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K.-Y. Kim, K. Kozaczek, S. M. Kulkarni, P. C. Bastías, and G. T. Hahn

Mechanical Engineering Department
P. O. Box 1592, Station B
Nashville, Tennessee, 37235
USA

MASTER

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K.-Y. Kim[1], K. Kozaczek[2], S. M. Kulkarni[3], P. C. Bastias[4], and G. T. Hahn[4]

Abstract

The evolution of texture in thin sheets of metastable austenitic stainless steel AISI 301 is affected by external conditions such as loading rate and temperature, by inhomogeneous deformation phenomena such as twinning and shear band formation, and by the concurrent strain induced phase transformation of the retained austenite (γ) into martensite (α'). The present paper describes texture measurements on different gauges of AISI 301 prior and after uniaxial stretching under different conditions.

Introduction

The texture evolution observed during deformation of FCC metals has been explained in different terms: a) The primary and conjugate slip systems, {111}<110>, are said to reach a stable copper-type texture, {112}<111>, for small plastic deformations, or a brass type alignment, {110}<112>, for larger deformation [1-3], b) Several textures coexist after small plastic deformations, {112}<111>, {110}<112> and {123}<634> [4]. Further deformation activates the twinning mechanisms and thus the copper component is transformed into the {552}<115> related component, which further rotates towards the {110}<001> [5-7], and finally {110}<112> [5]. Decreasing the stacking fault energy via alloying shifts the onset of twinning towards the lower deformation levels [8].

The characteristics of the strain induced martensitic transformation are conditioned by the parent phase [9]. However, the texture of the martensite cannot be predicted from the texture of the austenite by accounting for the variants alone. These different variants, which are determined from crystallographic relationships between austenite and martensite, i.e. Kurdjumov-Sachs [10], Nishiyama-Wasserman [11,12] and Bain [13], appear with different frequency and are affected by stress and temperature fields [14,15].

The present paper describes a systematic study conducted to ascertain the correlation between loading rate and temperature, and the martensitic transformation, and the texture evolution of both parent austenite and martensite.

Experimental Procedure

The texture measurements were conducted on metastable austenitic stainless steel AISI 301 with the following composition in wt.%: C - 0.06, Mn - 1.19, Si - 0.32, Cr - 17.3, Ni - 7.4, Mo - 0.36, Cu - 0.48, Co - 0.1, P < 0.03, S < 0.001, Fe - bal.

The material had been subjected to the following type of operations: (a) the 190 mm slab was heated to approximately 1177 °C, (b) hot rolled by a tandem milling to 25.4 mm, followed by water quenching, c) normalized, d) cold rolled to final thickness and pickled (1.29-1.51 mm), e) further cold rolling by 30-35% to the "3/4-hard" condition (0.94-1.13 mm). No transverse rolling was used.

Tensile specimens with a gage width of 7.0 mm were wire-electro-discharge machined from the plates with three orientations: parallel, transverse and at 45° w.r.t. the rolling direction. The specimens were then tested in uniaxial tension at four different temperatures: T = -40, 23, 100 and 400 °C, and at three different strain rates, $\dot{\varepsilon}^p$ = 1×10^{-4}, 1.0 and 1×10^{2} sec^{-1}. The total elongation varied between 6-30% for the 3/4 hard material and between 23-53% for the annealed material.

[1] Posco Steels, Pohan, South Korea.

[2] High Temperature Materials Laboratory, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6064, USA.

[3] TRW Vehicle Safety Systems, Mesa, AZ, 85215, USA.

[4] Mechanical Engineering Department, Vanderbilt University, Nashville, TN 37235, USA.

Texture measurements were carried out in the region 1-8 mm from the necked region in order to test the uniformly strained material and to contain the x-ray beam on the sample for high tilts. A highly colimated (less than 0.1° divergence) X-ray beam 1 mm in diameter of Cr K_α radiation was used for the measurements.

Initial measurements indicated substantial differences between the textures at the surface and in the bulk. The specimens were then thinned to half their thickness by electropolishing using the following electrolyte: 50% H_3PO_4, 25% H_2SO_4 and 25% H_2O.

