Textures and Microstructures, 1991, Vols 14–18, pp. 1037–1047
Reprints available from the publisher
Photocopying permitted by license only

INFLUENCE OF PASS SEQUENCE ON CROSS-ROLLING TEXTURES IN ARMCO-IRON

A. BÖCKER AND H. J. BUNGE

Department of Physical Metallurgy, TU Clausthal, FRG

ABSTRACT

The textures of different modes of "balanced" cross - rolling were studied in ARMCO-iron. Thereby equal partial rolling degrees are applied in longitudinal and transverse direction. Three modes of cross-rolling were used. In true multi-stage cross-rolling the rolling direction is changed by 90° after each small deformation pass. In two-stage rolling at first all longitudinal passes were done and then all transversal passes. In four-stage rolling four alternate groups of longitudinal and transversal passes were used. The main texture component is {001}‹110› the density of which increases from two-stage to multi-stage. A second component is a ‹111› || ND fibre and finally a minor cube component is observed.

INTRODUCTION

In an earlier paper (Böcker et al 1990) cross-rolling textures in Armco-iron were studied. After higher deformation degrees the main components of these textures were found to be the orientation {001}⟨110⟩ and a fibre texture component ⟨111⟩ || ND. The first one of these orientations reached orientation densities as high as 50x random whereas the ⟨111⟩ fibre texture reached densities of about 7x random. In these investigations cross-rolling was carried out in two different ways: True cross-rolling (or multi-stage rolling) was done with 90° rotation after each individual rolling pass. In two-stage rolling, on the other hand, the material was at first reverse-rolled in longitudinal direction to half of the final reduction in thickness. Then the rolling direction was changed by 90° and again it was reverse-rolled to the final thickness. These two modes of cross-rolling gave rise to strong differences in the orientation density of the main component {001}⟨110⟩. Furthermore, the first mode, i.e. true cross-rolling lead to nearly ideal tetragonal sample symmetry whereas two-stage rolling resulted on orthorhombic sample symmetry.
In multi-stage rolling the accumulated rolling degrees in longitudinal and transverse direction were equal whereas in two-stage rolling the second rolling degree was always higher than the first one. Hence, the two respective textures were not exactly comparable in this respect. It was thus the purpose of the present paper to study cross-rolling textures in ARMCO-iron with equal rolling degrees in both directions but with different sequences of rolling passes in these directions. Additionally to the former multi-stage cross-rolling, "ballanced" two-stage and "balanced" four-stage rolling was thus studied.

MATERIAL AND EXPERIMENTAL PROCEDURE

The material used was ARMCO-iron with 0.03% C, the same as in the previous investigation. It was received in the form of hot rolled sheet 8.8 mm thick. The material was at first annealed 2h at 950°C in an inert atmosphere and water quenched. It was then machined to different initial thicknesses in order to end up with the same final thickness after different rolling degrees.
Two-stage cross-rolling was carried out with a large number of passes in the original rolling direction, turning the direction by 180° after each pass. After that the rolling direction was changed to the original transverse direction and the same procedure was carried out with the same accumulated deformation degree.
Four-stage rolling started similar to two-stage rolling with the only difference that the rolling direction was turned three times by 90° after equal rolling degrees. Hence, the accumulated rolling

degrees in the original hot-rolling and original transverse direction were the same, only the sequences of individual rolling passes were different. The total rolling degrees as well as the corresponding partial rolling degrees for two - and four - stage rolling are given in Table 1.

Rolling degree Nominal	Actual	Partial Deformation Degrees	
a) Two-stage rolling			
80%	80.0%	55.3% ;	55.2%
85%	85.0%	61.8% ;	60.8%
90%	89.6%	68.4% ;	67.0%
92%	92.0%	73.3% ;	69.9%
b) Four-stage rolling			
80%	80.0%	33.1% ;	33.2%
		33.1% ;	33.1%
85%	85.0%	37.8% ;	37.8%
		37.9% ;	37.5%
90%	90.0%	43.8% ;	43.3%
		43.8% ;	43.7%
92%	92.0%	46.7% ;	46.6%
		46.7% ;	46.7%

