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Influence of Textured Clusters on the Goss Grains Growth in Silicon Steels Consideration of Energy and Mobility

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Abstract**—**In the Fe-3%Si sheets, grade Hi-B, with AlN and MnS as inhibitors, the Goss grains which abnormally grow do not have a size greater than the average size of the primary matrix. In this heterogeneous microstructure, the size factor is not a required condition for the secondary recrystallization. The onset of the small Goss grain abnormal growth appears to be related to a particular behavior of their grain boundaries, to the local texture and to the distribution of the inhibitors. The presence and the evolution of oriented clusters ensure to the small Goss grains a favorable neighborhood to grow. The modified Monte-Carlo approach, which is applied, considers the local environment of each grain. The grain growth is dependent of its real spatial position; the matrix heterogeneity is then taken into account. The grain growth conditions are considered in the global matrix and in different matrixes corresponding to A component clusters. The grain growth behaviour is considered with introduction of energy only, energy and mobility, energy and mobility and precipitates.

Keywords**—**Abnormal grain growth, grain boundary energy and mobility, neighbourhood, oriented clusters.

I. INTRODUCTION

HILLERT'S classical theory predicts the abnormal growth of the largest matrix grains, the normal or abnormal growth are linked to the matrix average radius [1]. In Fe–3%Si sheets of HiB type, with AlN and MnS inhibitors, the grain distribution is generally heterogeneous in terms of sizes and orientations, the Goss grains that abnormally grow do not have a size greater than the average size of the primary matrix. The Goss grain growth problem was over and over again studied. Two theories have been developed during these last years. The first is based on the hypothesis that the general boundaries with the high energy are responsible for the Goss grains growth [2-4], the second suggests the possible role of the CSL boundaries specially $\Sigma 9$, $\Sigma 7$ and $\Sigma 5$ on abnormal growth [5-8], the stagnation of normal grain growth and the presence of CSL boundaries around the potential secondary grains. No explanation for the selection mechanism has been offered, the high-energy boundaries have higher mobility than CSL boundaries, while these are less stopped by the impurities [9]. The abnormal growth of Goss grains appears to be linked to a special behavior of their boundaries in relation with impurities. In a heterogeneous structure it can be related to the local texture and to the presence of textured clusters [10,11]. The growth of a given grain is related to the evolution of its surrounding grain boundaries and not to the average evolution of the totality of the matrix, the mean parameters of the matrix can hide the effect of the real neighborhood for a grain located in a textured cluster.

II. SIMULATION PROCEDURE

TABLE I
ENERGY AND MOBILITY VALUES FOR GRAIN BOUNDARIES DISORIENTATIONS [15]
G ≡ {110}<001>; A ≡ ~{111><112>; B ≡ {100}<012>; R ≡ RANDOM

	G – A	G – B	G – G	A – A	A – B
Energy constant (J.m^{-2})	0.33	0.26	0.25	0.45	0.36
Mobility constant	2.5	0.1	0.1	0.2	2.3
Grain boundary	B – B	B – R	A – R	G – R	R – R
Energy constant (J.m-2)	0.25	0.35	0.38	0.3	0.65
Mobility constant	0.1	2.5	2.5	2.5	0.4

The Potts model based on Monte-Carlo technique [12, 13] is modified. The Monte-Carlo approach which is applied in this study for the consideration of the oriented cluster effect can be considered as a deterministic model [14]: sites are not characterized by an orientation number, but by a triplet ($\varphi 1$, φ, $\varphi 2$) corresponding to its real orientation in Euler space, the anisotropic grain boundary migration is considered; the matrix heterogeneity is taken into account. The M and J used values are reported on the Table I.

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III. EXPERIMENTAL PARAMETERS

In order to study the abnormal grain growth of Goss grains, the simulation procedure has been implemented using a real matrix Fe3%Si (HiB) characterized by EBSD and constructed A matrixes with maximum function near to {554}<225> orientation with different dispersion.

Fig. 1 shows the primary matrix microstructure and the corresponding {100} pole figure. The considered matrix consists of a component A with a maximum near to {554} <225>, a component B with a maximum near to {100} <012>, all remaining orientations are considered random. The fraction of Goss grains is less than 1%.

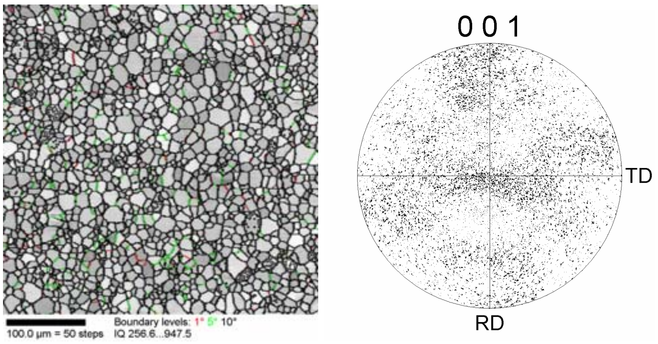


Fig. 1 Initial matrix and the corresponding {100} pole

The oriented volumes of A and B components are obtained from the maxima lines of the ODF (Orientation Distribution Function), the orientations of each component are achieved on each section of tube profile (Fig. 2).