Pole figures for both austenite and martensite were measured for three different reflections: a) 2θ = 67.12, 79.29 and 128.79° which correspond to the {111}, {200} and {220} families in the austenite, and b) 2θ = 68.71, 105.68, and 154.5° which correspond to the {110}, {200} and {211} families in the martensite. The pole figures were measured using the Schultz back reflection technique in the tilt range 0-80°, and corrected for absorption, defocussing and background radiation.

The following operations were conducted on the raw data: a) a rotation was applied to correct small misalignments of the specimen on the goniometer, b) the data was smoothed using a 2.5° breadth Gaussian filter, c) a self consistent harmonic analysis was used to normalize the data, d) a WIMV analysis [16] was conducted to determine the orientation distributions, e) the inverse pole figure was calculated. All these operations were conducted using the program *popLA* [16] implemented in a PC. The pole figures were analyzed with the aid of Diffract II [17]

Results

The deformation textures observed in each phase, i.e. austenite and martensite, after deformation under different conditions of loading rate, temperature and orientation are presented in Tables I and II for the process annealed and of the 3/4 hard material respectively.

The austenitic phase shows that the most pronounced texture is of the {110}<111> type regardless of the conditions under which the specimen was deformed. This is evident in Figures 1 and 2, which show the inverse pole figures for the austenitic phase in a process annealed specimen deformed at $\dot{\varepsilon}^p$ = 10^2 and for T = -40 and 400 °C respectively.

Annealed specimens deformed at higher strain rates show similar textures when tested over a temperature ranging from -40 to 400 °C. There is strong evidence of a {110}<111> type texture, and of a weaker, twinning related, {110}<001>, Goss-type texture.

Table I Prevalent Deformation Textures of Annealed Material

Mater.	$\dot{\varepsilon}^p$ (sec^{-1})	Temp. (°C)	Orient.	γ Textures	α' Textures
Annealed	10^{-3}	-40	RD	{112}<111> {110}<111> {123}<634} {120}<001> <111> wire	{122}<210> {115}<110>
"	10^2	"	"	{110}<111> {110}<001>	{123}<301> {122}<210>
"	10^{-3}	25	"	{110}<111> {110}<001>	{112}<110> {122}<210> {123}<301>
"	10^2	"	"	{110}<111> {130}<311>	{115}<110> {123}<301> {122}<210>
"	10^2	"	45°	{110}<111> {110}<221>	{112}<111>
"	"	"	TD	{110}<111> {110}<001>	{112}<201> {332}<113> {123}<301> {113}<301> {115}<110>
"	"	100	RD	{123}<634> {110}<111> <111> wire	{130}<310> {122}<210> {113}<301>
"	"	400	"	{110}<111> {123}<634>	No Pattern (*)
"	"	"	45°	{110}<111> {110}<001>	"
"	10^{-3}	"	TD	{110}<111> {135}<501>	"
"	10^2	"	"	{110}<111> {110}<001>	"

(*) The amount of transformed martensite was too small to provide for a meaningful diffraction pattern.

The textures are shaper for the specimens deformed at lower temperatures, which generally displayed larger total elongations. The specimens deformed at higher temperatures show a spread toward {110}<112>, {110}<113> and {110}<115>.

The orientation of the specimen relative to the rolling direction does not play any role in determining the final crystallographic texture. The undeformed annealed material had almost random texture; the 3/4 hard material showed a relatively weak rolling texture of the {110}<111> type, approximately 2-3 times less sharp than the textures observed after tensile testing. The fact that the final texture does not depend on the initial texture suggests that during the large plastic deformation the weak original texture is destroyed. This is confirmed by the remarkably isotropic mechanical properties [18]

The most prominent strain induced martensite textures are {122}<210> and {123}<301>. They are seemingly not influenced by the prior degree of cold rolling. The orientation of the loading axis w.r.t. to the rolling direction seems to have a weak influence on the texture of the martensite, which shows a component close to a {112}<111> in the case of samples oriented 45° and 90° w.r.t. R.D.

