in the direction of 0°, 45° and 90° with respect to rolling direction. To determine the effect of percentage elongation, the

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specimens were tested in tension by giving 15%, 20%, 30% and 35% of plastic strain much before fracture occurs.
Results: Experimental results showed that as the plastic strain increased from 15% to a maximum of 35% during tension test, the average plastic strain ratio increased from 0.988 to 1.122 respectively, and the same trend is seen in the values of planar anisotropy which varies between a minimum of 0.025 and maximum of 0.149. The equivalent plastic strain during deep drawing can be as high as 40%; therefore anisotropic behavior at 35% of plastic strain is more accurate and significant to be used in simulations.
Conclusion: The experimental studies showed increase in plastic strain ratio on increase in the percentage elongation.

Keywords: Anisotropy; plastic strain; rolling direction; uniaxial tension test.

1. INTRODUCTION

Austenitic stainless steels are characterized with excellent formability and high corrosion resistance, although nickel as austenitic stabilizer is most commonly used to produce austenitic steels. Stainless steels with a low nickel and high nitrogen and chromium content are classified as 200 series and are considered a substitute for 300 series stainless steels. Lowering the content of nickel makes this steel more economical for corrosion resistant deep -drawn products. From low end applications like cooking utensils and non structural architecture, to very sophisticated ones, such as in space vehicles, the use of austenitic stainless steel is indispensable [1]. In particular, the stainless steel 200 series is widely used for utensil manufacturing in India since early 1960's running into a production statistics of 200000 MT in 1988 to 600000 MT in 1999 [2]. This industrial sector holds a vital importance in Indian context as it provides direct and indirect employment to about 350000 personnel across the country. Cold rolled sheet metals may possess high anisotropy as a consequence of crystallographic texture during rolling process. Greatest improvement in drawability can be achieved by close control of crystallographic texture in the sheet metal [3]. Anisotropy can be defined as planar and normal, but normal anisotropy parameter 'R' is frequently used to determine the thinning resistance during deep drawing operation whereas, planar anisotropy (ΔR) suggests earring tendency in sheet metal. Higher normal anisotropy offers excellent deep drawability with high thinning resistance [4].

With the advent of computer aided engineering (CAE) in the field of sheet metal forming, R value is very important for accurate prediction of failure due to thinning during simulations in sheet metal forming operations. Many authors have contributed in the field of sheet metal forming to predict failure with the help of numerical simulations and have elaborated the effect of both normal and planar anisotropy [5-7].

Huh et al. [8] investigated the effect of the strain rate on plastic anisotropy at given range of strain rates. It is evident that strain rate has a distinct effect both on the shape and magnitude of the yield surface and the plastic anisotropy tends to diminish at a higher strain rate.

Srbislav et al. [9] has experimentally shown the significant variation of 'R' value in aluminium alloy and stainless steel sheet metals, during forming process and suggested the need of accurate determination of plastic strain during forming process.

In view of the above studies, an experimental attempt has been made in the present study to determine the effect of percentage elongation on normal and planar anisotropy parameters, especially for austenitic stainless steel sheets (AISI202).

2. MATERIALS AND METHODS

The selection of material is based on popularity of 200 series austenitic stainless steels in structural and non structural applications. The studied material is an austenitic stainless steel of AISI 202 type. The chemical composition was obtained by spectro - analysis and is shown in Table 1. The material was procured as cold rolled close annealed state, in the dimension of 500 mm × 500 mm and thickness 0.82 mm in an annealed state.

The AISI202 steel is characterised with very high uniform elongation of the order of approximately 60% and high strain hardening coefficient suggesting excellent deep drawability. It is observed that this steel suffers neck-free elongation in uniaxial tension test adding difficulty in determining the threshold plastic strain for accurate determination of anisotropic parameter. Although, standard ASTM E517 [10] recommends a plastic strain of 15% only during uniaxial tension test for determination of plastic strain ratio.

Tensile specimens as per ASTM-E8M, were laser cut from 0.82 mm thick sheet in the direction of 0º, 45º and 90º with respect to the rolling. To determine the effect of percentage elongation, the specimens were tested in tension by giving 15%, 20%, 30% and 35% of plastic strain much before the occurrence of fracture.

3. EXPERIMENTAL DETAILS

Typical tensile tests were carried out on a universal testing machine (Make; Tinius Olsen, model H50KS) of maximum capacity 5 tonne. Each test was performed at least three times to ensure good reproducibility of the experiments. The tests were carried out at a cross head speed of 5 mm/min. Typical engineering stress strain curve was plotted on the basis of force and displacement data acquired from the dedicated software.