Table 1: Nominal and actual rolling degree and the partial deformation degree

Texture samples of 33.9 mm diameter were cut from the rolled slabs. They were ground on SiC-paper to about the middle plane and then etched with an etchant of 45ml C_2H_5OH + 10ml HNO_3. Texture measurements were carried out with the automatic texture goniometer ATEMA-C in steps of $\Delta\alpha = 5°$, $\Delta\beta = 3.6°$ up to $\alpha_{max} = 70°$. Three pole figures i.e. (110)(200)(211) were measured, they were corrected for background scattering (as well as for misalignment of the rolling direction). Complete ODF were then calculated using the series expansion method up to λ_{max} =22. The odd terms were obtained by the zero range method.

RESULTS

The texture of the starting material is shown in Fig. 1 which gives the (110) - pole figure and three sections of the ODF. As is also indicated in this figure the maximum orientation density value was 3.08. Hence, the initial texture was not random but it was a rather weak texture.

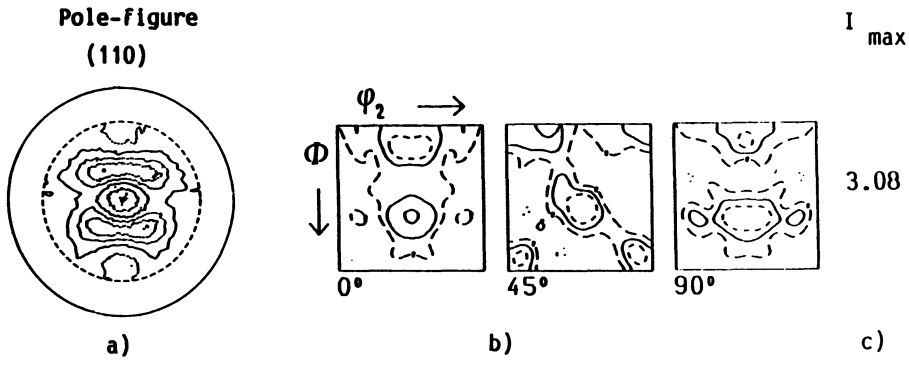


Fig. 1: The initial texture: a) (110)-pole figure
b) three ODF sections c) maximum orientation density

The (110)-pole figures of the four investigated rolling degrees and two modes of rolling are given in Fig. 2. It is seen qualitatively that the figures of four-stage rolling are closer to tetragonal symmetry whereas those of two-stage rolling deviate a little bit more from this symmetry towards orthorhombic symmetry.

