Texture Changes in Pass-Rolling of Steel Rods

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Dedicated to the memory of Professor Günter Wassermann

Neutron-diffraction was used to study the texture development during pass-rolling of rods of an austenitic (f.c.c.) steel X8CrNiTi18.10 and a ferritic (b.c.c.) material X8CrTi17 in a round→oval→round→oval→round groove sequence. The orientation distributions occurring in the core of the pass-rolled rods can be described in a good approximation in terms of orthorhombic sample symmetry and qualitatively interpreted either as press textures on conditions of anisotropic material flow in the plane perpendicular to the press direction or as rolling textures on condition of large spreading. However, though they must be characterized by components $\{hkl\}\langle uvw \rangle$ the pass-rolling textures are not rolling textures in the usual sense.

KEY WORDS: Deformation textures; Odf analysis; pass-rolling; alloyed steels; austenitic; ferritic; neutron diffraction.

1 INTRODUCTION

Textures occurring in the pass-rolling of metallic materials were firstly studied with wires of circular cross-section by V. Vargha and Wassermann (1933), for instance, more than 50 years ago. From the contributions of these and other authors, which were summarized by Wassermann (1939) und Wassermann and Grewen (1962), one

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could conclude that after pass-rolling in a ROUND/ROUND groove sequence the orientation changes within the central parts of a wire are similar to those occurring in wire drawing or forging. But already by v. Vargha and Wassermann (1933), it was also shown that the crystallite orientations near the surface cannot be described in terms of fibre textures. During the last two decades particularly the pass-rolling of steel rods and wires on hot-working conditions became more and more important. In this connection diverse types of groove geometry and pass sequences leading to materials with non-circular cross sections are used. The orientation changes associated with such more complicated procedures of pass-rolling have not been investigated systematically until now, but with regard to an exact explanation of the deformation-induced microstructures and changes in the properties of hot-rolled steel rods and wires their knowledge is necessary. The present paper informs on some basic features concerning the texture development in a four-step ROUND/OVAL groove sequence which was studied in an austenitic (f.c.c.) stainless steel X8CrNiTi18.10 and a highly-alloyed ferritic (b.c.c.) material X8CrTi17 after deformation at 973 K (cp. also Schubert *et al.*, 1984; Schubert, 1985). Since the pass-rolling texture formed in a ROUND/OVAL groove sequence cannot be expected to be simple, the main purpose of the work was a proper determination of the sample symmetry and the identification of the most important components of the pass-rolling texture.

2 EXPERIMENTAL PROCEDURES

The chemical composition of the sample materials is given in Table 1.

For the texture investigations steel bars with initial round-section (diameter 12.3 mm) were used which had been obtained by hot-rolling and subsequent annealing at 1273 K/30 min. The deformation in a four-step ROUND-OVAL-ROUND-OVAL-ROUND groove sequence was carried out at 973 K with a strain of $\varphi \approx 0.4\text{--}0.6$ per pass (final diameter 7.5 mm). The strain rate was $\dot{\varphi} \approx 1\text{ s}^{-1}$. After each rolling step a portion of the resulting wire was immediately quenched in water.

The pass-rolling textures were studied qualitatively by means of

Table 1 Chemical composition of steels used (wt.-%)

Material	C	Si	Alloy content in wt.-%					Fe
			Mn	Cr	Ni	Ti	Al	
X8CrTi17	0.055	0.5	0.51	17.6	—	0.71	—	balance
X8CrNiTi18.10	0.055	0.5	1.47	18.1	10.55	0.46	0.1	balance

X-ray diffraction (Co- K_{α} : back-reflection technique of Schulz (1949) and quantitatively by application of neutron scattering. For the neutron diffraction the equipment of the Central Research Institute for Nuclear Research at Rossendorf, GDR, as described by Kleinstück *et al.* (1976) could be used. All specimens for the neutron-diffraction experiments were prepared from the central parts of the steel wires.

