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A Texture Evolution Study Using The Texture Component Crystal Plasticity FEM

Franz Roters[1, a], Heyon S. Jeon-Haurand[1] and Dierk Raabe[1, b]

[1]Max Planck Institut für Eisenforschung, Department Microstructure Physics and Metal Forming, Max-Planck-Str. 1, 40237 Düsseldorf, Germany

[a]roters@mpie.de, [b]raabe@mpie.de

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Abstract. Crystal plasticity FEM simulations of plane strain compression were performed. The Texture Component Crystal Plasticity-FEM was used for the texture mapping. Two different starting textures (random and hot rolling texture) were studied using four different FE meshes and two different sets of boundary conditions. While for the random starting texture the evolution of the texture with deformation was found to be rather similar in all cases studied, the simulations using an experimental hot rolling texture as staring texture are much more sensitive to the boundary conditions and probably also to changes in the mesh geometry.

Introduction

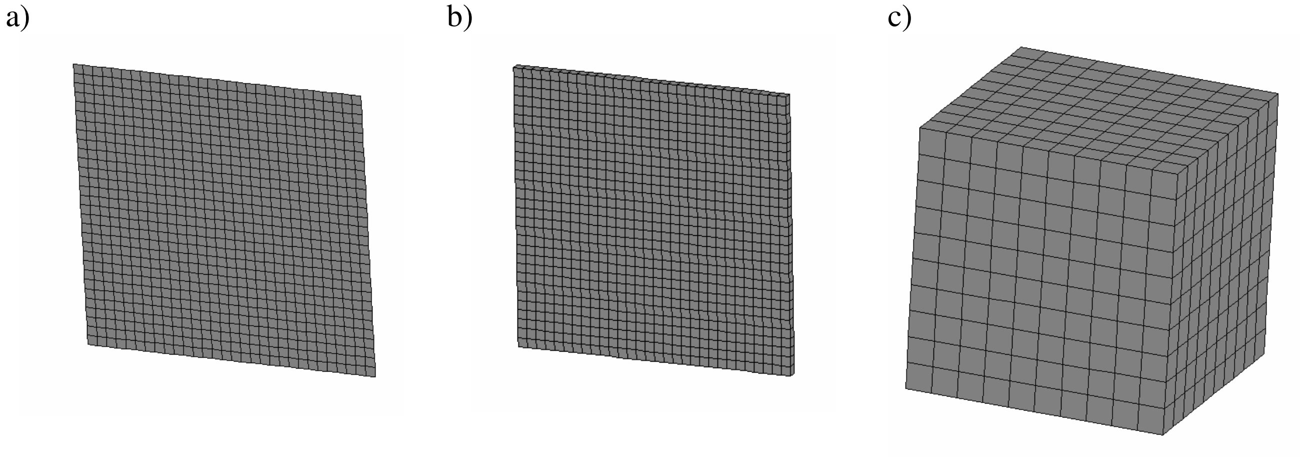
The conventional Crystal Plasticity FEM has huge potential for predicting forming textures [1, 2] when compared with other texture simulation models such as full constraint (FC) Taylor, relaxed constraint (RC) Taylor or self consistent schemes. Especially the consideration of realistic boundary conditions, for instance such as occurring during processing, is a great advantage of the FEM over the other methods. However, application of the method to forming simulations of "real" parts suffers from the fact that a huge number of single orientations are needed to approximate the crystallographic texture of real polycrystals.

This problem was recently solved by the introduction of the Texture Component Crystal Plasticity FEM (TCCP-FEM, [3]). This novel method works by using so called texture components for the texture approximation instead of single orientations. Comparison of experiments and numerical simulations for different forming operations has shown the feasibility of this idea.

In this study the TCCP-FEM is used for the prediction of deformation textures under plane strain or near plane strain conditions. The dependence of the resulting texture on the FE model (2D vs. 3D), its exact boundary conditions (fully prescribed boundary conditions vs. partially free boundary conditions) and starting texture (random vs. experimentally measured) is studied for fcc materials.

