Association of Metallurgical Engineers of Serbia *Scientific paper*
AMES *UDC: 669.146.018.2*

THE ROLE OF AlN PRECIPITATES IN THE DEVELOPMENT OF A STRONG (111) TEXTURE ON SUBSEQUENT COLD ROLLING AND ANNEALING OF Al-STABILIZED STEEL

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Abstract
The thermomechanical treatment consisting of either static (SSA) or dynamic strain aging (DSA) followed by cold rolling and annealing was applied to develop a strong texture in Al-stabilized steel. The effectiveness of SSA and DSA treatments in developing a high average plastic strain ratio and a high (222)/(200) intensity ratio is related to the size and distribution of AlN precipitates. It is assumed that a fine distribution of AlN particles, capable of pinning effectively subgrain boundaries produced on subsequent cold rolling and annealing, is essential for developing of a high proportion of recrystallized grains with the (222) orientation at the expense of grains with the (200) orientation.
Key words: Al-stabilized steel, thermomechanical treatment, AlN precipitate, texture

Introduction
The superior drawing properties of Al-stabilized steels are generally attributed o to a strong (111) texture [1-3]. An important prerequisite for the development of strong (111) texture is the precipitation of AlN after deformation [4-5]. It is also possible to produce a strong (111) texture, if very fine Nb [6], Ti [7], or V[8] carbonitrides are precipitated before deformation. This is reported not to be true for AlN precipitated before deformation [1], but some results [9-11] seem to contradict this view.

The purpose of the present investigation was to reexamine the role of AlN precipitated before deformation in Al-stabilized steel. It has been assumed that a selective strain aging treatment will give rise to a fine distribution of AlN precipitate, which will promote the development of a strong (100) texture on subsequent cold rolling and annealing.

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Experimental

Material

Commercial Al-stabilized steel in the form of 2 mm thick hot-band sheet was used in this work. The chemical composition (in wt.%) was as follows: 0.04C, 0.32Mn, 0.014P, 0.019S and 0.055Al.

Thermomechanical treatment

Thermomechanical treatment consisted of either static or dynamic strain aging followed by cold rolling and annealing.

Static strain aging – SSA (Fig. 1a) consisted of straining by cold rolling 5, 10, 15, 20 or 25% reduction in one pass + aging to 520^{o}C at a rate of 10, 20, 50 or 100^{o}C/h + water quenching.

Dynamic strain aging – DSA (Fig 1b) consisted of a stepwise aging for 1h at 10^{o}C/h intervals up to 520^{o}C and simultaneous straining (for 10min at the end of each aging interval) in an Instron high temperature attachment (for details see Ref. 12) at a crosshead rate of 0.002 cm/min. This treatment resulted in an average aging rate of 10^{o}C/h and a total strain of 21%.

All strain aged specimens were cold rolled up to 70 reduction (including prior straining) using heavy passes (20-25%) + annealed at 700^{o}C for 21 h + temper rolled 1%.

The relative intensities of eight different reflections (100), (200), (211), (310), (222), (321), (420) and (332) for each specimen, and the average plastic strain ratio, $R = (R_o + 2R_{45} + R_{90})/4$, for selected specimens (R_o, R_{45} and R_{90} are plastic strain ratios at 0^o, 45^o and 90^o to the rolling direction) were determined, following procedure described in the previous paper [13].

Method of investigation

The effect of dynamic and static strain aging on texture has been studied by an inverse pole figures technique and plastic strain ratio measurements.

Results

Effects of SSA

Texture: the effect of aging rate and percent strain on relative intensities of the (100), (200), (211), (310), (222), (321), (420) and (332) reflections development on subsequent cold rolling and annealing is shown in Figs. 2 and 3, respectively. The intensities of (310), (321) and (420) reflections are represented by average curves. For the sake of comparison the relative intensities developed in a sample with no prior strain aging (sample No. 2) and in two selected specimens with prior strain aging (samples No. 3 and 4) are given in Table 1.