To avoid constraints from the grips, the plastic strains were measured at five equidistant points marked on a gauge section of 50 mm in the mid section of the tensile specimen as shown in Fig. 1.

Anisotropy is present not only in the plane of the sheet but also in its thickness direction. The former is called planar anisotropy and the latter is called normal anisotropy. Plastic-strain ratio is a measure of anisotropy in thickness direction in sheet metals and is defined as the ratio of width strain (ϵ_w) to thickness strain (ϵ_t) i.e. $R = (\epsilon w/ \epsilon t)$. In order to obtain the average value of plastic strain ratio '$\bar{R}$', value is measured parallel

Table 1. Chemical composition of AISI 202 stainless steel

Element	C	Si	Mn	Cr	Ni	Mo	Cu
% by wt.	0.07	0.35	9.44	12.73	0.34	0.055	1.55

Fig. 1. Tensile tested specimens for determination of plastic strain ratio

(R_0), transverse (R_{90}) and at 45° to the rolling direction (R_{45}) and normal anisotropy is determined.

Normal anisotropy or average plastic strain ratio is given by the equation:

$$\bar{R} = \left(\frac{R_0+2R_{45}+R_{90}}{4}\right) \quad (1)$$

The *planar anisotropy* denoted by ΔR is measured in the plane of the sheet and is given by the equation:

$$\Delta R = \left(\frac{R_0-2R_{45}+R_{90}}{2}\right) \quad (2)$$

4. RESULTS AND DISCUSSION

To determine the variation in tensile properties, the tensile tests were performed on the specimens laser cut from sheet metal at different orientations with respect to rolling direction. The variations of tensile properties i.e. yield strength, Ultimate tensile strength and percentage elongation, are shown in Fig. 2. The yield strength i.e. onset of permanent deformation, was obtained by using 0.2% offset method and is approximately 378 MPa on an average basis. Tested tensile specimen oriented at 0° to the rolling direction, shown minimum yield strength of approximately 300 MPa, while the specimen oriented at 90º to the rolling direction depicts 385 MPa of yield strength. The variation in the tensile properties may be attributed to the anisotropic behaviour of stainless steel sheets. Ultimate tensile strength was determined by maximum load and original cross-section area of the specimen and is found to be in the order of 1000 MPa.

Similar trend was observed in true stress- true strain curves as shown in Fig. 3. The variation in tensile properties and neck-free elongation in stainless steel specimens tested in three different directions with respect to the rolling direction. Highest strength was observed in the specimen orientated at 90º to the rolling direction followed by specimens oriented at 45º and 0º to rolling direction, respectively. However, maximum elongation was achieved in the specimen oriented at 45º to the rolling direction and minimum elongation in specimen orientation of 0° to the rolling direction, depicting the anisotropic behaviour of AISI202.

The results of experimental studies are shown in Table 2. It is observed that as the plastic strain increases from 15% to a maximum of 35% during tension test, the average plastic strain ratio increases from 0.988 to 1.122 respectively and the same trend is seen in the values of planar anisotropy which varies between a minimum of 0.025 and maximum of 0.149.

