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Recovery and Grain Growth in a 2% Si - 0.3% Al - 0.003% C Steel

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Abstract: The scope of our investigation covered the effect of carbon on the processes of recovery and grain growth in cold-rolled non-oriented silicon steel, of laboratory and industrial provenance. Decarburized and non-decarburized cold-rolled electrical steels were annealed in a deoxidized lead bath in the temperature range from 550 to 800°C. The microstructure was examined and average grain size assessed. The process of recovery was investigated on specimens annealed at lower temperatures by measurement of hardness. Industrially manufactured samples of non-oriented sheet were used for comparison. The sheets of both industrial and laboratory manufacture were decarburized by annealing in wet hydrogen with different dew points at temperatures ranging from 800 to 860°C. The rate of decarburization was controlled by chemical analysis of carbon.

1. INTRODUCTION

The investigation was performed on two laboratory steels of virtually identical base composition, decarburized (D1) and non-decarburized (N4), and on two industrial steels as delivered (L0) and after decarburization (L1).

2. EXPERIMENTAL

In a vacuum induction furnace and from soft iron, silicon and aluminium, two steels (N4, D1) were manufactured in the laboratory with the compositions given in table 1. The industrial steels (L0, L1), whose compositions are also given in table 1, were also examined.

Table 1: Chemical composition of the steels investigated in wt%

	C	Si	Mn	Al	P	S
N4	0,031	1,78	0,22	0,28	0,001	0,001
D1	0,0035	2,12	0,22	0,28	0,001	0,001
L0	0,017	2,00	0,27	1,00	0,020	0,003
L1	0,011	2,02	0,25	1,00	0,014	0,003

Laboratory ingots of thickness 40 mm were hot rolled to 2.5 mm strips, descaled, cold rolled to 1.2 mm, annealed for recrystallization in a vacuum furnace for 30 min. at 840°C and finally cold rolled to 0.5 mm. The industrial 2.3 mm thick strip was descaled, cold rolled to 1.2 mm; half of it was annealed for recrystallization and decarburization at 840°C to 0.0035% C and rolled to 0.5 mm. After hot rolling the microstructure of both laboratory steels consisted of coarse, elongated grains whose size and shape indicated the absence of recrystallization during the final passes. After cold rolling to 1.2 mm and recrystallization the microstructure consisted of polyhedral grains of ferrite, rare small grains of pearlite and cementite particles. After the intermediate recrystallization annealing the microstructure was very similar in all the steels with exception of the decarburized steel, which had a coarser grain size and was free of cementite and pearlite.

After cold rolling to 0.5 mm specimens were annealed in a deoxidized lead bath at temperatures in the range 550 to 800°C. Then the microstructure was examined under an optical microscope. On specimens annealed at low temperatures the hardness was measured.

3. RESULTS AND DISCUSSION

3.1 Recovery

The steels examined are classified among steels with diminished austenite stability. In steel N4 for instance, with 0,03% C and 1,8% Si the microstructure after hot rolling consists of 80% of ferrite at 950°C (1). For the static recrystallization of ferrite about 62% deformation is required (2, 3).

The processes of recovery and polygonization are very rapid in the deformed ferrite (1). At intermediate annealing temperatures, recovery and polygonization as well as recrystallization decrease strain hardening at similar rates, which depend upon the annealing temperature.

The hardness measurements showed that hardness during the process of recovery decreases as much as during recrystallization. Softening of the steels investigated was observed in the temperature range 575 to 675°C.

Figure 1: The effect of annealing time and temperature on hardness for non-decarburized laboratory steel

3.2 Nucleation and recrystallization

Recrystallization nuclei were found in laboratory steels only along shear bands (figure 2). No nucleation was observed at grain boundaries. Recrystallization continued with the formation of new nuclei and growth of nuclei inside some grains prior to their complete recrystallization, while no recrystallization visible by optical microscope occurred in neighbouring grains.

Figure 2: Recrystallization nuclei in non-decarburized laboratory steel at 550°C (Etchant.: 500 x)

Significant growth of nuclei was observed at 600°C, when the hardness decreased very fast. At lower temperatures the growth of nuclei was hardly detectable. Strain hardening decreased to the same extent in all grains, in those recrystallized to small polyhedral grains and in those where no optically visible recrystallization occurred. In grains where recrystallization was delayed because of the longer incubation time required for the formation of nuclei, recrystallization occurred at a higher temperature. This suggests that the delayed recrystallization occurred as a result of an increase in the polygonization of subgrains as suggested in ref. 4.

No difference was found between the laboratory steels in the micromorphology of formation of recrystallization nuclei. It is not clear at this moment why virtually no recrystallization nuclei were formed at grain boundaries.

Microscopic examination showed that in the non-decarburized industrial steel recrystallization nuclei appeared along deformation bands, as in the laboratory steel with a similar carbon content. In the decarburized steel the first recrystallization nuclei were found at sticking points of three ferrite grains, along grain boundaries, and in the interior of grains. The non-decarburized industrial steel showed a recrystallization process similar to that of the laboratory steel, that is to say by growth of new small recrystallized grains in the interior of deformed grains, while in the decarburized steel recrystallization also continued in the sticking area and new grains grew without regard to the initial boundaries.

3. 3 Growth of recrystallized grains

The annealing temperature was limited to 800°C with the aim of preventing abnormal grain growth (5). The lead bath was deoxidized and decarburization during annealing prevented, since it has a considerable effect on the micromorphology and kinetics of recrystallized grain growth. In figure 3 the growth of recrystallized grains is shown for both laboratory steels. Under identical annealing conditions for industrial steels the proportion of recrystallization is smaller in decarburized steel, which is also the case for both laboratory steels.

Figure 3: Average size of recrystallized grains versus annealing time

3. 4 Effect of decarburization

In figure 4 the kinetics of decarburization of non-oriented steels in wet hydrogen is shown.

Figure 4: Carbon content and time of decarburization annealing at 820°C ; the dew point of hydrogen was 40°C

Comparison of the results showed that in industrially manufactured steel the decarburization process is slower than in the laboratory steel in spite of the fact that the initial carbon content was lower. The explanation could be a difference in the permeability of carbon oxide through the oxide layer structure which formed on the surface during and after rolling. With the same annealing temperature, grain growth rate is significantly greater after decarburization.

It is evident that the presence of carbon in the form of cementite particles has a strong effect on the formation of recrystallization nuclei, on the kinetics of recrystallization and on the kinetics of recrystallized grain growth. It increases the rate of nucleation of recrystallization grains and impairs their growth rate.

4. CONCLUSIONS

1. In the laboratory and industrial non-decarburized steels investigated, recrystallization nuclei were found only inside the deformed grains. No grain boundary nucleation was found.
2. Recrystallization nuclei grow only in the interior of deformed grains. At uncompleted recrystallization the microstructure consists of completely recrystallized grains and recovered grains without any internal substructure visible by optical microscope. Both constituents of the microstructure have similar hardness.
3. After decarburization the rate of formation of recrystallization nuclei is diminished and the rate of growth of recrystallized grains is greatly increased by comparison with the non-decarburized steel.

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