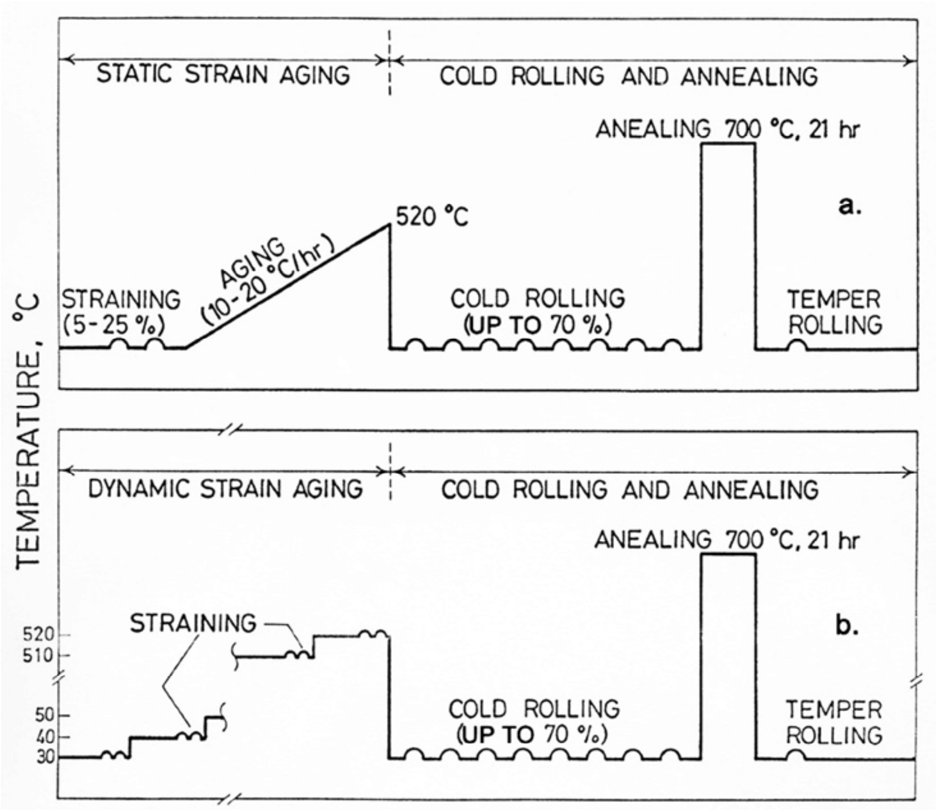
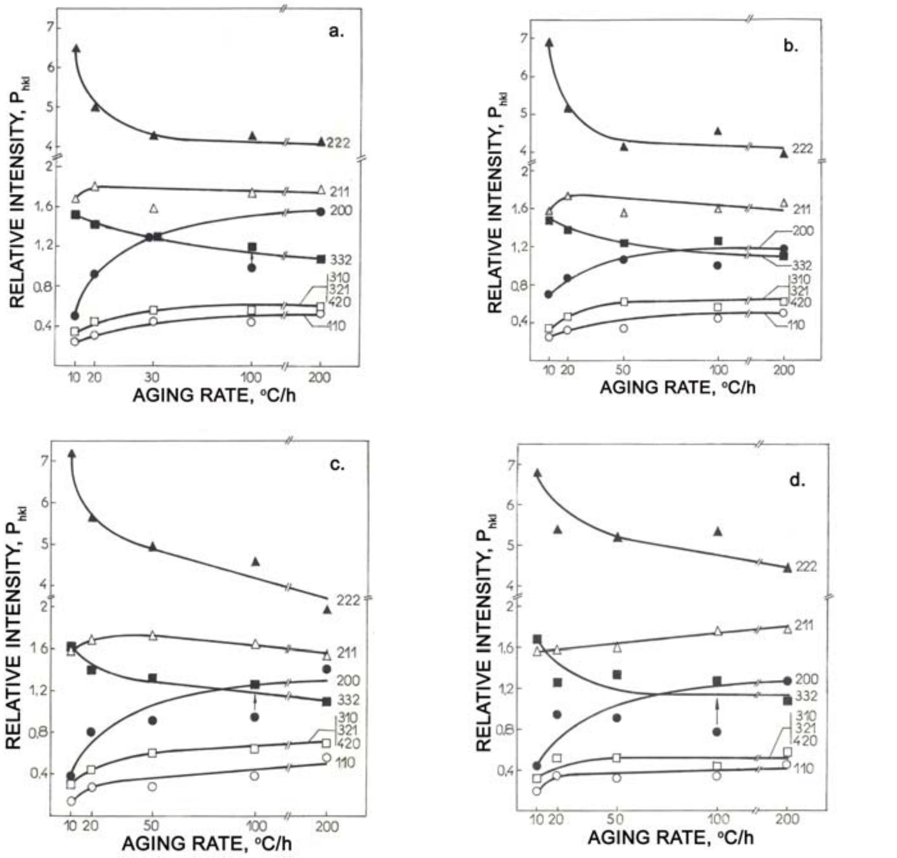


Fig.1 Schematic diagrams: (a) Static strain aging + cold rolling and annealing; (b) Dynamic strain aging + cold rolling and annealing.

