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EFFECT OF INITIAL GRAIN SIZE AND SHAPE ON TEXTURES IN SHEET STEEL

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ABSTRACT

Steel samples have been prepared with a range of different equi-axed grain structures and with columnar grains having an aspect ratio of ~ 20:1. These have been cold rolled to different reductions and the textures examined using ODFs. Computer simulations have been carried out using various models of constraint. Starting textures were quite weak but these had nevertheless a major influence on resulting deformation textures. Grain size and shape appear to play subordinate roles.

INTRODUCTION

It is now well established (e.g.[1]) that the rolling texture of iron or low carbon steel comprises two main fibres. One of these is the partial α-fibre with <011>//RD extending from {100}<011> to {111}<011>, and the other is the complete <111>//ND γ-fibre having only minor deviations in its position and intensity. The latter fibre is particularly important because it is retained with relatively small modification after recrystallisation and thereby controls the deep-drawability of annealed steel sheet. Whereas annealing textures are known to vary considerably depending on steel chemistry, microstructure, and processing, it is generally held that the textures developed on cold rolling are rather invariant. However, closer scrutiny of some factors such as initial grain size and texture is justified since these have been observed to affect the rate of texture formation in other metals[2]. Numerous attempts have been made to predict rolling textures in (bcc) steels using computer simulations. Application of the fully constrained Taylor model with {110}<111> planar glide predicts a 'β-fibre' texture from {11,11,8}<4,4,11> to {211}<011> with some spread towards {100}<011>[3]. Sachs type models with the same slip mode lead principally to {211}<011>. Neither of these upper or lower bound models is compatible with the observed γ-fibre, especially in the vicinity of the {111}<011> orientation.

Use of {hkl}<111> pencil glide or an admixture of {112}<111> slip produces only minor changes in the deformation texture predicted according to the Taylor and Sachs models[4, 5]. Effects of different critical resolved shear stresses and asymmetry on the {112}<111> systems have also been investigated[6]. Textures predicted according to the Taylor model varied considerably but in no case did they approach closely to reality, especially regarding the γ-fibre texture.

Relaxed constraint models have also been tested for bcc metals[5, 7]. For a lath model (de_{13} relaxed) employing {110}<111> planar glide it is found that the {111}<112> orientation is stabilised as opposed to {11,11,8}<4, 4, 11> which agrees with experimental observation. However, other components in the γ-fibre are not predicted to occur. Pencil glide assumptions together with the

lath model give even less good agreement[7]. When a pancake model of deformation is assumed (de_{13} and de_{23} relaxed), the α-fibre is predicted to occur spreading from {100}<011> as far as {111}<011>. In this case, however, the {111}<112> end of the γ-fibre is not satisfactorily explained.

Thus, none of the models so far tested can explain fully the normal texture of steels and other bcc metals. The present work was therefore aimed at further investigation by use of carefully controlled starting materials and various analytical methods. Most of the relaxed constraint models are based on principles relating to grain shape. To test these more critically, a steel sample has been prepared having an initial (texture-free) columnar structure for comparison with the more usual equi-axed structures. Grain size has also been varied in the starting materials.

EXPERIMENTAL PROCEDURE

Starting materials were low carbon steel hot bands which were then laboratory heat treated in order to vary the grain structures prior to cold rolling. In all cases the final heat treatment involved decarburisation to ~ 10 ppm C in wet hydrogen. Four different grain sizes, A = 13 μm, B = 18 μm, C = 39 μm and D = 94 μm were achieved as described elsewhere[8].

One hot band (Q/M) was first carburised to a level of 0.5 % C in the austenite temperature range and subsequently decarburised at 790° C for 5 days. The resulting structure had columnar grains extending from the sheet surfaces and an equi-axed zone as the central 20 % of the sheet thickness.

Samples were reversibly cold rolled with good lubrication. Examination was made using optical microscopy and ODF texture measurements as described elsewhere[9]. By chemically thinning to different depths it was possible to measure textures in both the columnar (Q) and equi-axed (M) grain regions of the sheet QM.

