ORIENTED NUCLEATION IN THE REVERSE TRANSFORMATION
OF Fe-30 Ni

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Abstract: Reverse transformation of different
martensite textures has been investigated. Start-
ing with austenite the martensite was produced by
rolling, deep cooling, or by a combined treatment.
In most cases, during the reverse transformation
the reconstitution of the original austenite tex-
ture occurred. This is explained by oriented
nucleation of residual austenite during reverse
transformation.

Reconstitution of the original austenite orienta-
tion in the transformation cycle austenite-martensite-
austenite is a frequently observed process in alloys of
iron with 30 wt.% Ni. On cooling to low temperatures,
austenitic single crystals yield 12 different martensite
orientations which can be derived from the orientation
of the austenite with the aid of the Nishiyama orienta-
tion relationship.[1,2] After the reverse transformation
they again become single crystals with the same orienta-
tion as in the initial state.[2] Polycrystalline sheets
with the cube texture also revert to the cube orienta-
tion after a transformation cycle[3,4]; and the reversion
to the original austenite orientation is observed in
wires[5-7] and sheets with orientations differing from
the cube texture,[8] even when plastic deformation had oc-
curred between the forward and reverse transformations
leading to individual deformation textures in each of the
two phases.[6,7] The reconstitution of the original austen-
ite texture, the few exceptions to which are based on elec-
tron microscopic observations,[9] has been explained in terms

of nucleation by retained austenite.[6,7] Since this inter-
pretation is disputed, the reverse transformation of
various martensite textures has been reinvestigated.

PROCEDURE

The iron-nickel sheet under investigation (30.28
wt.% Ni, 0.02 wt.% C, 0.02 wt.% Cr, remainder Fe) was
hot-rolled to 10 mm, and cold-rolled to 0.7 mm (as re-
ceived). According to magnetic measurements of the re-
tained austenite, and x-ray determination by Debye-
Scherrer photographs, the as-received material contained
almost 50% strain induced martensite. The cube texture
was produced by a 3-hour vacuum anneal at 1000°C. All
other anneals were carried out in salt baths for 5 min.
On deformation, the material is converted to about
60% deformed martensite; and it transforms almost com-
pletely to martensite when cooled in liquid nitrogen.
Speciments in the as-received (deformed) and then cooled
condition, contain somewhat more retained austenite than
cooled cube-textured specimens. For microscopic examina-
tions, the specimens were etched with a reagent[10] which
permits the differentiation of austenite from martensite
based on their color contrast.
The determination of the pole figures in the back
reflection and transmission regions was undertaken with
an automatic texture-determination device.[11] The re-
sults are quantitative with the exception of the {111}
pole figure of the cube texture. The intensity is ex-
pressed in the calculated units of random orientation.

EXPERIMENTAL RESULTS

Textures

Starting material. The austenite of the deformed
sheet has the normal copper-type rolling texture. Figure
1 shows the texture of the strain induced martensite
which develops during the rolling process. Whereas this
texture shows the normal orientation spread of the roll-
ing texture of b.c.c. iron, its maxima are not in accord-
ance with the b.c.c. rolling texture, but correspond only
to the orientation (112)[$\bar{1}$10].
Annealing the as-received sheets at 500°C leads to
the disappearance of the martensite. It does not,
however, change the austenite texture, and is therefore
the first example of reversion to the austenite texture
in an alpha→gamma reverse transformation. At tempera-
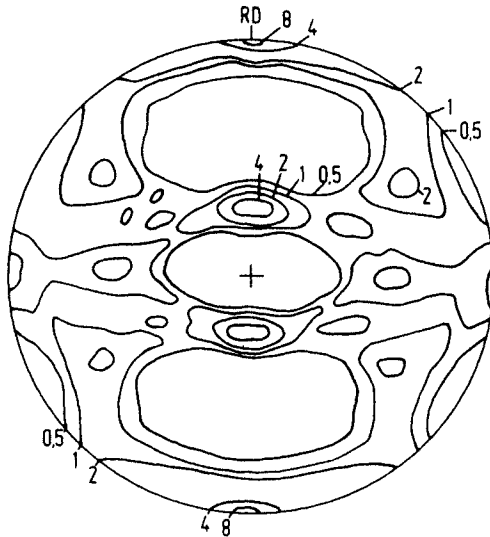tures above 600°C a very sharp cube texture is produced.[4]

FIGURE 1. {110} pole figure of strain induced
martensite in the as-received material.