The data of Table 1 show that the general effect of SSA is to increase the intensity of (220) component the expense of (110), (200), (310) (321) and (420), while (211) remains practically unchanged.



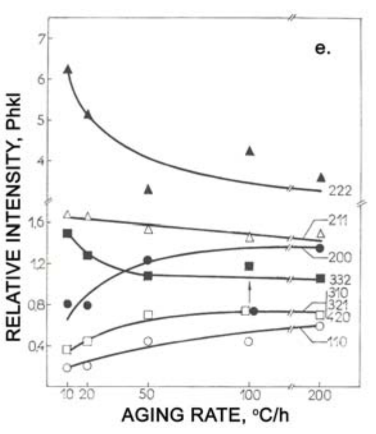


Fig.2 Effect of aging rate (SSA) on texture developed during subsequent cold rolling and annealing. (a) 5%, (b) 10%, (c) 15, (d) 20% and (e) 25%.

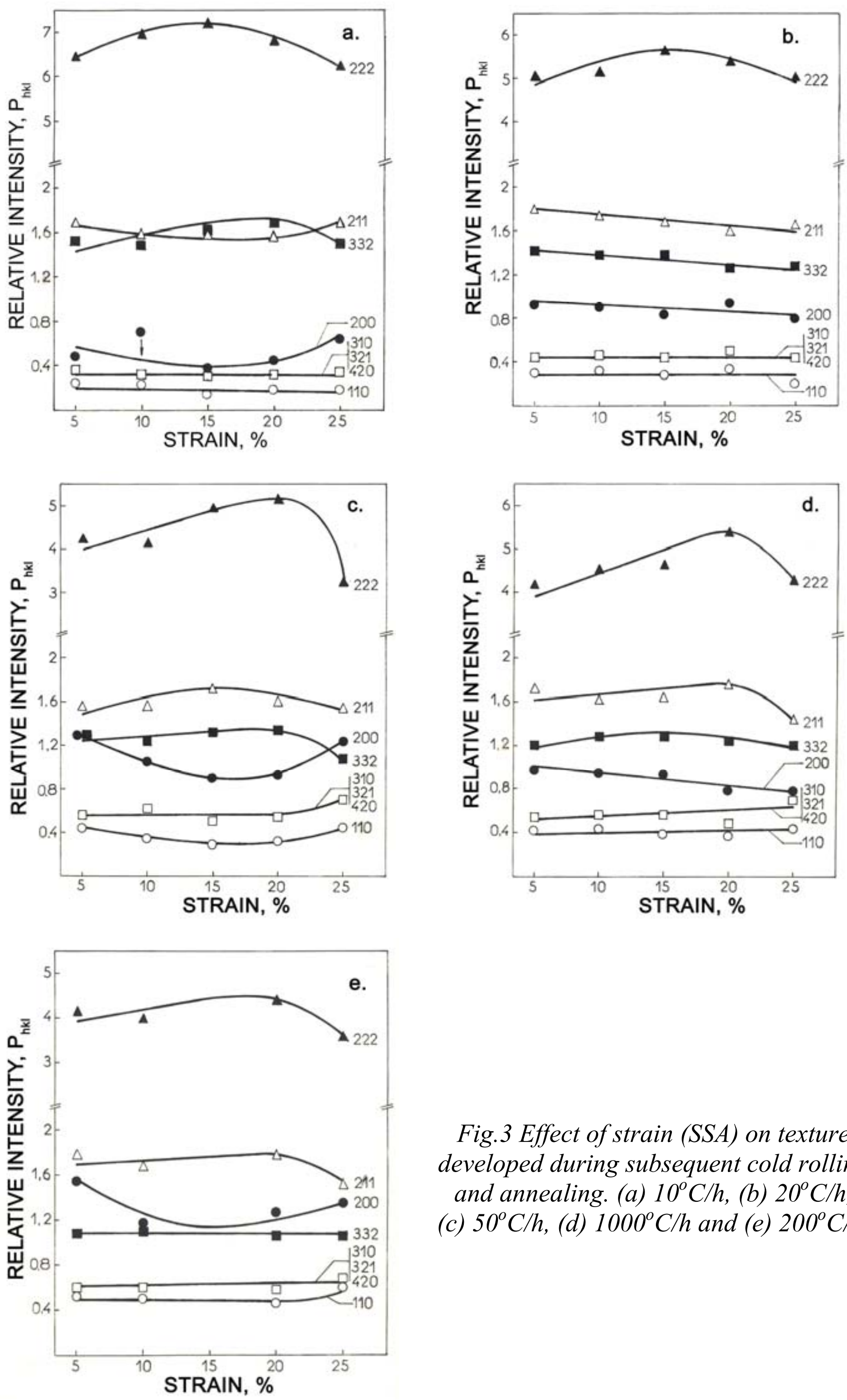


Fig.3 Effect of strain (SSA) on texture developed during subsequent cold rolling and annealing. (a) 10^{o}C/h, (b) 20^{o}C/h, (c) 50^{o}C/h, (d) 1000^{o}C/h and (e) 200^{o}C/h.

The data of Fig. 2 show that with decreasing aging rate the relative intensities of the (222) and (200) components are increased and reduced, respectively, the effect being most pronounced on passing from 50°C/h to 20°C/h. At the same time the (322) and (211) intensities are slightly increased, while the (110), (310), (321) and (420) are slightly reduced. Increasing strain (Fig. 3) causes (222) intensity to increase to a peak value following 15-20% strain. A similar strain is indicated by the (2110 and (332) components. At the same time the (200) is reduced to its minimum value, while the (110), (310), (321) and (420) are little affected.

Plastic strain ratio: The effect of SSA on the plastic strain ratio for the two selected SSA treatments (No.3 and 4) is illustrated in Table 2. A high average plastic strain ratio about 1.7 and 2.0, as well as the grain size structure (Fig. 4), comparable to that experienced by conventionally treated Al-stabilized steel of deep drawing quality (No. 1), is observed.