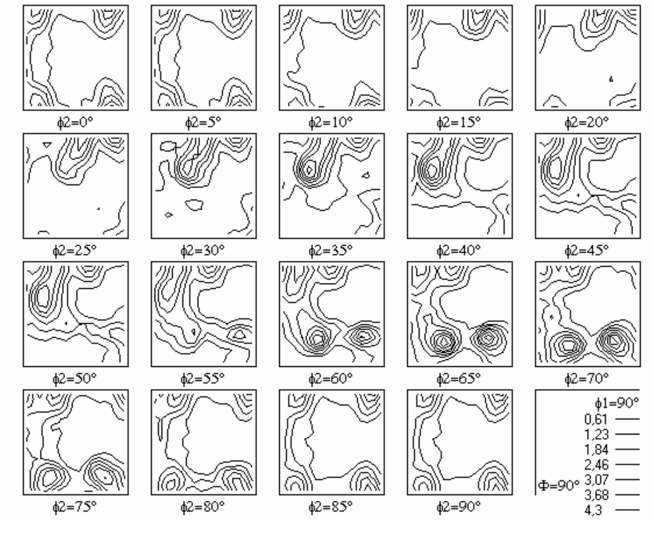
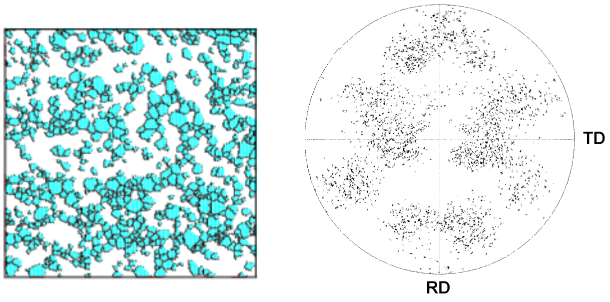
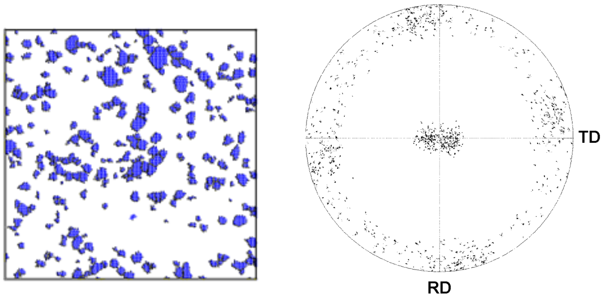


Fig. 2 Sections of ODF at Φ2 constant

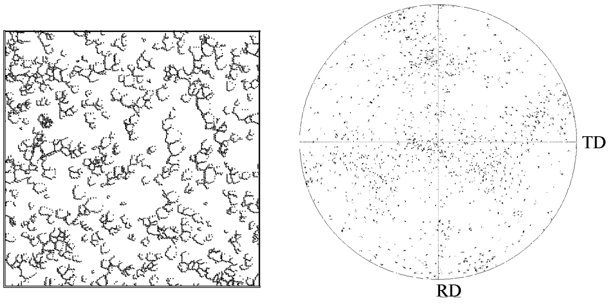
Spatial distributions and corresponding {100} pole figures of the reconstructed matrixes are reported on the Fig. 3. That selection example is obtained with dispersion equal to 12.5° around the maxima lines of ODF. We have considered different dispersions for the cluster influence consideration.



A matrix, vol. fraction ~50%



B matrix, vol. fraction ~25%



Random, vol. fraction ~25%

Fig. 3 Spatial distribution and {100} pole figures of the reconstructed matrixes. Selection obtained with dispersion equal to 12.5° around the maxima lines of ODF