The quantitative texture analysis was based on three-dimensional orientation distributions functions (Odf) which were calculated from the pole figures $\{110\}$, $\{200\}$, $\{211\}$, and $\{310\}$ of the ferritic steel X8CrTi17 and $\{111\}$, $\{200\}$, $\{220\}$, and $\{311\}$ of the austenite X8CrNiTi18.10 by means of Bunge's formalism (Bunge, 1982; Bunge and Esling, 1982, for instance). A discussion of ghost phenomena (Matthies 1981, 1982, for instance), which is important for a more refined interpretation of the pass-rolling texture, has not been performed until now.

3 RESULTS AND DISCUSSION

3.1 TEXTURE homogeneity and symmetry

In a ROUND/OVAL groove sequence, the deformation geometry of which is illustrated in Figure 1, no rotational symmetry of the orientation distribution of the crystallites is obtained because the various elements of the cross-section are differently deformed and, moreover, the rod (wire) is rotated by $\pi/2$ after each rolling step. However, according to Schubert *et al.* (1984) a sample-related axis system ($\vec{e}_1$, $\vec{e}_2$, $\vec{e}_3$) can be introduced, the directions $\vec{e}_2$ (transverse direction TD) and $\vec{e}_3$ (normal direction ND) of which are perpendicular to symmetry planes of the deformation process. For this reason the texture within the central parts of the rod (wire) can be

Figure 1 Cross-section changes of steel rods in round-oval (a) and oval-round (b) deformation steps of pass-rolling.

supposed to be of orthorhombic sample symmetry. On the other hand, because of the temperature gradient between the core and the surface layers as well as the friction stresses occurring near the surface the pass-rolling texture must also be expected as very inhomogeneous over the cross-section of the rod (wire) especially on hot-working conditions.

In order to study the texture inhomogeneity, specimens were

Figure 2 Qualitative X-ray pole figures (Iso-lines are characterized by count impulses (10^3 min^{-1})) of the austenite X8CrNiTi18.10: (1) after the first (round → oval) and (2) the second (oval → round) rolling pass: (a) surface-layer texture; (b) texture with increasing distance from the surface; (c) midsection texture.

taken from the wires after the first (ROUND/OVAL) and the second (OVAL/ROUND) deformation step of the groove sequence, successively thinned parallel to the rolling plane defined by the directions $\vec{e}_1$ (rolling direction RD) and $\vec{e}_2$ (transverse direction TD) of the sample-related axis system (Figure 1) and studied by means of X-ray diffraction. Results obtained in this way are shown in Figure 2 for the austenite X8CrNiTi18.10. Near the surface (Figures 2.-1a, 2a) the texture is very irregular. But with increasing distance from the surface the orientation distribution becomes more and more defined (Figures 2.-1b, 2b) and, at least, a well-developed midsection texture with orthorhombic sample symmetry is found (Figures 2.-1c, 2c). A clearly defined orthorhombic midsection texture, which very well agrees with that of Figures 2.-1c, 2c, is also obtained by neutron diffraction (Figure 3). This means, that it can be formally described in terms of components $\{hkl\}\langle uvw \rangle$ like flat-rolling textures and quantitatively treated by means of the usual Bunge formalism of texture analysis for sheets (Bunge, 1982; Bunge and Esling, 1982, for instance). If the specimen includes an increasing part of the cross-section around the core of the wire, the symmetry of the observed texture is not significantly influenced, but the orientation distribution becomes weaker and the scattering of the texture components increases. In the measurements presented here the influence of the texture inhomogeneity was minimized by

Figure 3 Quantitative $\{111\}$ pole figures of the texture being present after the first (a, round $\rightarrow$ oval) and after the second (b, oval $\rightarrow$ round) rolling-pass in the f.c.c. material X8CrNiTi18.10.

careful preparation of the specimens for neutron diffraction (cp. Schubert, 1985).