FE models used

Simulations of plane strain compression were carried out using the TCCP-FEM. Four different meshes were used as shown in figure 1: first a quadratic 2D model consisting out of 30 by 30 4 node quadratic elements, second a 3D model consisting of one layer of 900 (30x1x30) 8 node brick elements third a cube consisting of 1000 (10x10x10) 8 node brick elements and finally a mesh with 10000 (10x100x10) 8 node brick elements. Two kinds of boundary conditions were used in the simulations: first we impose ideal plane strain deformation to the outer surfaces, i.e. the z-axis (y-axis for the 2D model) is the compression axis, x-axis is the direction of elongation and for the 3D models the movement of the xz-sample surfaces in +/-y direction is restricted to zero, all surface planes (lines in the 2D case) are forced to stay planar. The second set of boundary conditions is the same only the yz-sample surfaces (edges parallel to y-axis in 2D) are not forced to stay planar. As in both cases the boundary conditions are prescribed on the outer surfaces (edges) only, the inner



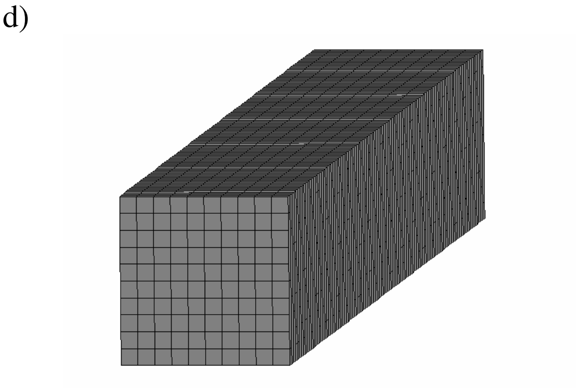


Figure 1: The four different meshes used:
a) 30x30 2D elements
b) 30x1x30 3D elements
c) 10x10x10 3D elements
d) 10x100x10 3D elememts

elements have the freedom to develop shears in all setups. However, in the 2D models only shears in the rolling and in the normal direction are possible, while for the 3D models also transverse shears are possible.

In the first set of calculations we used a random starting texture, i.e. in the framework of the TCCP-FEM we choose one random component, so that one random orientation is assigned to each integration point. In a second step simulations were performed using a typical fcc hot rolling texture as starting texture (we used the data published in Zhao et al. [4]) We used the usual set of the twelve slip systems for the fcc lattice, i.e. the {111}<110> slip systems.

Results and Discussion

2D model versus 3D model The 2D models are more constraint than the 3D models as a 2D mesh does not allow transverse shear. Figure 2 shows a comparison of the deformed meshes after a height