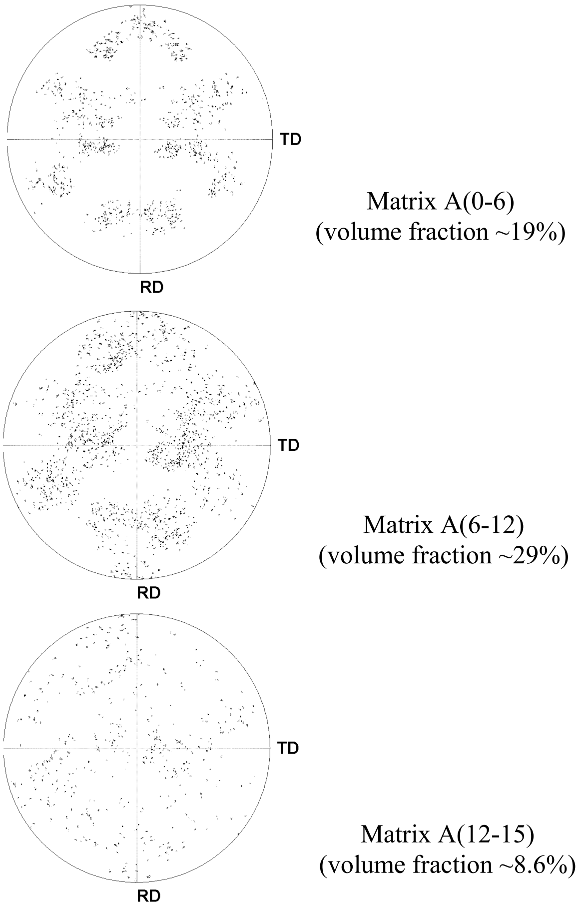
IV. ORIENTED CLUSTERS

Previous study shows that the Goss grains disappear in B clusters while they can grow abnormally in A clusters [10, 11]. In the present work, the impact of A component on the Goss grain growth is considered in different oriented clusters A. For the dispersion equal to 15°, the A tube orientations are separated, on three parts. The fractions of each part are regrouped in Table II.

TABLE II
FRACTIONS OF THE CONSIDERED A MATRIXES (PARTS OF TUBE A)

Matrix	A(0-6)	A(6-12)	A(12-15)
Misorientations / skeleton line (°)	0-6.5	6.5-12.5	12.5-15
Fraction (%)	19.07	29.07	8.63
Fraction 0°-12°	48.14		▨
Fraction 0°-15°	56.77		

The Fig. 4 shows {100} pole figures for the three considered A matrixes, with different deviations around skeleton line of A component:
1- matrix A(0-6) with the dispersion around skeleton line equal to 6.5° (volume fraction ~19%) (Fig. 4a),
2- matrix A(6-12) with disorientations around skeleton line between 6.5° and 12.5° (volume fraction ~29%) (Fig. 4b),
3- matrix A(12-15) with disorientations around skeleton line between 12.5° and 15° (volume fraction ~8.6%) (Fig. 4c).



Matrix A(0-6)
(volume fraction ~19%)

Matrix A(6-12)
(volume fraction ~29%)

Matrix A(12-15)
(volume fraction ~8.6%)

Fig. 4 Pole figures for the three considered A matrixes

V. Results and Discussion

The grain growth behaviour is considered in the global matrix and in the different oriented clusters with introduction of: energy only, energy and mobility, energy and mobility and precipitates. All the considered grains have the same local environment in size and shape of neighbours in the initial step of grain growth, only orientation parameter is different at initial stage of growth.

The initials characteristics of the considered Goss grains are regrouped in Table III.

TABLE III
Goss Grains Characteristics: Initial Size, Average Size of Neighbours and Surrounding Disorientations at Initial Step

Grain	G15	G24	G25	G39
Δθ° / {110}<001>	1.63	1.57	1.63	1.75
Grain size [sites]	15	24	25	39
< neigh. size> in global matrix	57	40	18	19
Misorientations in global matrix	5G	2G, Σ19	5G,Σ9, 1CAD,	5G, 1CAD
<neigh.size > in A matrixes	36.60	45.25	43.75	26
Misorientations in A(0-6)	1G,3LA, 1CAD	2G,3LA	1G,4LA, Σ 33	4G,2LA
Misorientations in A(6-12)	4G,1LA	3G,1LA	3G,1CAD	4G,1LA, Σ5
Misorientation in A(12-15)	4G, 1CAD	3G, Σ 9	2G, 2LA,	5G, 1CAD

A. Goss Grain Growth in the Global Matrix

When only energy is considered, all Goss grains disappear in the global matrix, also those that grow rapidly in the beginning (Fig. 5). With the introduction of mobility, only the largest grain G39 (39 sites) and G25 (25 sites) persist and do not vanish. The consideration of both energy and mobility parameters implies a growth behavior linked to a morphological selection.