3.2 TEXTURE components of pass-rolling

3.2.1 Austenite X8CrNiTi18.10. The preferred orientations being present in the f.c.c. material X8CrNiTi18.10 after the first (ROUND/OVAL) and the second (OVAL/ROUND) rolling step of the groove sequence described in section 2 are illustrated in Figures 4 and 5. Moreover, the skeleton line of the texture after the first rolling pass (Figure 6) and the maximum orientation densities of the main texture components occurring in all passes of the groove sequence are presented (Figure 7). The experimentally found results can be summarized as follows:

—The initial texture of the (completely recrystallized) austenite was very weak. It can be characterized by two components $\{001\}\langle 100 \rangle$ and $\{011\}\langle 111 \rangle$ with a ratio 5:3 of the maximum orientation densities.

—After the first rolling step well-defined preferred orientations of the crystallites are observed (Figure 4). The corresponding Odf (Figure 5a) shows an orientation tube between $\{011\}\langle 111 \rangle$ and $\{112\}\langle 110 \rangle$ (Figure 6) which obviously represents the pure deformation texture of the ROUND/OVAL rolling pass. The

Figure 4 Quantitative pole figures of austenitic stainless steel X8CrNiTi18.10 (first rolling-pass: round→oval).

Figure 5 Orientation distribution functions of austenitic stainless steel X8CrNiTi18.10: (a) first rolling-pass round→oval; b) second rolling-pass: oval→round.

$\{001\}\langle 100 \rangle$ component of the initial texture is strongly reduced (Fig. 7).

—During the second (ROUND/OVAL) rolling step the deformation texture of the wire is significantly reduced (Figure 5b). Its main components are $\{011\}\langle 111 \rangle$, $\{011\}\langle 100 \rangle$ and, in addition, $\{112\}\langle 111 \rangle$.

Figure 6 Orientation densities along the skeleton line of Odf of pass-rolled X8CrNiTi18.10 (first rolling-pass: round→oval).

Figure 7 Orientation density changes of the main texture components occurring in pass-rolling of X8CrNiTi18.10 in a four-step round/oval groove sequence.

—After the third and the fourth rolling step no remarkable changes of the deformation texture could be found yet (Figure 7). However, a re-increasing of the cube texture $\{001\}\langle 100 \rangle$ was observed now, which in agreement with the results of hot-compression tests at 973 K (Schubert, 1985) indicates increasing influence of dynamic (and eventually postdynamic) recrystallization on the austenite texture (cp. also Ahlborn *et al.*, 1966).

If the components $\{hkl\}\langle uvw \rangle$ of the pass-rolling texture are compared with those of the flat-rolling textures of hot-worked austenite (Goodman and Hu, 1970; Hu, 1974; Klimanek *et al.*, 1981a, b, for instance; cp. also Table 2), no satisfactory correspondence can be found with the exception of $\{001\}\langle 100 \rangle$. This indicates that pass-rolling textures have to be considered as a special kind of deformation textures.

3.2.2 Ferrite X8CrTi17. The textures occurring in the b.c.c. alloy X8CrTi17 after the first (ROUND/OVAL) and the second (OVAL/ROUND) rolling step of the groove sequence are illustrated in Figures 8, 9 and 10. Moreover, the skeleton lines of the texture component $\{hkl\}\langle 110 \rangle$ and the maximum orientation densities of all important orientations $\{hkl\}\langle uvw \rangle$ of the ferrite texture are presented in Figures 11 and 12 for all rolling steps of the groove sequence used. The experimental work can be summarized

Table 2 Deformation texture components of f.c.c. and b.c.c. materials in different deformation modes