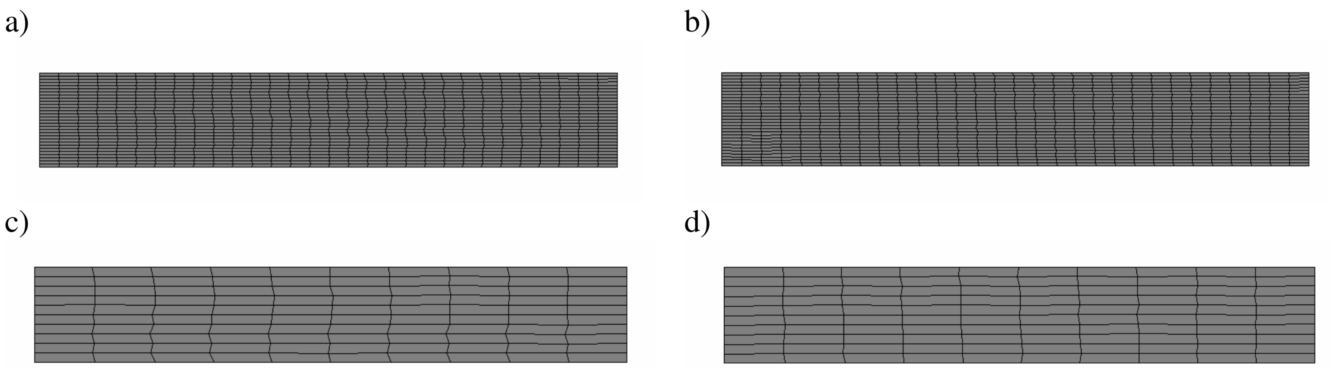


Figure 2: Side view of the deformed mesh after 60% height reduction. a) 2D model b) 3D model one element layer c) and d) 3D model 10 element layers; a) – c) random starting texture d) hot rolling texture as starting texture

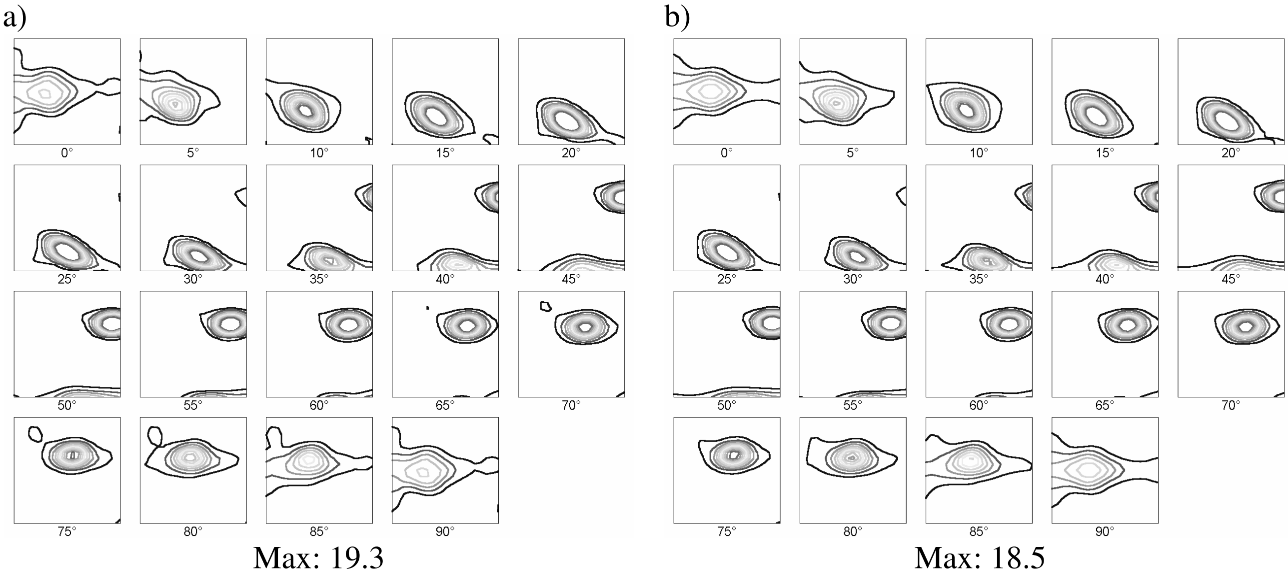


Figure 3: ODF (φ_2 = const. sections) after sixty percent height reduction with fully prescribed boundary condition, isoline levels 1, 2, 3, …, 10
a) 2D model b) 10x10x10 element mesh

reduction of 60% for the 2D model and the 3D models with one and ten element layers, respectively. All simulations were carried put using boundary condition 1, i.e. perfect plane strain conditions for the outer surfaces. It can be seen, that these boundary conditions are realized by all systems by shearing the element layers alternatingly. There are no marked differences to be seen for the different meshes (figure 2a) to c)) as well as for the different starting textures (figure 2c) and d)) When we compare the ODF plots for the first three simulations, which all used a random starting texture also no marked differences are seen between the simulations (Figure 3 shows the results for the 2D model and the 10x10x10 element mesh as example).