Effect of DSA

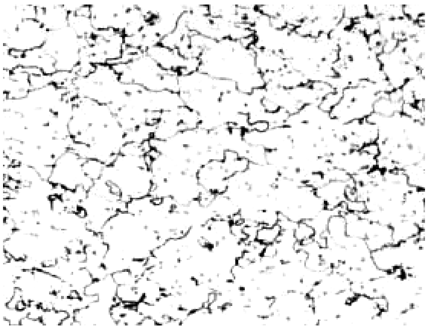
The effect of DSA on relative intensities of eight textural components developed during subsequent cold rolling and annealing is illustrated in Table 1 (No. 5). A high intensity of (222) component and high 222/(200) intensity ratio, comparable to or greater than in SSA steel (no 3 and 4), or in Al-stabilized steel of deep drawing quality (No 1), is observed.

Table 1. Relative intensities

No	Strain Aging	Cold Rolling and Annealing	(110)	(220)	(211)	(222)	(332)	R*	(222)/(200)
1		Al-stabilized steel of drawing quality	0.13	0.50	1.80	6.50	1.60	0.35	13
2		70%; 700°C, 21 h	0.52	1.07	1.80	5.11	1.04	0.53	5
3	SSA (15% strain; aging 10°C/h)	up to 70%; 700°C, 21 h	0.14	0.38	1.58	7.23	1.60	0.30	19
4	SSA (20 % strain; aging 10°C/h)	up to 70%; 700°C, 21 h	0.19	0.45	1.56	6.80	1.68	0.32	15
5	DSA (15% strain; aging 10°C/h)	up to 70%; 700°C, 21 h	0.23	0.38	1.70	7.68	1.42	0.30	20

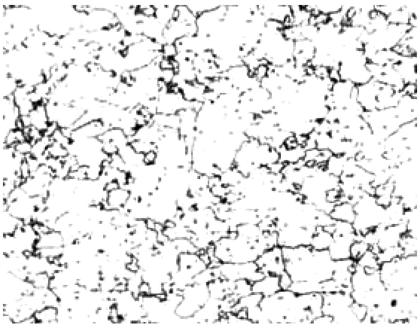
Table 2. Plastic Strain Ratio

No	Strain Aging	Cold Rolling and Annealing	Ro	R45	R90	$\bar{R}$
1	Same as in Table 1		1.49	1.21	2.42	1.60
3	Same as in Table 1		2.22	1.22	3.34	2.00
4	Same as in Table 1		1.58	1.22	2.66	1.66



a

b



c

Fig.4 Light Microscopy. Microstructure (x300) : (a) No 1, (b) No 3, (c) No 4 (strain aging and cold rolling and annealing same as in Table 1.