Lattice	Pass-rolling texture	Flat-rolling texture	Fibre textures in	
			Compression	Tension
f.c.c.	—orientation tube $\{011\}\langle 111\rangle \dots$ $\{112\}\langle 110\rangle$	—concepts of peak-type and fibre-type texture		
	—single orientation $\{011\}\langle 100\rangle$ (Schubert <i>et al.</i> , 1984)	Cu-position $\{112\}\langle 111\rangle$ Bs-position $\{011\}\langle 211\rangle$ S-position $\{123\}\langle 634\rangle$ —single orientation Goss $\{011\}\langle 100\rangle$ (Goodman and Hu 1970; Hu 1974, Klimanek <i>et al.</i> 1981a, b Lücke, 1981; for instance) —concept of fibre-type texture $\alpha\{001\}\langle 110\rangle \dots$ $\{112\}\langle 110\rangle$ $\beta\{112\}\langle 110\rangle \dots$ $\{554\}\langle 225\rangle$ $\gamma\{111\}\langle 110\rangle \dots$ $\{111\}\langle 112\rangle$ δ orientations near $\{112\}\langle 110\rangle$ (Därmann <i>et al.</i> , 1984; Österle, 1984; for instance)	$\langle 110\rangle$ $\downarrow$ $\langle 112\rangle$ (Wassermann, 1962)	$\langle 111\rangle$ + $\langle 100\rangle$ (Wassermann, 1962)
b.c.c.	—orientation tube $\{001\}\langle uvw\rangle$ $\{111\}\langle 110\rangle \dots$ $\{111\}\langle 112\rangle$ $\{001\}\langle 110\rangle \dots$ $\{111\}\langle 110\rangle$		$\langle 111\rangle$ + $\langle 100\rangle$	$\langle 110\rangle$ $\downarrow$ $\langle 112\rangle$
	(Schubert <i>et al.</i> , 1984)			(Wassermann, 1962)

Figure 10 Orientation densities along skeleton lines of Odf of pass-rolled X8CrTi17: (first rolling-pass: round→oval); a) $\{001\}\langle uvw \rangle$; b) $\{111\}\langle 110 \rangle \dots \{111\}\langle 112 \rangle$.

orientation tube between $\{111\}\langle 110 \rangle$ and $\{111\}\langle 112 \rangle$ (Figure 10b). The fibre texture $\{001\}\langle uvw \rangle$ (Figure 10a) is reduced (Figure 11) but important yet.

—Because of the fact that during hot-working at 973 K only dynamic recovery takes place in the steel X8CrTi17 (Schubert, 1985), the tube texture becomes stronger in the second (OVAL/ROUND) deformation step (Figures 9b, 11). The orientation densities of the fibre component $\{001\}\langle uvw \rangle$ are not changed in this case.

—During the deformation in the third and the fourth rolling pass the tube texture becomes weaker again and the $\{001\}\langle uvw \rangle$ fibre remains practically independent of the rolling procedure. According to Figure 12 which shows the skeleton line of the orientations running from $\{001\}\langle 110 \rangle$ to $\{111\}\langle 110 \rangle$ for all deformation steps of the groove sequence, the weakening of the component $\{111\}\langle 110 \rangle$

Figure 11 Orientation density changes of the main texture components occurring in pass-rolling of X8CrTi17 in a four-step round/oval groove sequence.

Figure 12 Orientation densities along the skeleton lines of the texture component $\{hkl\} \langle 110 \rangle$ of pass-rolled X8CrTi17.

is connected with the formation of preferred orientations around $\{112\}\langle 110 \rangle$ and, consequently, of a fibre component $\{hkl\}\langle 110 \rangle$.

In the case of the b.c.c. material X8CrTi17 the correspondence between the pass-rolling and the flat-rolling textures seems to be somewhat better. The dominating orientation tube is close to the so-called γ fibre running from $\{111\}\langle 110 \rangle$ to $\{111\}\langle 112 \rangle$, and the so-called α fibre of the flat-rolling texture (Heckler and Granzow, 1970; Inagaki and Suda, 1972; Därmann *et al.*, 1984; Österle, 1984, for instance; cp. also Table 2) corresponds to a part of the component $\{hkl\}\langle 110 \rangle$. However, the formal agreement should not be overestimated.

3.3 FORMAL interpretation of the texture development in the round/oval groove sequence

From the investigations of the steels X8CrNiTi18.10 and X8CrTi17 two important conclusions concerning the texture development in a ROUND/OVAL groove sequence can be drawn:

—Although a low hot-working temperature was chosen, the pass-rolling textures of both sample materials are weak and a significant increase of the deformation components takes place only during the first rolling step.