In the following we will therefore concentrate on α-fibre plots, which show more clearly the

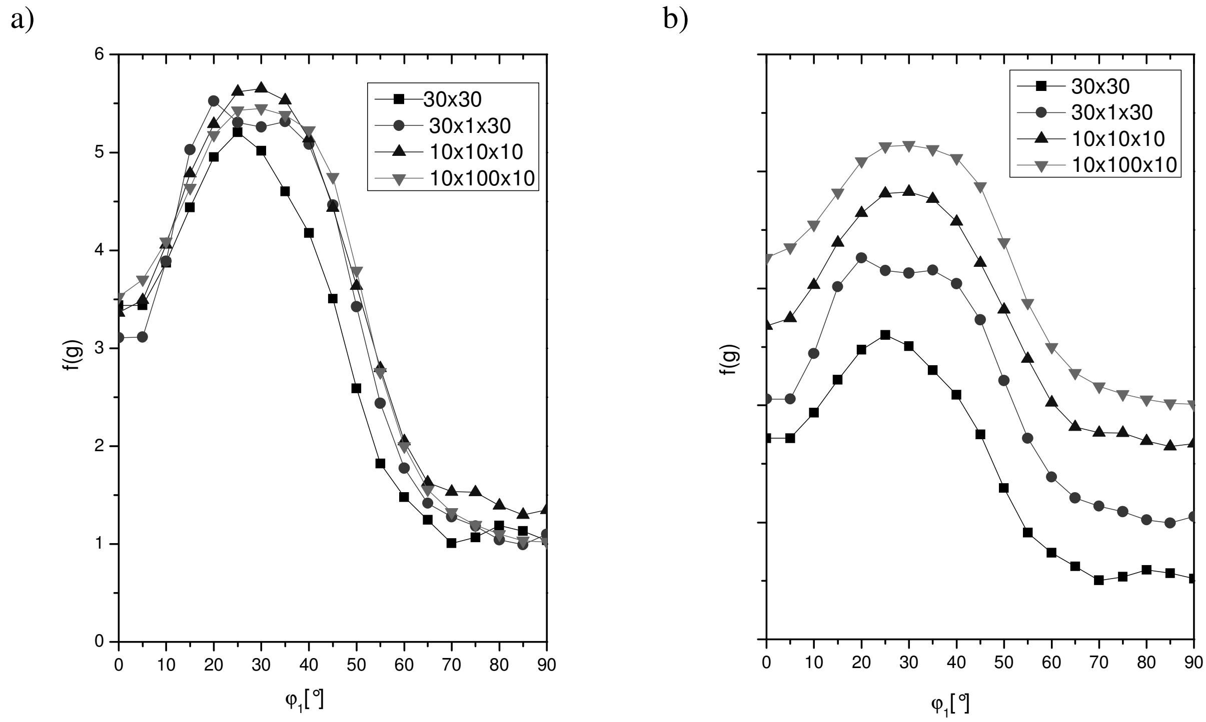


Figure 4: α-fibre plots for the 4 different models after 60% height reduction with fully prescribed boundary conditions a) direct comparison b) displaced curves

differences between the models. Figure 4 shows the final α-fibre for all four models with fully