Discussion

It is well established that precipitation after deformation is essential for the development of strong (111) texture in Al-stabilized steels [4, 5]. The effect is associated with the fine AlN particles which retard recrystalization [14]. However, the present results indicate that precipitation before deformation may be equally effective. The data of Figs. 1 and 2 and Table 1 and 2 show that as strong (111) texture and as high an R may be produced as in conventionally treated steels, if appropriate SSA or DSA pretreatment was introduced prior to cold rolling and annealing.

The effect strain aging pretreatment may be rationalized in terms of fine distribution of AlN precipitates being developed during strain aging and prior cold rolling and annealing. The role of AlN precipitates is likely to be the same as in Nb, Ti or V bearing steels, which contain carbonitrides before deformation. It has been shown that Nb, Ti or V carbonitride precipitates retard recrystallization and promote development of a strong (111) texture [4, 5, 7, 8] by a mechanism similar to that operating in Al/stabilized steels, *i.e.* the nucleation of (111) grains being less inhibited than the nucleation of the other orientation [16]. For this to be possible a critical particle size and interparticle spacing seem to be essential [22]. For instance, it is found that NbC particles are effective only if their size lies between 4 and 50 nm [4, 5]. In spite of no attempt being made to identify the AlN precipitates by electron microscopy, it seems reasonable to assume that a small distribution of small AlN particles at subgrain boundaries is also produced in the present work. The size and distribution of AlN particles is controlled by percent strain and aging rate introduced during strain aging. A slow aging rate about 10^{o}C/h, and a moderate strain of about 15 to 20% introduced before or simultaneously with aging, seem o seem to create the most favorable conditions for the formation of fine densely populated precipitates. Dislocations introduced during strain aging act as nucleation sites for AlN precipitates. The present results indicate that an optimum population of nucleation sites is obtained following about 15 to 20% strain. However, to ensure a fine particle size a slow aging rate seems to be essential, otherwise coarse AlN particles, which are ineffective in promoting the (111) texture are produced. It is assumed that a fine distribution of AlN precipitates , capable of pinning effectively the subgrain boundaries produced on subsequent cold rolling and annealing, is essential for developing of a high proportion of recrystallized grains with the (222) orientation at the expense of grains with the (200) orientation.

Conclusions

The general effect of SSA, consisting of 5 to 25% straining by rolling prior to aging the specimen to 520^{o}C at rate of 10 to 200^{o}C/h, is to increase the (222) and (332) textural components at the expense of the (110), (2000) (310), (321) and (429) during subsequent cold rolling and annealing at 700^{o}C, while the (211) remains virtually unchanged. With decreasing aging rate the (222) component increases and the (200) component decreases, the effect being pronounced on passing from 50^{o}C/h to 20^{o}C/h. A strain of about 15 to 20% introduced prior to aging causes the (222) component to increase to a peak value. At the same time the (200) component reduces to its minimum value. A SSA treatment consisting of 15 to 20% strain prior to aging the specimens to 520^{o}C at a rate of 10^{o}C/h, followed by cold rolling and annealing at 700^{o}C for 21 h, gives a material with an average plastic strain ratio 1.7 to 2.0 and the (222)/200 intensity ratio of 15 to 19, which is comparable to or better than in Al-stabilized steel of dee-drawing quality.

The DSA treatment consisted of either simultaneous stepwise aging at 520^{o}C (at an average rate of 10^{o}C/h) and interrupted straining (to 21% elongation), or simultaneous aging at 520^{o}C and straining (to 7% elongation at a crosshead rate of 0.02 to 0.002 cm/min). The first treatment is found to be effective in producing high (222)/(200) intensity ratio of about 20 on subsequent cold rolling and annealing at 700^{o}C for 21 h, while the second treatment proved to be ineffective.

The effectiveness of SSA and DSA treatments in developing a high average plastic strain ratio and a high (222)/(200) intensity ratio is related to the size and distribution of AlN precipitates. It is assumed that a fine distribution of AlN particles, capable of pinning effectively subgrain boundaries produced on subsequent cold rolling and annealing, is essential for developing of a high proportion of recrystallized grains with the (222) orientation at the expense of grains with the (200) orientation.

Acknowledgement

The authors are grateful to the Ministry of Education and Technology of the Republic of Serbia for the financial support realized through the Project No. 172005.

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