Cooling of copper-type rolling texture to low tem-
peratures. If an annealed (500°C) sample of the start-
ing material is cooled to low temperatures, the alpha
texture in Figure 2 results. The remarkable feature of
this texture is that the {110} poles in the plane
ND-RD are at the same position as two {111} poles of the
austenite texture. On reverse transformation at 500°C
the initial texture is reconstituted. Furthermore, at
temperatures above 600°C a cube texture is produced,
which is as sharp as that produced by annealing the
starting material (Figure 3).
     Rolling and cooling of cube texture. If a sheet with
the cube texture is rolled, which was possible to a degree
of 87%, the austenite texture illustrated in Figure 4 is
formed, whilst the martensite produced by the deformation
assumes the texture shown in Figure 5. Reverse transform-
ation leads to an austenite texture scarcely different
from the initial texture (deformed cube texture) as shown
in Figure 6. Perfect coincidence of the two textures can-
not be expected inasmuch as different textures could not
be investigated on the same specimen. If cooling to low
temperatures is interposed between the deformation and the
reverse transformation (Figure 7), reverse transformation
again yields a texture similar to Figure 6. The texture
of the strain induced martensite is, however, slightly
altered by the cooling and the associated transformation
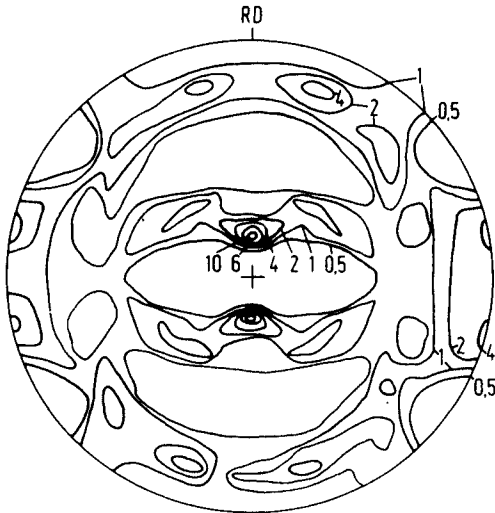of the retained austenite (Figure 7).

FIGURE 2.   {110} pole figure of the martensite
formed by deep cooling the annealed (at 500°C)
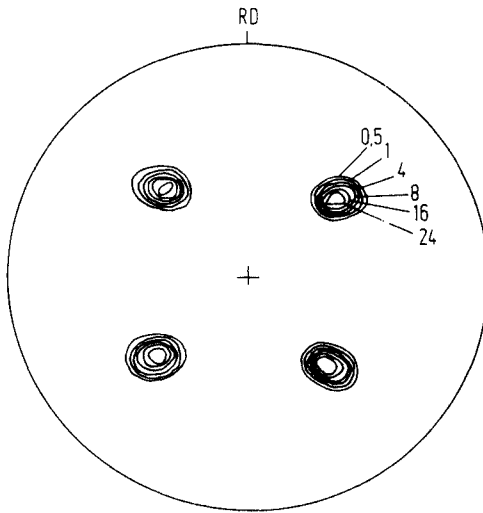austenite with the copper-type rolling texture.

FIGURE 3.   {111} pole figure showing the cube tex-
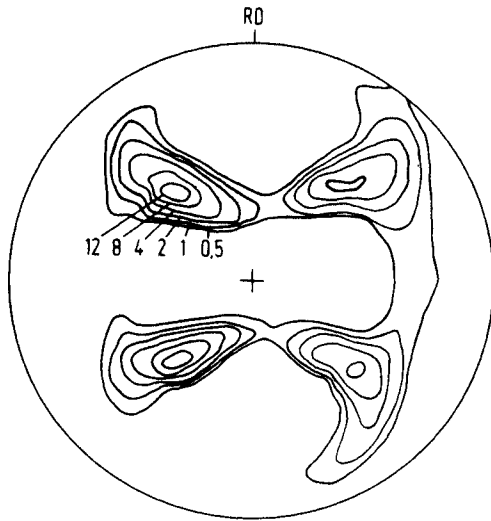ture developed at 700°C in a specimen deep-cooled
and reverse-transformed at 500°C.

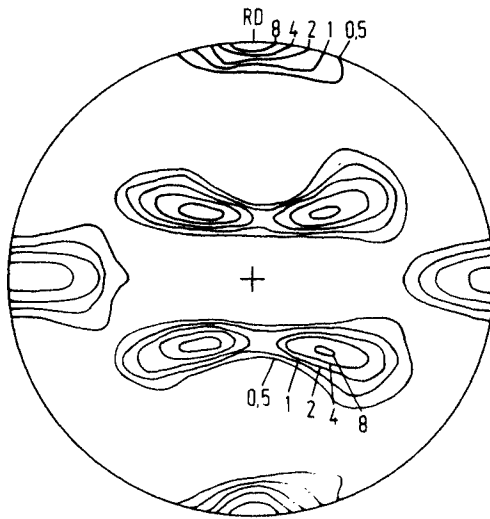FIGURE 4. {111} pole figure showing cube-textured austenite after rolling 87%.