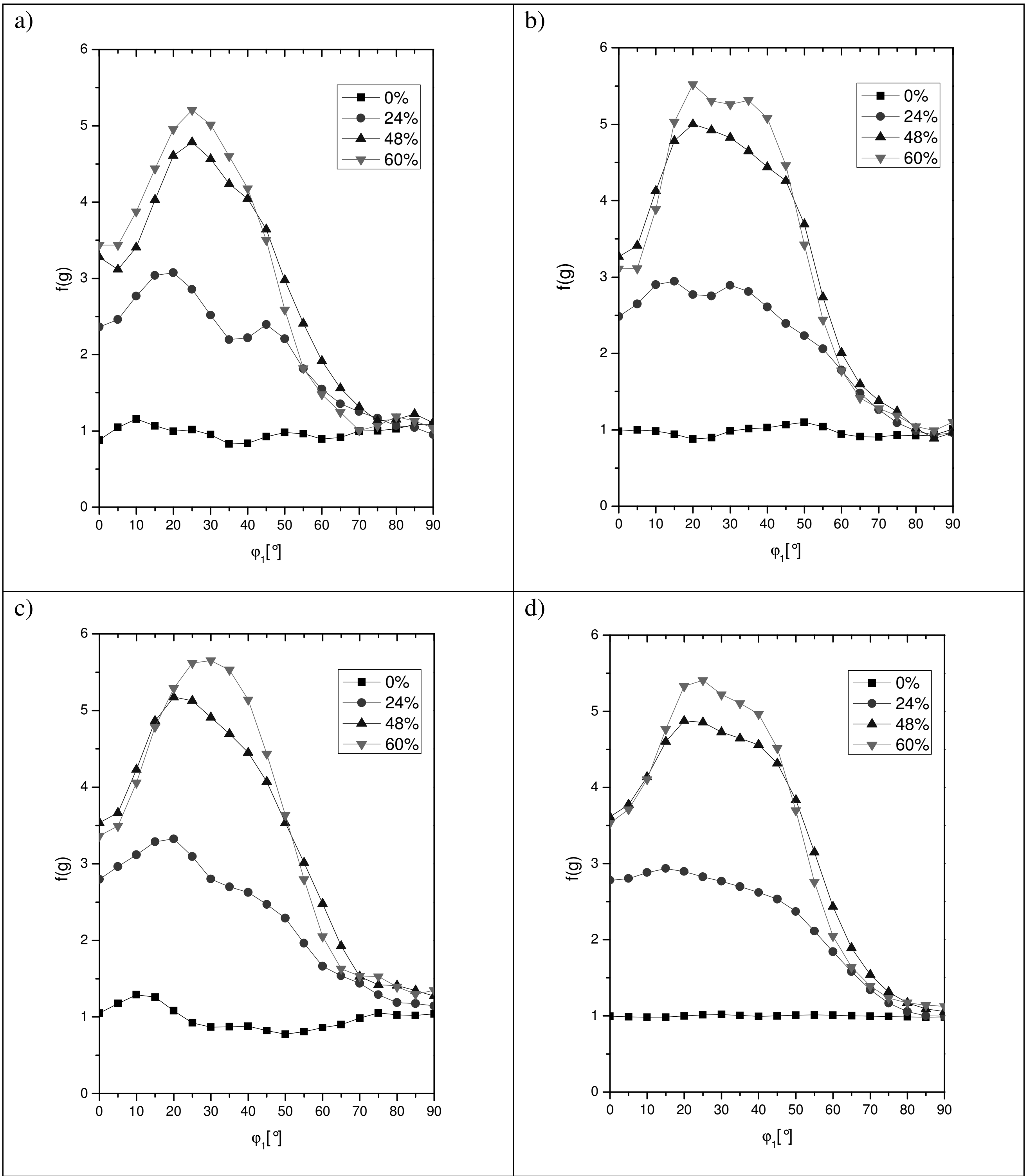


Figure 5: Development of the α-fibre with increasing deformation for the four meshes studied and fully prescribed boundary conditions