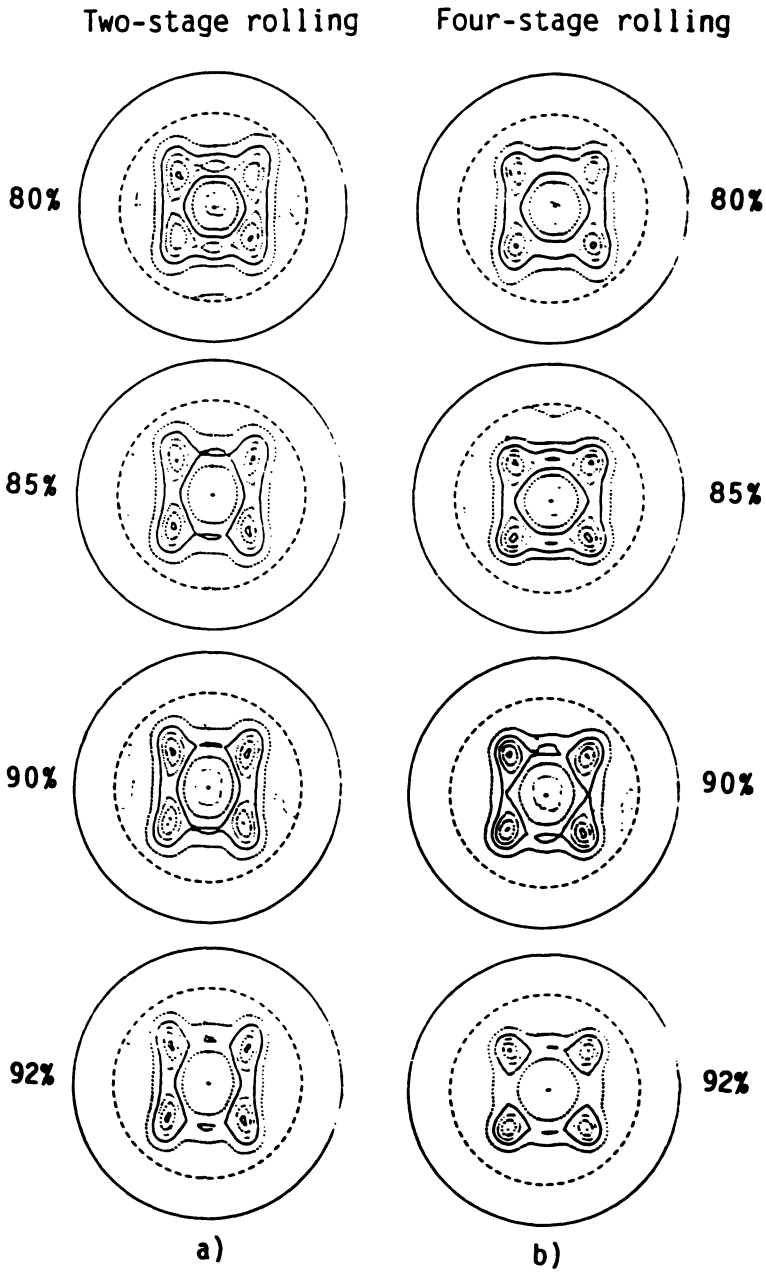


Fig. 2: pole figures (110) for four deformation degrees
a) two-stage rolling b) four-stage rolling

ODF calculated from three pole figures, each, are given in Fig. 3.

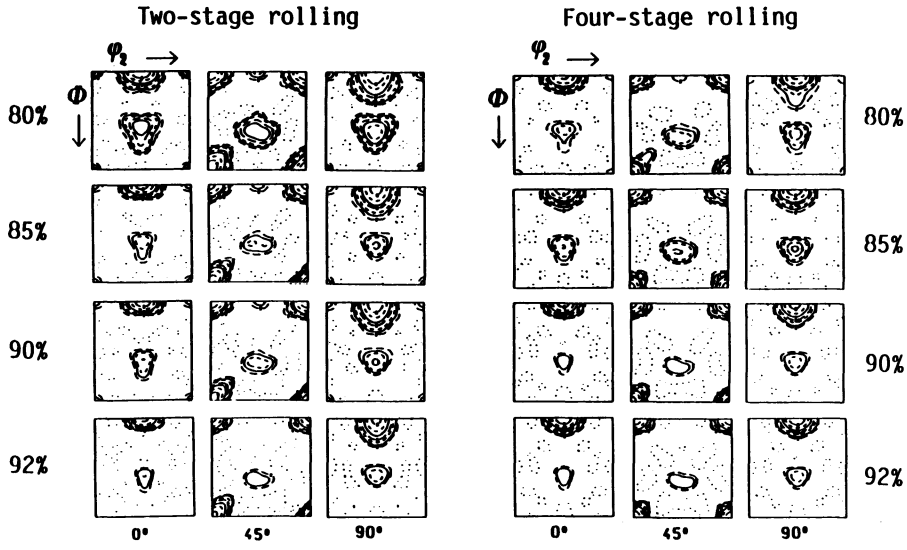
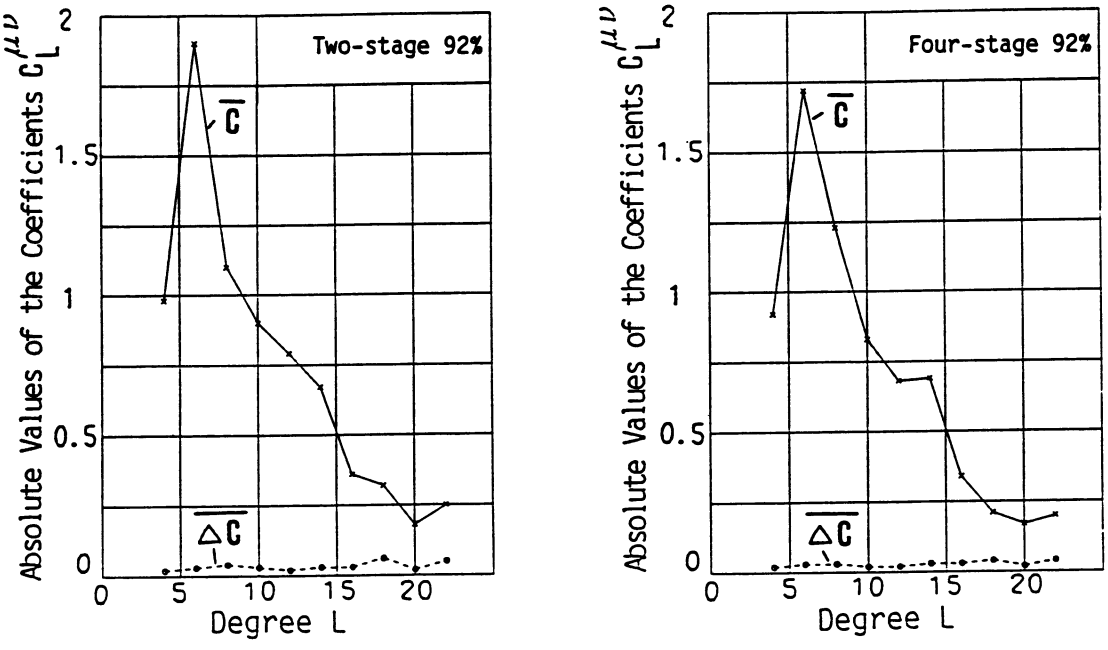