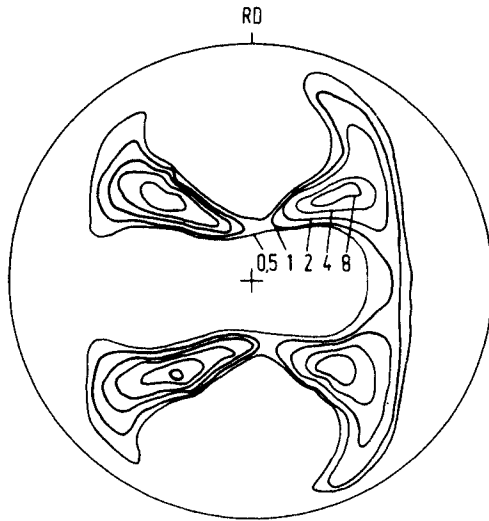FIGURE 5. {110} pole figure of martensite developed from austenite in cube texture (Figure 4) by rolling.

FIGURE 6. {111} pole figure of austenite after re-
verse transformation at 500°C. The texture of the
strain induced martensite is shown in Figure 5, and
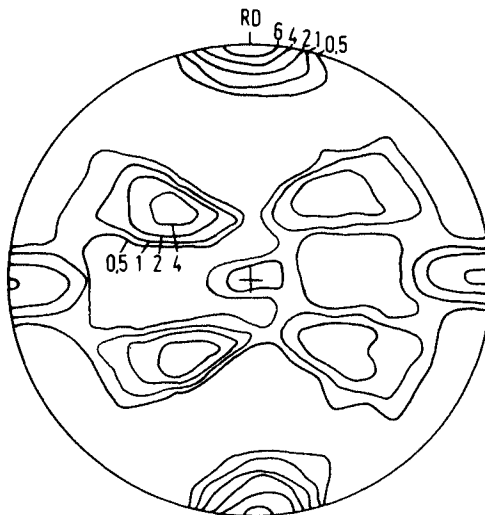that of the residual austenite is shown in Figure 4.

FIGURE 7. {110} pole figure of martensite developed
by deep cooling a sample with deformed cube texture
(Figure 4) and strain induced martensite (Figure 5).

Rolling of previously cooled starting texture and cube texture. If the as-received material having the copper-type rolling texture and a martensite texture, as in Figure 1, is first cooled to low temperatures and then deformed, reverse transformation does not lead to the copper-type rolling texture but to a completely new texture. The same applies if the cube texture is first cooled, then deformed, and transformed.[12] If, however, these newly formed austenite textures are cooled to low temperatures and then transformed by annealing, the material always reverts to the austenite texture existing before the cooling.

Metallographic Investigation

Figures 8a-d show a series of micrographs of a specimen cooled to low temperatures and annealed 30 seconds at successively higher temperatures. Just as the athermal martensite transformation the reverse transformation into austenite comes to a halt if the material is held at a constant temperature. The micrographs all show the same specimen which has been repolished and re-etched so that each time a lower level is exposed. This results in small changes in the proportion and shape of the crystals which have nothing to do with the anneal. The austenite phase is the structural component which shows up most brightly. Even in Figure 8a where parts of the martensite have very light contrast, the retained austenite can still be recognized clearly.

Before cooling, the sheet had the cube texture. Figure 8a shows a polished section of the cooled specimen with athermal martensite and residual austenite (white areas). An earlier investigation[4] has already shown that some of the martensite crystals are very large and others very small. Small quantities of residual austenite could be detected metallographically, but were not indicated by the Debye-Scherrer photographs, or by the magnetic measurements of the residual austenite.

The austenite transformation began at about 370°C. Upon annealing at only 380°C, the proportion of austenite had increased, and this increase continued as the annealing temperature was raised (Figure 8b and c) until the reverse transformation was complete at about 482°C. The pictures show clearly that the growth of austenite starts in the residual austenite regions, i.e. in the region among fine martensite needles, after which the large martensite needles are also gradually consumed.