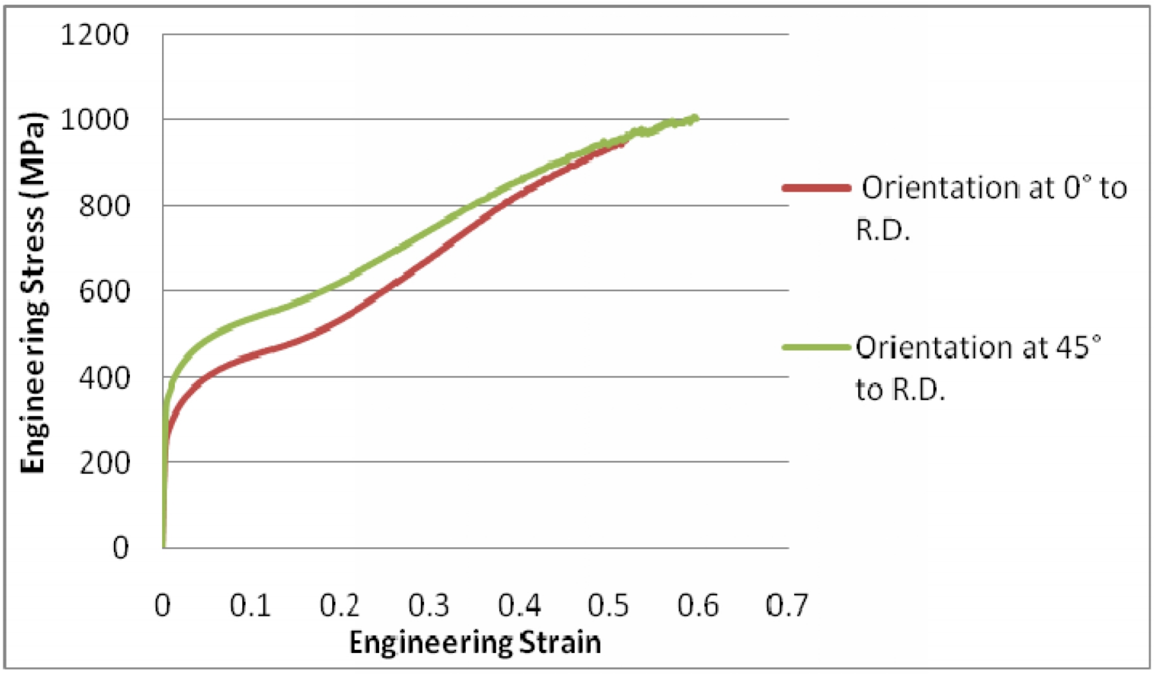

Fig. 2. Engineering stress -strain curve showing tensile properties with respect to rolling direction (R. D.)

The equivalent plastic strain during deep drawing can be as high as 40%, therefore anisotropic behaviour at 35% of plastic strain is more accurate and significant to be used in simulations.

It is illustrated in the Fig. 4 that in each tensile test, highest plastic strain is observed in specimen orientated at 90º to rolling direction followed by orientations of 0º and 45º respectively.

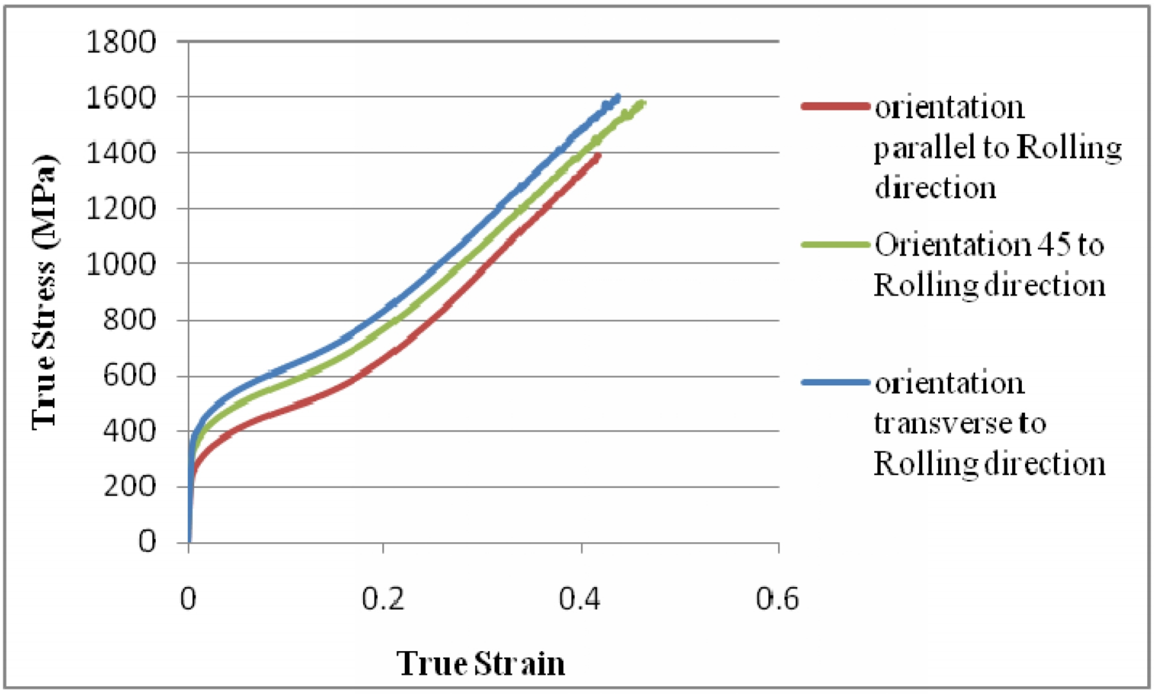

Fig. 3. True stress -strain curve depicting variation in tensile properties with respect to rolling direction