Fig. 3: ODF of cross-rolling textures of Armco-iron for four rolling degrees and two modes of deformation

Since the textures are rather sharp consisting of a few components only as specified in Fig. 6 of the earlier paper, it is sufficient to give only three sections of the ODF. The mean values of the coefficients $C_L^{\mu\nu}$ and their respective errors $\Delta C_L^{\mu\nu}$ are given in Fig. 4 for the two deformation modes for the highest deformation degree. It is seen that the error coefficients are rather low. As was already mentioned in the former paper the texture coefficients $C_L^{\mu\nu}$ can be divided into two groups, i.e. those with $\nu = 4n$ (4-fold) and those with $\nu = 4n+2$ (two-fold). In the case of tetragonal symmetry the latter ones should be zero. In Fig. 5, mean values of the two-fold and four-fold coefficients are given as a function of the degree L. It is seen that the two-fold coefficients for two-stage rolling are higher than those of four-stage rolling. Fig. 6 shows the orientation densities along the orientation tube corresponding to the ‹111› || ND fibre texture. It shows two peaks in the orientations 1={111}‹110› and 2={111}‹112› respectively.
The main feature of the textures can be summarized by the orientation densities in five characteristic orientations as is shown in Fig. 7. The points 1 and 2 characterize the ‹111› fibre texture (1 = {111}‹110›, 2 = {111}‹112›) point 3 = {001}‹110› is the main texture component, points 4 = {001}‹100› and 5 = {110}‹001› are two minor components.



a) b)

Fig. 4: Mean absolute values of the texture coefficients $C_L^{\mu\nu}$ and their errors $\Delta C_L^{\mu\nu}$ as a function of the degree L for 92% cross-rolling.
a) two-stage rolling b) four-stage rolling

Finally, Fig. 8 summarizes the development of maximium orientation density in the main texture component, i.e. point 3 = {001}⟨110⟩. This figure also repeats the results of the two deformation modes studied in the former paper, i.e. multi-stage rolling and "non-balanced" two-stage rolling. The upper three curves thus correspond to cross-rolling modes with equal accumulated rolling degrees in both directions. Only the sequence of the individual rolling passes is different in these three curves.