—Although the pass-rolling textures have to be described in terms of orthorhombic sample symmetry they are clearly different from the textures observed in flat-rolling.

The weak deformation dependence of the texture, which additionally is caused by recrystallization in the case of the austenitic steel X8CrNiTi18.10, can well be explained by the fact that a pass-rolled rod (or wire) is rotated by $\pi/2$ after each deformation step. Since this procedure leads to an interchange of the transverse and the normal directions $\vec{e}_2$, $\vec{e}_3$ of the sample-related axis system (Figure 1), it causes redistribution of the crystallite orientations during the subsequent rolling step with respect to the new rolling plane, and prevents a further increase of the orientation densities. In this connection the following geometrical interpretation of the observed orientation changes can be given (cp. Figure 13):

—In the f.c.c. material the main component $\{011\}\langle 111 \rangle$ of the

Figure 13 Geometrical interpretation of the observed orientation changes due to wire rotation in pass-rolling.

deformation texture is transformed by rotation of $\pi/2$ around the rolling direction $\bar{e}_1 // \langle 111 \rangle$ into the position $\{112\}\langle 111 \rangle$ which can be observed directly after the second rolling pass. (After the third and the fourth deformation step the orientation is obviously suppressed by the recrystallization.) The positions $\{001\}\langle 100 \rangle$ and $\{011\}\langle 100 \rangle$ are transformed into equivalent orientations.

—The texture development of the b.c.c. ferrite is more complicated than that of the austenite. Here the rotation of the wire leads to the following transitions of the texture components (Figure 13): $\{001\}\langle 100 \rangle \rightarrow \{001\}\langle 100 \rangle$; $\{001\}\langle 110 \rangle \rightarrow \{110\}\langle 011 \rangle$; $\{111\}\langle 110 \rangle \rightarrow \{112\}\langle 110 \rangle$; $\{111\}\langle 112 \rangle \rightarrow \{011\}\langle 211 \rangle$. According to the relations, which easily permit to understand the behaviour of the texture component $\{111\}\langle 110 \rangle$ and, particularly, the formation of a fibre $\{hkl\}\langle 110 \rangle$ during the third and the fourth rolling step, the weakening of the ferrite texture is mainly the consequence of orientation redistribution. Therefore, if there is no influence of dynamical or postdynamic recrystallization, the pass-rolling textures of b.c.c. materials should be more intensive than in f.c.c. alloys.

A phenomenological explanation of the meaning of the main texture components $\{hkl\}\langle uvw \rangle$ of the pass-rolling textures seems to be possible on the base of the following considerations:

—According to Figure 1 especially an OVAL/ROUND deformation step can be described as a compression along the normal

direction $\vec{e}_3$, which is connected with very anisotropic material flow (elongation along the rolling direction $\vec{e}_1$) in the plane perpendicular to the compression axis. It is interesting, that the main texture components $\{011\}\langle 111 \rangle$ of the f.c.c. steel X8CrNiTi18.10 and $\{111\}\langle 110 \rangle$ of the b.c.c. material X8CrTi17 are obtained by combination of the preferred orientations occurring in compression and tension (Table 2).

—Figure 1 also shows that, particularly in the ROUND/OVAL rolling pass, the deformation of the central part of a rod can be compared with flat-rolling on condition of large spreading. Indeed, investigating the textures of flat-rolling iron sheets Schläfer and Bunge (1974) found that increasing spreading favoured the formation of the $\{111\}\langle uvw \rangle$ orientation tube which was discussed above.

Finally it shall be mentioned yet that deformation textures very similar to those of the f.c.c. austenite X8CrNiTi18.10 were also obtained by pass-rolling of Al and Cu in a groove sequence ROUND/OVAL at room temperature (Klimanek *et al.*, 1985). This indicates that the results concerning the texture components as observed in the present work can be generalized. In order to obtain a physically sufficient explanation of the pass-rolling textures, however, further investigations are necessary.

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