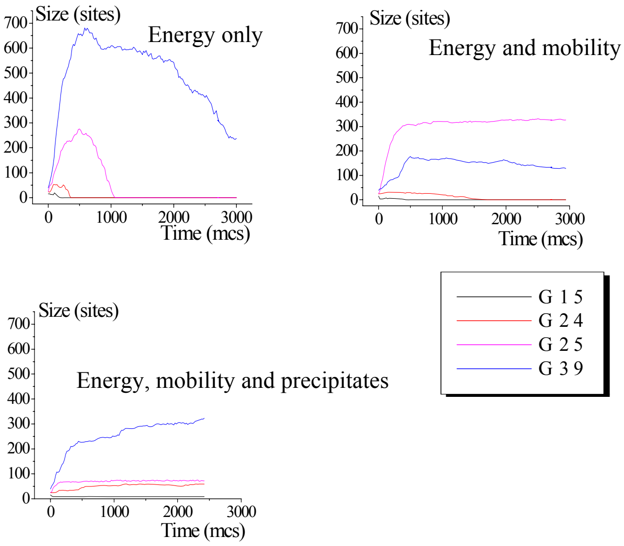


Fig. 5 Goss grain growth in the global matrix

With the introduction of inhibitor effect, only G39 (39 sites) grain can grow abnormally, while the grains G24 (24 sites) and G25 (25 sites) grow normally and G15 (15 sites) disappear. The morphological effect emphasize again.

B. *Goss Grain Growth in A Matrixes*

All Goss grains can grow in A matrixes, the Fig. 6 shows the results with consideration of energy and mobility. It is considered that the evolution of neighbors is similar in the 3 matrixes. It is assumed that the different behaviors are caused by disorientations around the grains in these matrixes. The Goss grains grow better in presence of special grain boundaries particularly Σ9, Σ11, Σ27 and Σ5.

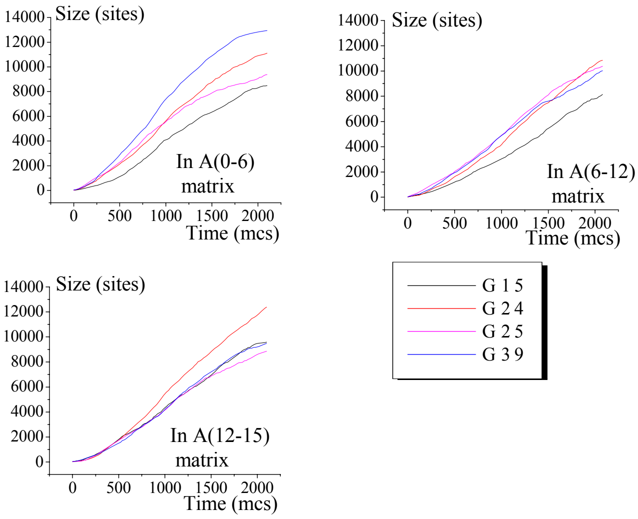


Fig. 6 Goss grain growth in A matrixes (energy & mobility)

C. *Growth Behaviour of the Smallest Goss Grain (5 Sites)*

With the introduction of the precipitates in addition of energy and mobility, the smallest grain G5 (real grain with 5 sites which exists in the initial matrix obtained by EBSD) can grows, especially in A(0-6) matrix, where that smallest grain is often surround by special boundaries Σ9 and it grows (Fig. 7).

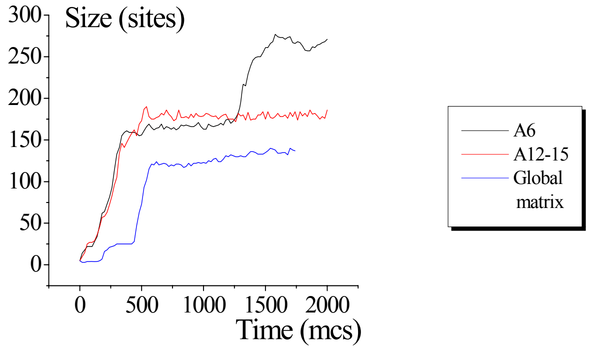


Fig. 7 Growth of the smallest Goss grain (5 sites)

It can be seen, in the presence of precipitates, the kinetics of grain growth reveal the existence of levels, in three matrixes A(0-6), A(12-15) and global matrix. The growth mechanism seems to be constituted of several successive steps of stagnation and evolution. That behavior can be related to an adequate neighborhood in oriented cluster.

VI. CONCLUSION

The present study performed on Hi-B sheets in Fe-3%Si alloys, reveals that the heterogeneous structure of the primary matrix ensures a favourable crystallographic neighbourhood to the small Goss grains, for the onset of their abnormal growth. It is the presence of oriented clusters A which gives that favourable neighbourhood, by providing them first the presence of special boundaries especially Σ9, second the presence of small neighbours. A selective growth of the Goss grains in textured clusters of small grains with orientation A can conduct to a strong Goss texture with a small dispersion. That selective growth in textured clusters A can conduct to the increase in size before the abnormal growth. As well, when the energy is only considered, all Goss grains disappear, even those that grow rapidly in the beginning, whereas the introduction of mobility in addition to the energy induces the stability of some Goss grains; also, the presence of precipitates permit to the smallest Goss grains to grow abnormally.

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