a) 30x30 2D elements | b) 30x1x30 3D elements

c) 10x10x10 3D elements | d) 10x100x10 3D elements

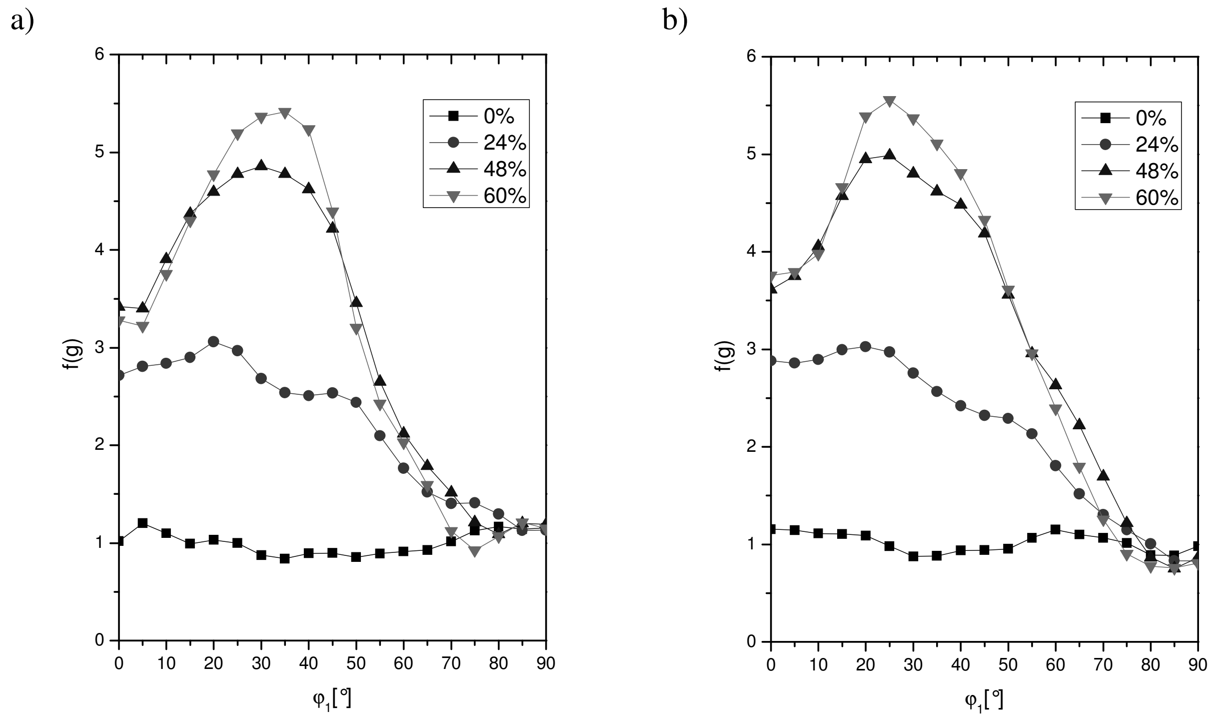


Figure 6: Development of the α-fibre with increasing deformation for two of the meshes studied and partially relaxed boundary conditions
a) 30x30 2D elements b) 10x10x10 3D elements

prescribed boundaries after 60 % height reduction. For clarity we displaced the different curves with respect to each other in figure 6b). It can be seen, that while the overall intensity level is about equal for all simulations, the position of the maximum shifts systematically from $\varphi_1 = 25°$ to $\varphi_1 = 30°$ going from the 30x30 to the 30x1x30 to the 10x10x10 and finally to the 10x100x10 element mesh. $\varphi_1 = 30°$ is the position, where the maximum is also found experimentally [5]. At the same time the peak width increases, where the 2D simulation shows a much sharper peak than all the 3D simulations.

The development of the α-fibre with increasing deformation is shown in figure 5 for all four meshes and fully prescribed boundary conditions. In this comparison it can be seen, that the differences between the models are more pronounced for the smaller deformations. However this is partly due to the weak statistics of the simulation results so far. As we use the TCCP-FEM starting with only one random component, the starting textures are not identical and certainly not perfectly random. It can be clearly seen that the largest model shows the best randomness for the starting texture, as it has at least ten times more elements than the other mesh. As the 2D elements have four integration points only, the factor for the number of integrations point is even bigger in this case, namely 22.

Fully prescribed versus partially free boundary In a second set of simulations the boundary conditions were relaxed in that the planes perpendicular to the x-axis were not forced to stay planar anymore. Figure 6 shows the development of the α-fibre for the 2D mesh and the 3D mesh with 10x10x10 elements. These have to be compared with figure 5a) and c). Once again no marked differences are found. Probably the slight difference in the boundary condition is not sufficient to change the overall deformation behaviour. However, for the calculations using a hot rolling texture as starting texture, we do see differences for the two sets of boundary conditions.