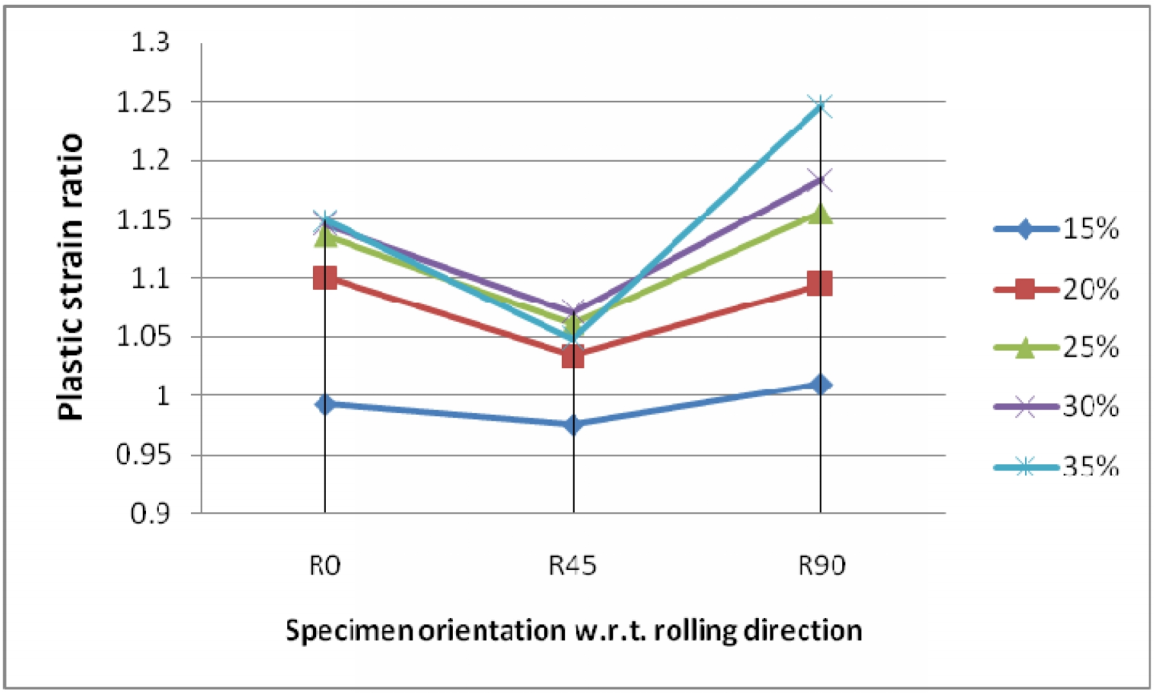

Fig. 4. Variation of plastic strain ratio with respect to rolling direction

Table 2. Measured normal and planar anisotropy

Plastic strain	Specimen orientation to rolling direction	Initial gauge length (mm)	Final gauge length (mm)	Initial average width (mm)	Final average width (mm)	Plastic strain ratio (R)	Normal anisotropy $\bar{R}$	Planar anisotropy ΔR
	0°	49.53	52.86	12.60	12.20	0.992		
15%	45°	50.21	53.94	12.54	12.10	0.975	0.988	0.025
	90°	50.11	53.46	12.50	12.10	1.010		
	0°	50.20	54.95	12.36	11.79	1.101		
20%	45°	50.31	54.82	12.31	11.79	1.034	1.066	0.063
	90°	50.32	54.72	12.32	11.79	1.094		
	0°	49.71	55.47	12.60	11.89	1.136		
25%	45°	49.72	55.94	12.46	11.73	1.061	1.103	0.084
	90°	49.81	55.91	12.55	11.80	1.155		
	0°	50.15	57.46	12.53	11.65	1.145		
30%	45°	49.92	57.43	12.47	11.60	1.070	1.117	0.094
	90°	49.92	56.96	12.60	11.73	1.183		
	0°	50.32	58.24	12.66	11.72	1.149		
35%	45°	50.10	59.10	12.43	11.43	1.047	1.122	0.149
	90°	50.31	59.10	12.53	11.43	1.246		

5. CONCLUSION

The following conclusions can be drawn from the present experimental studies:

1. The yield strength of AISI202 was obtained by using 0.2% offset method and is approximately 378 MPa on an average basis. Ultimate tensile strength was determined by maximum load and original cross section area of the specimen and is found to be in the order of 1000 MPa on an average.
2. All the tensile specimens showed neck free uniform elongation of approximately 59.6% resulting in abrupt fracture at the end of the tensile test.
3. Planar anisotropy increases with increase in plastic strain depicting the earing tendency in AISI202.
4. Normal anisotropy increases with increase in plastic strain suggesting deep drawability of tested material, although the increase is nominal but accurate.
5. Highest plastic strain is observed in specimen orientation at 90º to rolling direction followed by orientations of 0º and 45º respectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=753&id=22&aid=7829