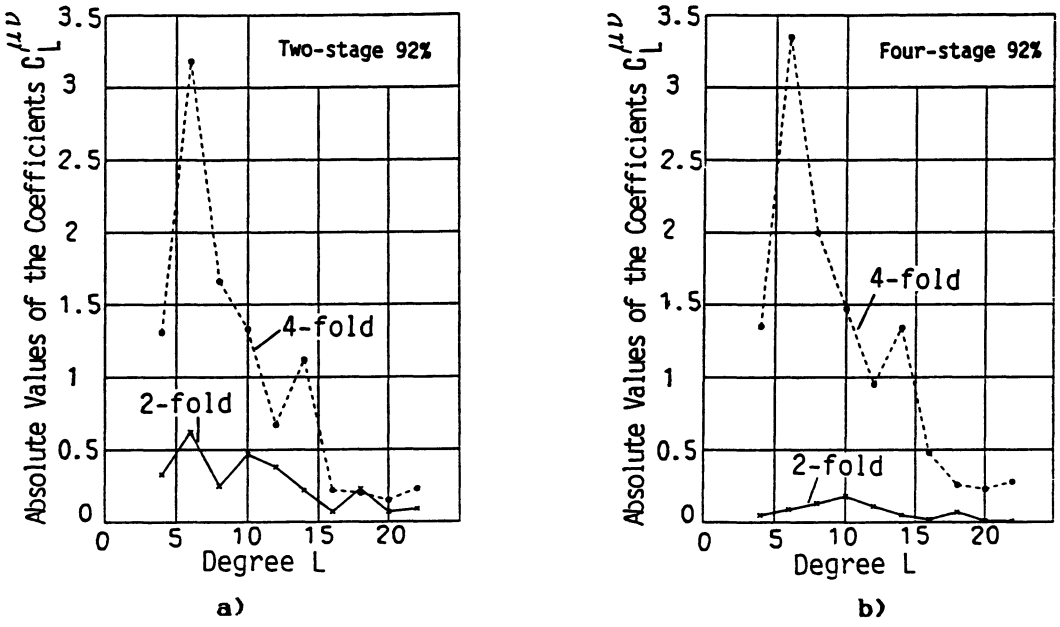


Fig. 5: Mean absolute values of the two-fold and four-fold texture coefficients $C_L^{\mu\nu}$ for 92% cross-rolling
a) two-stage rolling b) four-stage rolling

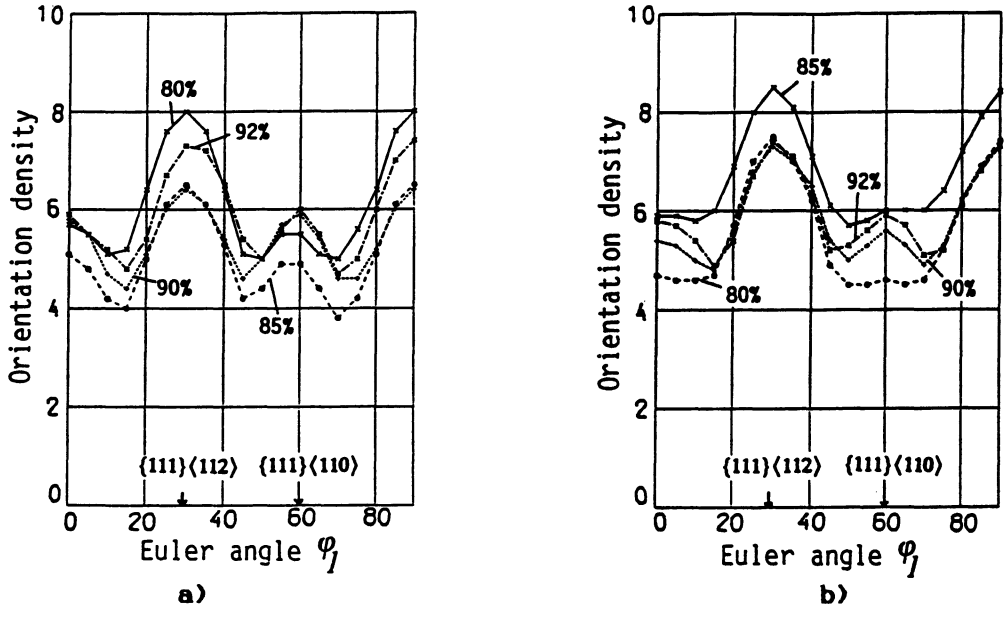


Fig. 6: Orientation density along the {111} || ND fibre component
a) two-stage rolling b) four-stage rolling