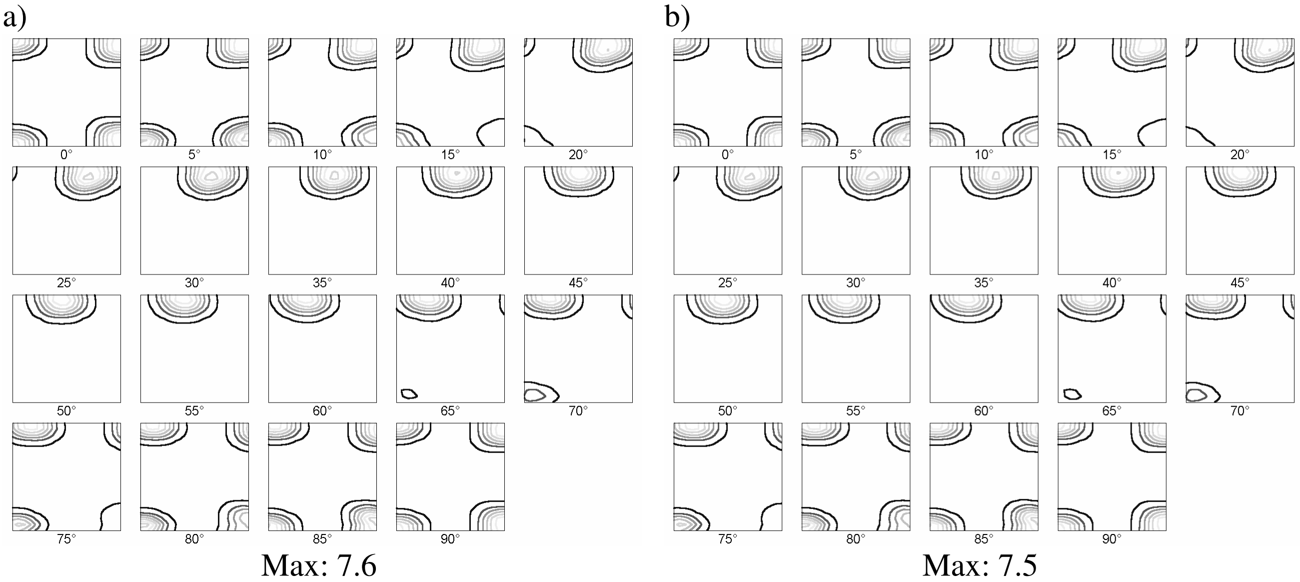


Figure 7: Starting ODF (φ_2 = const. sections) for two different calculations using a hot rolling texture as starting texture, isoline levels 1, 2, 3, …, 10
a) 10x10x10 element mesh, fully prescribed boundary condition
b) 10x10x10 element mesh, partially relaxed boundary condition

Hot rolling starting texture It is very well known that the correct starting texture plays a key role in the prediction of deformation textures. Therefore another series of simulations was performed using a typical aluminium hot rolling texture as starting texture. Figure 7 shows the starting ODF as created by the TCCP-FEM from the given component information for two different calculations. We used the data as given in [4], that is we used one near cube component (φ_1 = 197.87°, ϕ = 6.47°, φ_2 = 245.00°) with 15.27° scatter and a volume fraction of 29.03 % the remaining 70.97 % are modelled by one random component, moreover we assumed orthorhombic sample symmetry. It can be seen again that due to the random procedure used during mapping the components to the FE mesh the two ODFs differ slightly from each other. However, as they show a rather pronounced texture the deviations are much smaller than in the fully random case. This can also be seen from figure 8, which shows the development of the α-fibre for the 10x10x10 element mesh with fully prescribed and partially relaxed boundary conditions. Even though the difference between the two boundary conditions is quite small and no big effect was found for the random starting texture these two fibre plots do show some characteristic differences. While both simulations start at an almost constant intensity level of about 0.8, the calculation with fully prescribed boundary develops a much sharper peak than the simulation with partially relaxed boundary condition. In the first case an absolute maximum of about 4.5 is reached, while for the second case we find a much broader peak with an absolute maximum of about 4. Also the position of the maximum deviates clearly for the two simulations. In the first case it is found near φ_1 = 35° and in the second case the absolute maximum is shifted to a much lower angle of φ_1 = 20°. However it should be mentioned, that for the second simulation we find a plateau between φ_1 = 15° and φ_1 = 40° with almost constant intensity.