RESULTS

The equi-axed materials A - D showed the normal type of grain flattening after rolling to different reductions. Micrographs showing the sample Q/M in the starting condition and after rolling to different reductions are given in Fig. 1. The columnar grains had an average diameter of 50 μm and length of ~ 1000 μm in the initial state. These grains become progressively shortened on rolling and were approximately equi-axed when viewed in the TD section after

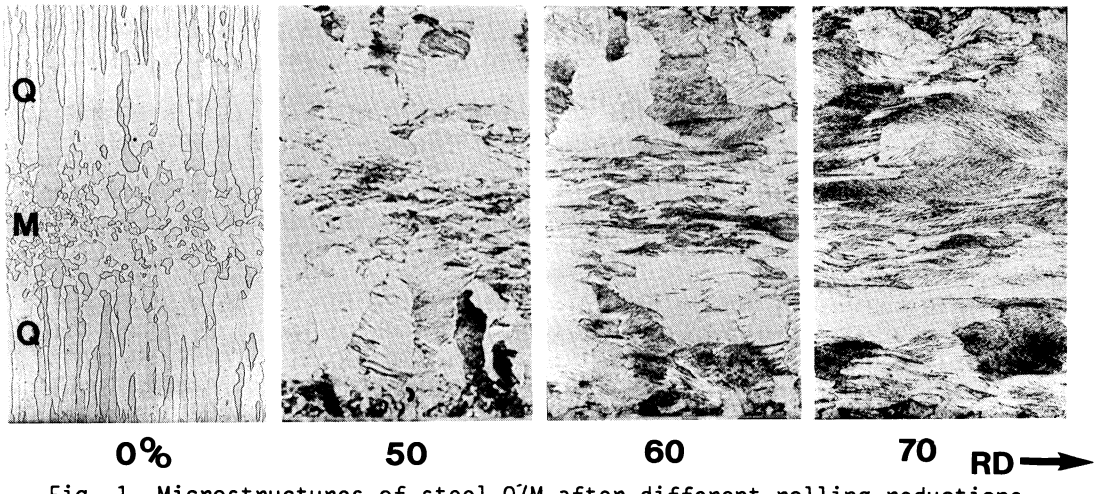

Fig. 1 Microstructures of steel Q/M after different rolling reductions.

70 % reduction which is in agreement with a state of homogeneous plane strain compression. The central (M) zone of this specimen produced the usual flattened and elongated structure.

Initial textures were generally weak but not random as shown by the φ_2=45° sections in Fig. 2 for materials A, C, M and Q. They may be described as

A (13 µm equi-axed) random (slight cube)
C (39 µm equi-axed) strong α-fibre {100} to {211}<011>, 5 x R
M (50 µm equi-axed) strong cube//ND, {001}<100>, 4 x R
Q (50 µm x 1000 µm columnar) ~ random, slight Cube//ND and γ-fibre, 1.5xR

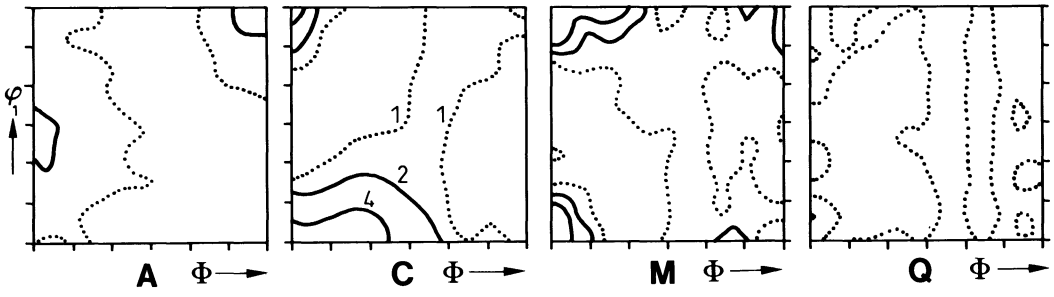

Fig. 2 φ_2 = 45° sections of ODFs of the starting textures.

After cold rolling, the expected α- and γ-fibres were developed but some differences existed between the different materials. Figure 3 shows φ_2 = 45° sections after 80 % cold rolling. Steels A - D, irrespective of grain size, produced a major peak in the vicinity of {233}<011> which was not evident in either M or Q. This discrepancy, as well as variations within the strength of the α-fibre can be traced back to starting textures. For example, materials C and M had very similiar initial microstructures but developed rather different rolling textures due to the presence of an initial α-fibre in C. Orientation densities along the α and γ fibres (80 % reduction) are shown in Fig. 4 (a) and (b) together with the position of the γ-fibres in Fig. 4 (c). The most perfectly developed <111>//ND γ-fibre texture is found in the columnar grained steel Q where the {111}<011> end of the fibre is most symmetrical. In all cases the orientation density was maximum within 2° of {111}<112> and was not located at the Taylor orientation {11,11,8}<4,4,11> which is 8° away from this.