(a)   (b)

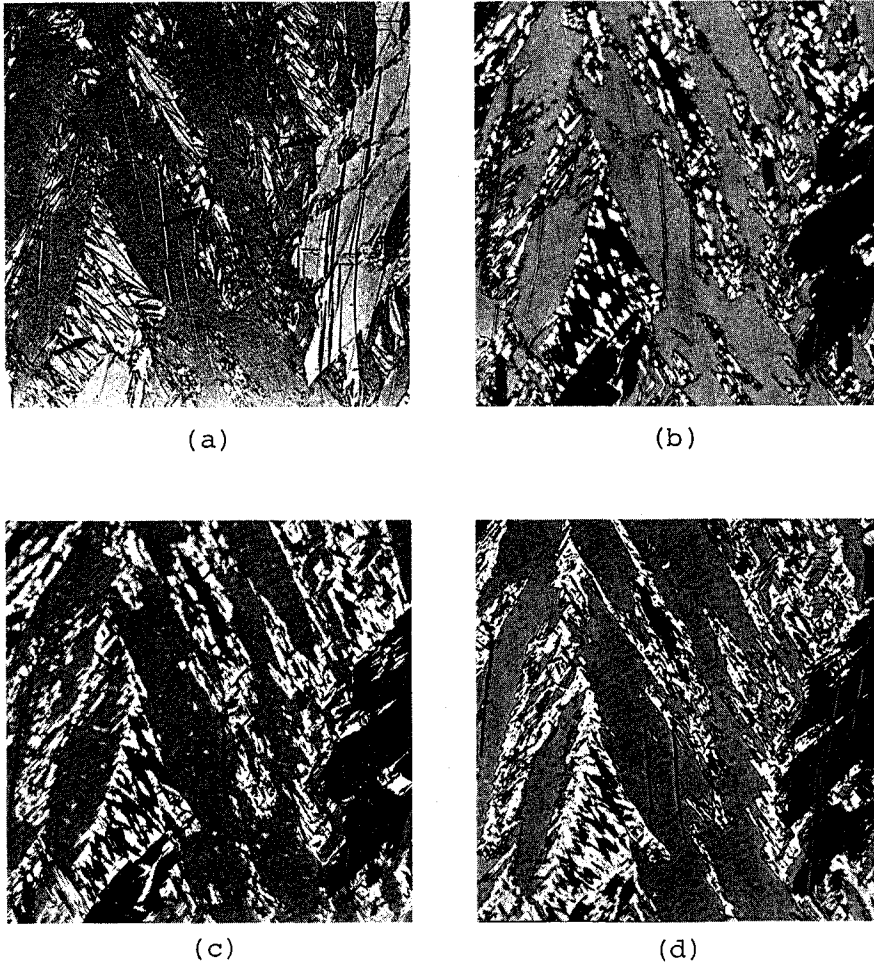(c)   (d)

FIGURE 8a-d. Microstructures of a deep-cooled
specimen with cube texture (a), after heating to
380°C (b), 380 + 386 + 391°C (c), and 380 + 386 +
391 + 400°C (d) (in every case 30 s), x 400. The
arrows point to the retained austenite.

DISCUSSION

Martensite Textures

     As was shown in an earlier publication,[4] all 12
orientations possible according to the Nishiyama mech-
anism [(111)γ‖(110)α and [$\bar{1}$10]γ‖[001]α] arise when the
cube texture is cooled to a low temperature. Whether

or not this is also true for the copper-type rolling tex-
ture cannot be established because of the large number
of different orientations shown by this texture in the
scatter regions around its ideal orientations. At all
events, attempts in calculating a martensite texture by
utilizing various ideal copper-type orientations were
unsuccessful. The earlier mentioned coincidence of the
two {110}α and the two {111}γ poles in the plane of the
normal to the sheet and the rolling direction (ND-RD)
is however striking.

Two different martensite textures were formed on
deformation. In one case the cube texture, which, as
a result of deformation, had developed a strong scatter
best described by rotation about the rolling direction
(RD), gave rise to martensite in the (001)[$\bar{1}$10] orienta-
tion. In the other case, the copper-type rolling tex-
ture yields a texture corresponding to the overall roll-
ing texture of b.c.c. metals but with maxima which could
be described by only one ideal orientation, namely
(112)[$\bar{1}$10]. This ideal orientation is normally used to
describe the rolling texture of b.c.c. materials, but
in that case it is only one among many orientations which
can be derived from a fiber texture parallel to the roll-
ing direction.[13] Besides, a second fiber texture is also
present.