Table II Prevalent Deformation Textures of 3/4 Hard Material

Mater.	$\dot{\epsilon}$ (sec^{-1})	Temp. (°C)	Orient.	γ Textures	α' Textures
3/4 Hard	10^{-3}	-40	RD	{110}<111> {123}<634> {112}<111}	{332}<113> {112}<201> {123}<301> {115}<110>
"	10^{3}	"	"	{110}<111> {123}<634>	{115}<110> {122}<210> {123}<301>
"	10^{3}	25	"	{110}<111> {123}<634>	{115}<110> {113}<301> {122}<210>
"	10^{-3}	400	"	{110}<111>	No Pattern
"	10^{3}	"	"	{110}<111>	"

Discussion

The current experimental results indicate that the {110}<111> texture pattern seems to be an inherent feature of the austenite deformed by rolling or by uniaxial stretching under diverse conditions. This is expected for a material with low stacking fault energy, i.e. $\gamma_{SF} = 11$ mJ/m^2.

In the case of AISI 316L stainless steel [19], a low stacking fault material, which develops a {110}<112> preferential texture, profuse mechanical twinning has been observed in all the grains after a 40% reduction by cold work, and even at lower strains in tension, compression or cyclic loading. This suggests that a low stacking fault energy and twinning may play a role in the formation of the similar {110}<111> texture in AISI 301.

The development of the {110}<001> Goss component (which is nearly a twin orientation to copper type {112}<111> texture) has to be considered as an intermediate stage towards the evolution of the stable {110}<112> texture in AISI 301[20].

An exception to this result was found in specimens deformed quasistatically at -40 °C; this specimen displays a pronounced {112}<111> copper type texture. This is contrary to earlier observations which predict a transition from a {112}<111> copper type to a {110}<112> brass type texture as the temperature is decreased. The absence of the brass component may be related to the active, strain induced martensite formation which is accompanied by a steep work hardening.

The texture of the martensitic phase is related to the texture of the austenite. The inverse pole figures obtained from the present measurements indicate that the orientation of the martensite is not limited to one favorable direction but that it rather spreads towards BCC slip planes, e.g. {123} and {112}. Evaluation of the angular relationships between the γ and α' textures reveals that they are related by the Nishiyama -Wasserman condition, which accurately predicts both the planar and directional relationship under varied loading conditions. In other words, the texture of the strain induced martensite of the AISI 301 stainless steel sattisfies the shear-induced mutual orientation relations.

Several specimens of annealed material deformed quasistatically at room temperature display a strain induced martensite texture {112}<110>, that is identical to that observed in athermal martensite texture [21,22]. This indicates that both the athermal and the strain induced martensite can have a similar evolution of texture but only under specific deformation conditions. However, as indicated by Grewen and Wasserman [21] the texture in the strain induced martensite does not have all the possible orientations (variants).

Conclussions

Studies of texture evolution in uniaxially deformed AISI 301 stainless steel showed that:

1) The low stacking fault AISI 301 stainless steel develops, under diverse deformation conditions, a pronounced {110}<111> texture in the austenitic phase.

2) There is evidence of a transition of the austenite

texture from {110}<111> to {110}<112>, brass type, {110}<113> and {123}<634>, S type, as the stacking fault energy increases with temperature from 25 to 400 °C.

3) The orientation of the loading axis w.r.t. the rolling direction does not seem to influence the evolution of texture of the austenite showing that the initial weak texture is destroyed during deformation. The following textures: {123}<634>, {112}<111> and {135}<501> are distinguishable in specimens deformed along, at 45° and transversal to the rolling direction.

4) There is no significant effect of the prior cold work on the final, stable, austenitic texture. Process annealed specimens show evidence of an intermediate {110}<001> Goss type texture component. The cold worked 3/4 hard specimens show mainly the {110}<111> texture.

5) The strain induced martensite shows {122}<210>, {112}<uvw>, and {123}<301> textures.

6) The evolution of the martensite texture is not affected by the prior cold work.