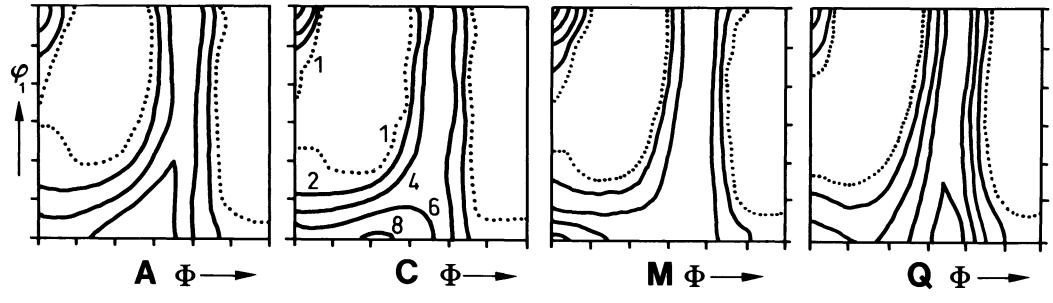

Fig. 3 φ_2= 45° sections of ODFs after 80 % cold rolling reduction.

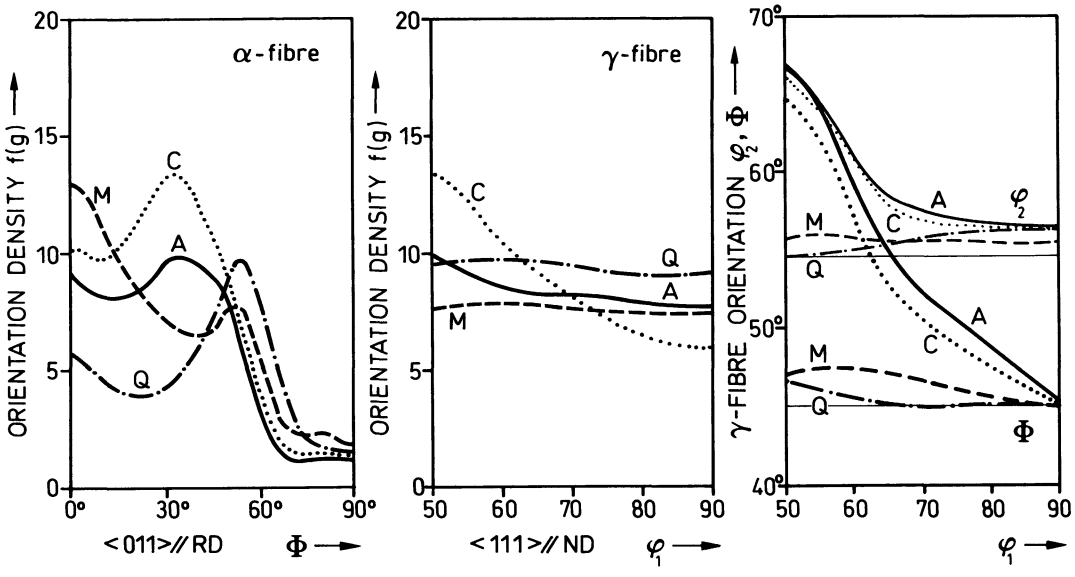

Fig. 4 Orientation densities and γ-fibre position after 80 % rolling reduction

ANALYSIS

Simulations of the rolling textures have been carried out using the measured initial textures as starting points, assuming {110}<111> glide and a variety of different relaxed constraints conditions as described previously[10]. Model F is the fully constrained Taylor condition. C is the 'lath' model where only de_{13} is relaxed whereas the transverse shear de_{23} is relaxed in S. Model SC is the 'pancake' model where both these shears are relaxed. Examples of some of these simulations are given for steel Q in Fig. 5 (compare Fig. 3 (d)), while positions of the predicted skeleton lines are shown in Fig. 6 for cases where the initial textures were assumed to be random. The significance of initial textures was clearly evident when comparing the simulated textures. This is an important point since it emphasises the difficulty of drawing conclusions about mechanisms of texture evolution. Even weak starting textures have a distorting effect. Present observations supported by theoretical simulations show that the