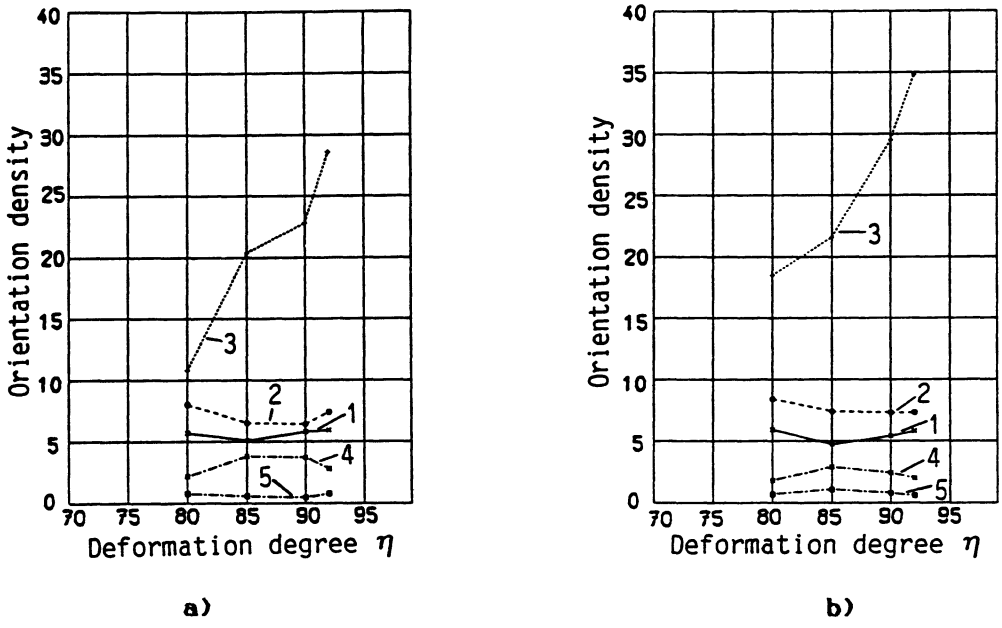


Fig. 7: Orientation densities in the main and minor components after various degrees of cross-rolling a) two-stage rolling b) four-stage rolling; 1 = {111}‹110›; 2 = {111}‹112›; 3 = {001}‹110›; 4 = {001}‹100›; 5 = {110}‹001›

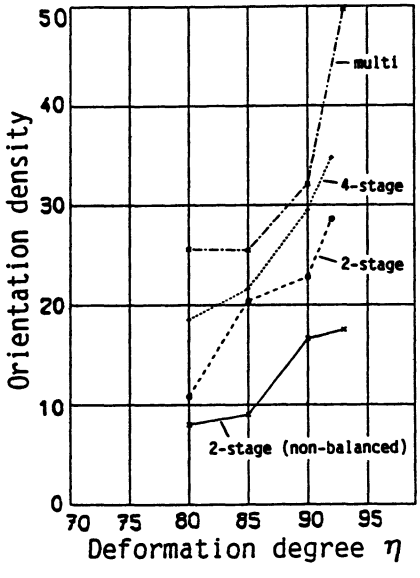


Fig. 8: Orientation densities in the main orientation {001}‹110› as a function of the deformation degree.