In interpreting these textures, the superposition
of transformation and change in orientation due to roll-
ing must be taken into account. On rolling, the austen-
ite, which, as in the case of the cube texture, can it-
self change its orientation, is transformed into marten-
site; and the transformed martensite also undergoes
orientational changes on rolling. The transformation
is accomplished continuously while traversing various
austenite orientations during the rolling process. As-
sessment of these relationships is complicated by the
fact that it is not known whether strain induced and ather-
mal martensite have the same orientation relationship
with the austenite. If, however, the pole figures of
the deformed cube texture (Figure 4) and that of the mar-
tensite derived from it (Figure 5) are compared with the
martensite orientations derived from the cube texture
according to the Nishiyama mechanism in Figure 9, a good
agreement is observed. From this it can be inferred that
the orientation relationships must at least be similar.
The absence of certain orientations, especially at the
center of the pole figure, does not contradict this in-
asmuch as it is known that one or more of the possible
orientations may fail to arise as a result of stresses.[4,14]
Also to be taken into account is the deformation of the
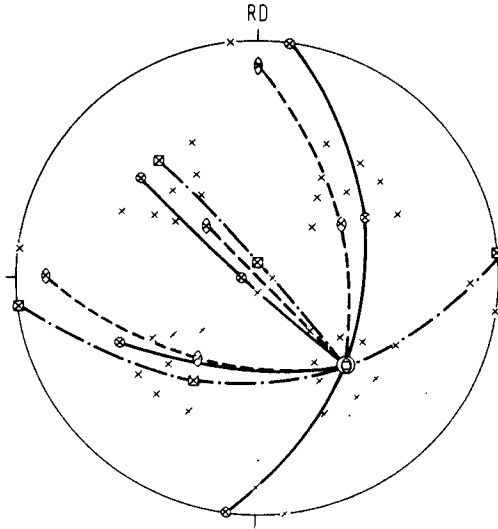martensite which starts virtually as soon as it forms.

FIGURE 9. {110} poles of martensite constructed
by Nishiyama orientation relationship from cube
texture (001)[100].   3 of 12 possibilities are
marked by different symbols.

        If the specimen with the deformed cube texture is
cooled to a low temperature after rolling, the orienta-
tions previously absent at the center of the {110} mar-
tensite pole figure (Figure 7) appear (*cf*. Figures 5, 7,
and 9).   Also, the scatter towards ND around the RD in
the pole figure shown in Figure 7 is now such that all
the constructed {110} poles (Figure 9) fall within the
experimentally observed orientations.
        The formation of strain induced martensite from
copper-type rolling texture is even more complicated than
that of athermal martensite from the same starting tex-
ture.   Here, again, differences exist between the textures
of athermal martensite (Figure 2) and strain induced mar-
tensite (Figure 1), but there is also a certain similarity.
Again, in the case of strain induced martensite it is
noticeable that there is a pole in the ND-RD plane oc-
cupying almost the same position in the {111} as in the
{110} pole figure, even though the agreement is not as
good as in athermal martensite.   Moreover, maxima occur
around the RD in both pole figures of the strain induced
martensite.   These intensity maxima are absent in those
pole figures of athermal martensite.
        These investigations on the formation of martensite
by deformation and by cooling to low temperatures do not
permit a definite conclusion as to whether the two types

of martensite are formed according to the same orienta-
tion relationship. However, there are many indications
that this is the case. The texture of strain induced
martensite differs from that of athermal martensite in
that not all orientations possible according to the ori-
entation relationship are in fact formed because of the
stresses. Moreover, the martensite orientations are
changed in the direction of the stable final texture of
b.c.c. metals by the deformation subsequent to the
transformation.

Reverse Transformation

     With the exception of the two cases mentioned ear-
lier of a transformation by cooling to low temperatures
before deformation,[12] reverse transformation always re-
sults in the austenite texture existing prior to the
first transformation. The metallographic investigations
show very clearly that the reverse transformation begins
at the retained austenite. On this basis, it is con-
cluded that the retained austenite has a nucleating ef-
fect, and that this is a case of oriented nucleation in
a phase transformation. In the case of specimens which
showed no recovery of texture on reverse transformation,
only extremely small amounts of residual austenite could
be detected metallographically. Clearly, these were in-
sufficient to control the formation of the austenite tex-
ture. So far one explanation for the reconstitution of
the austenite texture was that in martensite transforma-
tion and in reverse transformation the same paths were
followed. These would be destroyed if a deformation is
interposed between the martensite and the reverse trans-
formation. This could explain why a new martensite tex-
ture developed in the case which was mentioned last.
Despite this, few examples do exist in which the austen-
ite texture is reconstituted even though a deformation
has been imposed. For example, during the rolling of a
cube-textured specimen strain induced martensite is
formed, which transforms again into cube texture upon
annealing. It appears, therefore, that the reconstitu-
tion of the austenite texture can only take place by
oriented nucleation of the residual austenite.

ACKNOWLEDGMENT

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