a) b)

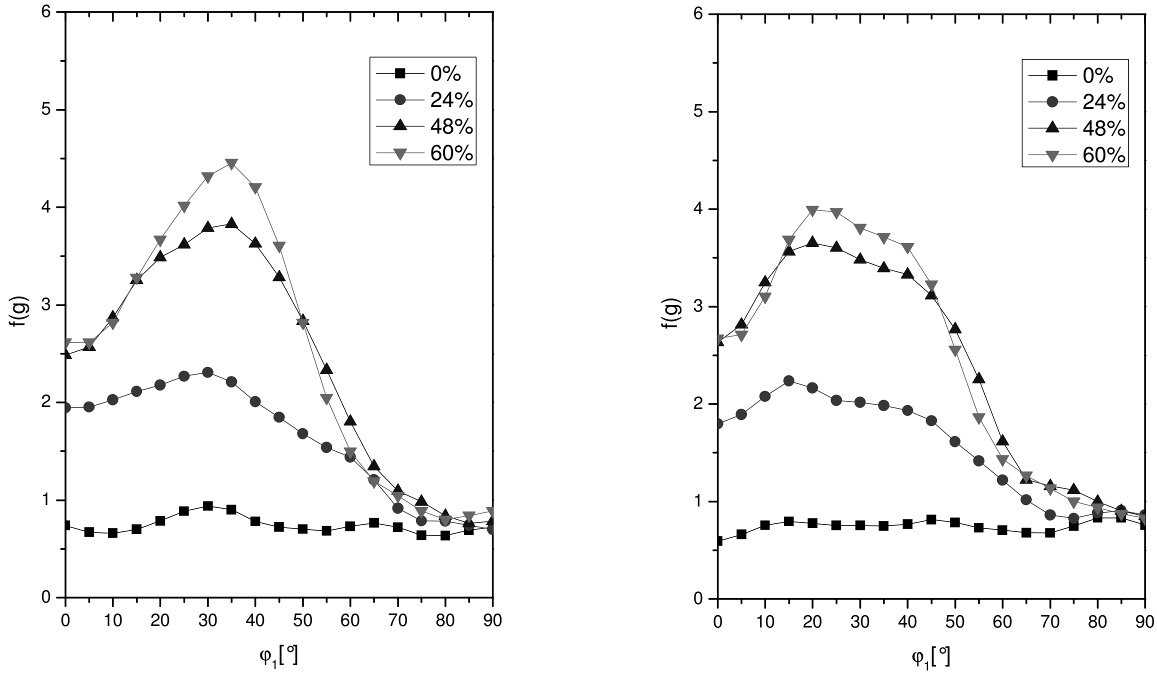


Figure 8: Development of the α-fibre with increasing deformation for a hot rolling starting texture
a) 10x10x10 element mesh, fully prescribed boundary condition
b) 10x10x10 element mesh, partially relaxed boundary condition

Summary

For the simulations with a random starting texture it can be summarized, that neither the mesh nor the exact boundary condition shows a big influence on the texture development. There might be systematic deviation for the 2D model (much sharper peaks in the α-fibre plot), but these have to be confirmed by additional simulations due to the statistic element in the TCCP-FEM. In opposition to these findings the results for a more realistic starting texture do show marked differences for the two different boundary conditions. Moreover first results not shown here also indicate a much more pronounced influence of the mesh geometry.

In the future more simulations will performed to eliminate the influence of the statistical orientation mapping procedure of the TCCP-FEM. Finally the influence of friction will be an additional aspect to study. All simulations shown here were free of friction.

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