DISCUSSION

The main result of the present investigation is contained in the upper three curves of Fig. 8. The orientation {001}‹110› has often been found as one of the stable end-orientations of uni-directional rolling. This orientation is symmetric to longitudinal and transverse rolling. In uni-directional rolling the spread range about this orientation is, however, strongly anisotropic. The strongest spread of this orientation is a rotation about the rolling direction whereas spread about transverse and normal direction is much smaller. In multi-stage rolling, the rolling direction is changed after each step. Hence, the spreading out of this orientation in one rolling step is corrected immediately afterwards in the next step. This way, the orientation {001}‹110› becomes a stable orientation with respect to all three dimensions in Euler space. In uni-directional rolling, on the other hand, crystals flowing into this orientation from two directions in Euler space may "escape" from it in the third direction. Two-stage and four-stage rolling are in between uni-directional and multi-stage rolling. In two-stage rolling crystals are allowed to "escape" in one direction during the longitudinal rolling steps and are only being driven back during transverse rolling. In four-stage rolling "driving-back" takes place in shorter intervals. Hence, increasing orientation densities must be expected when going from two-stage over four-stage to multi-stage rolling, as is seen in Fig. 8. These experimental results are corroborated by model calculation using flow fields calculated on the basis of Taylor theory (Bunge et al 1986, Klein et al 1991).

The second - though somewhat weaker - main component is the orientation tube {111}‹uvw›. In uni-directional rolling an orientation tube was found which stretches out between the orientations {112}‹110› and {111}‹112› + 5°. This latter orientation tube is near to {111}‹uvw›. In longitudinal and transverse rolling it deviates from the latter one in different directions in Euler space. Hence, non of the orientations belonging to {111}‹uvw› is really stable with respect longitudinal and transverse rolling simultaneously. The stable orientations of the individual rolling passes oscillate so to speak about the tube {111}‹uvw›. In multi-stage rolling the orientation density along this tube was found to be nearly constant, whereas "unbalanced" two-stage rolling showed a slightly increased density in the orientation {111}‹112›. The same has been found in this investigation with balanced two-stage and four-stage rolling. Fig. 6 shows a maximum density in the orientation {111}‹112› and a second smaller maximum in {111}‹110›. The latter one seems to be a little bit more pronounced in two-stage rolling compared with four-stage

rolling. It is difficult to say what is the relative error in the ODF. For this purpose Fig. 5 has to be considered. In the present investigations the error coefficients $|\overline{\Delta C_L^{\mu\nu}}|$ were somewhat lower than in our former investigation. Hence, the relativ error in the present ODF-values may be lower than in the former paper. On the other hand, the series expansion was extended up to L = 22 in both investigations, leaving some truncation error of the same magnitude. It may be doubtfull whether the relativ maximum in the orientation {111}‹110› is relevant. The maximum in {111}‹112› seems, however, to be realistic.
In the former investigation a cube component {001}‹100› was observed which took on medium values of up to 6 in the lower deformation degrees and decreased to the order of 1.5 at the higher degrees. In the present study this component was found to be slightly higher even at higher deformation degrees, i.e. 4 in the case of two-stage rolling and 3 in four-stage rolling. It is assumed that this is beyond the range of experimental and computional error.

CONCLUSIONS

Balanced cross-rolling, with equal deformation degrees in both directions, in ARMCO-iron produces textures consisting of two main components. The strongest component is the orientation {001}‹110›. It takes on maximium density values of up to 50x random after true multi-stage cross-rolling of 93%. Upon four-stage and two-stage cross-rolling this density decreases to 35 and 28 respectively. This is attributed to the fact that an individual rolling step leads to a spread of this orientation about the rolling direction.
The second main component is a ‹111› || ND fibre component which is a compromise between the uni-directional rolling texture "tube" running from {112}‹110› to {111}‹112› + 5° and its equivalent rotated 90° about ND corresponding to rolling in transverse direction. Besides these two main components a minor cube texture component was found.

REFERENCES

Böcker, A.; Klein, H. and Bunge, H.-J. (1990); Development of Cross-Rolling Textures in ARMCO-Iron, Textures and Microstructures 12, p. 103-123

Bunge, H.-J.; Esling, C.; Dahlem, E. and Klein, H. (1986); The Development of Deformation Textures Described by an Orientation Flow Field, Textures and Microstructures 6, p. 181-200

Klein, H.; Esling, C. and Bunge, H.-J. (1991); Model calculations of Cross-Rolling Textures, Proceedings of ICOTOM 9 (to be published)