7) The texture of the martensite is affected by the orientation of the loading axis; the specimens oriented at 45° and transverse to the rolling direction show evidence of {112}<111> in addition to the expected {122}<210> and {123}<301>

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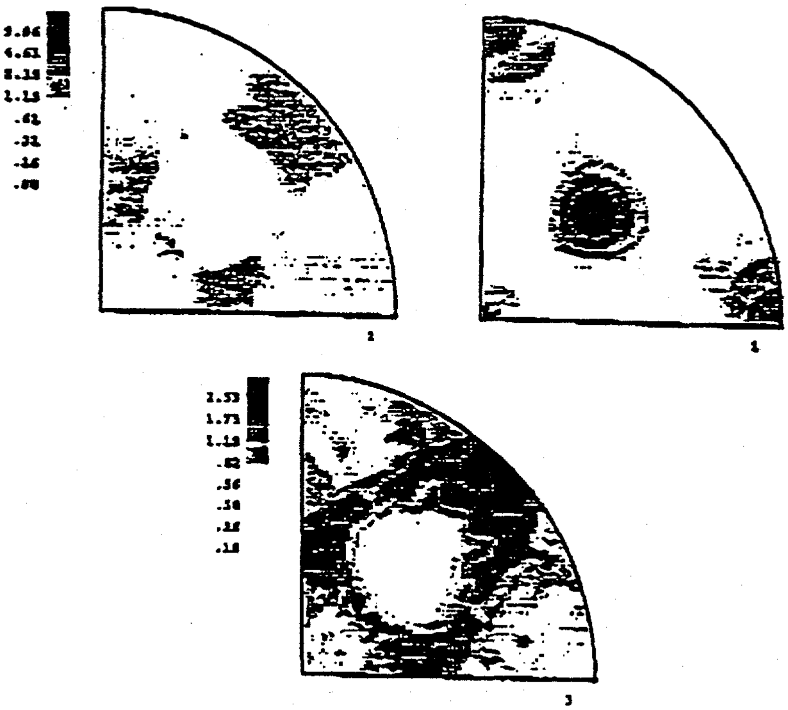

Figure 1 Inverse pole figure for the austenitic phase in an annealed specimen deformed at moderate strain rates and at -40 °C. Specimen machine d parallel to the rolling direction. 1 - roll.dir., 2 - transv. dir., and 3 - normal to the plate. (Stereographic projection)

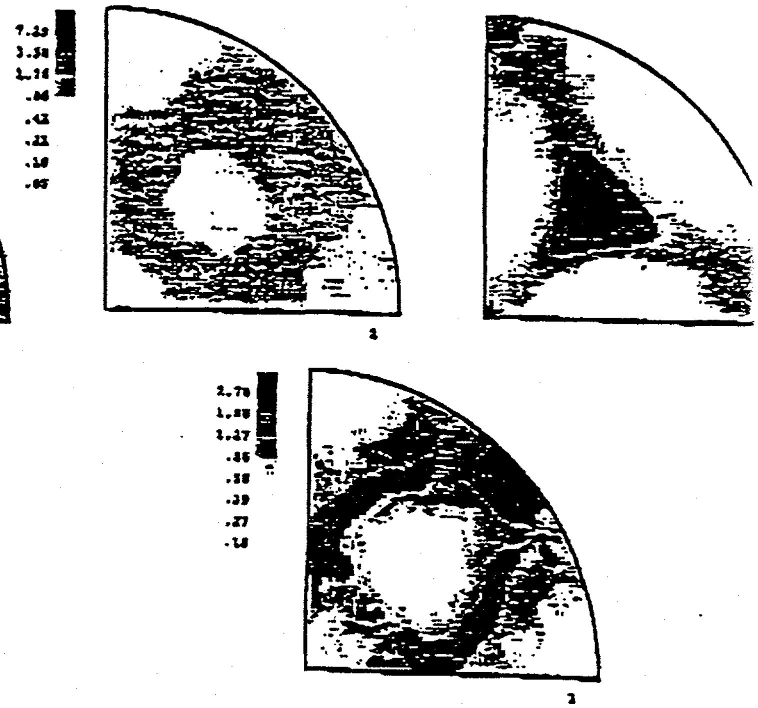

Figure 2 Inverse pole figure for the austenitic phase in an annealed specimen deformed at moderate strain rates and at 400 °C. Specimen machine d parallel to the rolling direction. 1 - roll.dir., 2 - transv. dir., and 3 - normal to the plate. (Stereographic projection)