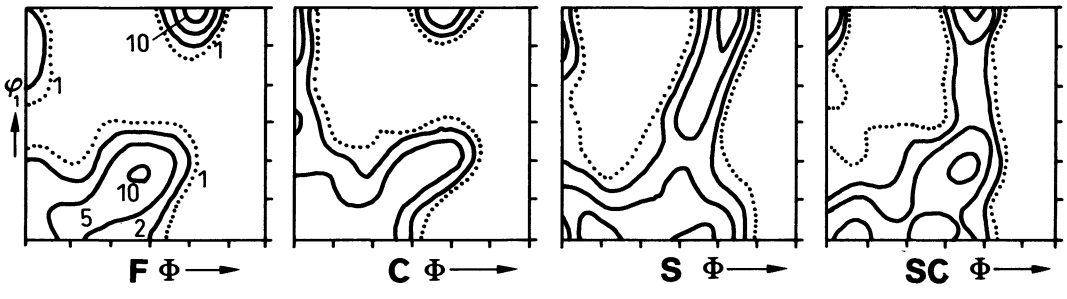

Fig. 5 Simulated rolling textures (φ_2 = 45°) according to different models based on the initial texture present in steel Q.

final texture is a strong α-fibre in cases where (i) cube is present, due to ND and subsequent RD rotations (e.g. A) or (ii) cube//ND is present (M) or (iii) α-fibre orientations are already present (C). Excepting these cases, most orientations rotate into the γ-fibre (e.g. Q). However, even when the known starting textures were taken into account here none of the models produced realistic simulations of the complete experimental textures. Closest approach was found for the pancake model SC or BSC where also the strain de_{21} is relaxed.

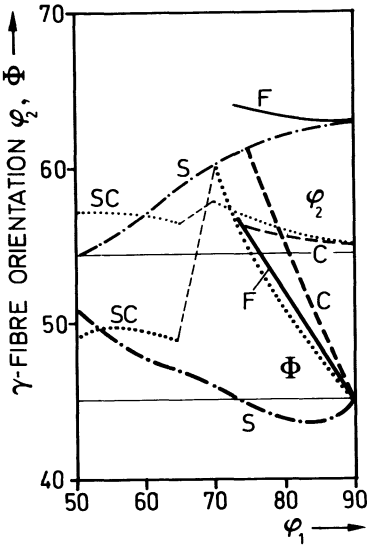

Fig. 6 Calculated positions of the γ-fibre according to different models of constraint relaxation (ref. 10).

DISCUSSION

While the present observations do not rule out some effect of grain size, examination of observed and simulated texture evolutions suggest that the differences observed for different initial grain sizes are probably most attributable to variations in their starting textures. A previous report of a coarse grain size effect[1] was for material processed in a similar way as for the present steels C and D. The close agreement observed between all these textures suggests that starting texture may also have played a significant role in the earlier work.

More interesting are the observations relating to the initial columnar grain structure in material Q since these permit some interpretation of the concepts underlying relaxed constraint theories. These rolling textures are in fact closely similar to the corresponding equi-axed material M and show very well developed <111>//ND γ-fibres, extending fully to the orientation {111}<011> and with virtually no deviation away from the {111}<112> orientation. They are thus typical of bcc rolling textures and show no tendency towards the fully constrained Taylor condition . This situation contrasts with observations on aluminium where an initial columnar structure of similar nature was used[11] and the observed texture was of the Taylor type. However, the aluminium had an intense <100> fibre starting texture which may have been a dominant factor in those experiments. For intermediate rolling reductions (~ 70 %) the grain dimensions (d) in steel Q can described as $d_{ND} \sim d_{RD} > d_{TD}$. On a geometrical basis[12] it is not therefore justifiable to relax constraints of the type de_{13} or de_{23} although some freedom in de_{12} might be possible.

Thus, even though the pancake model (SC) of texture formation does bear some similarity to observation, it is not apparently as a result of grain shape. Constraints associated with grain boundaries have been suggested as playing a significant role[13] in formation of the γ-fibre but this is not supported by the relative insensitivity to grain size and shape observed here. Other patterns of constraint relaxation must be considered, possibly involving cooperative effects within clusters of grains as has recently been discussed in connection with rolling textures in fcc metals[14].

CONCLUSIONS

Rolling textures in iron are sensitive to the starting texture of the metal even when this is quite weak. Initial grain size appears to have a relatively minor effect on development of the deformation texture. An initial columnar grain structure does not affect rolling texture evolution to any major extent which indicates that grain shape is not the principal source of constraint relaxation.

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