Strong η texture development and magnetostriction in recrystallized Fe$_{81}$Ga$_{19}$ thin sheet

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Abstract. Texture evolution in Fe$_{81}$Ga$_{19}$ thin sheets produced by specially designed rolling and annealing process was examined using X-ray diffraction analysis. Cold rolled sheet is characterized by strong γ fiber (<111>//ND) , α fiber (<110>//RD) and widely distributed shear bands through the thickness. A strong η fiber (<001>//RD) through sheet thickness was obtained and the magnetostriction was significantly improved under the appropriate annealing temperature.

Introduction

Fe-Ga alloys with 17-21 at.% gallium are attractive magnetostrictive materials due to the excellent magnetic and mechanical properties [1]. In consideration of its high efficiency and low cost compared with single-crystal fabrication, the rolling method is selected to produce textured polycrystalline Fe-Ga alloy sheet. It is known that, in Fe-Ga alloy, it exhibits a maximum magnetostriction along the <100> crystal orientation, so a strong η fiber texture is required for its polycrystalline rolled thin sheet[2].

Texture control of Fe-Ga alloy has much less been investigated although texture is a key factor for magnetostriction. In body-centered cubic (BCC) metals, γ fibers and α fibers are typical texture components, and the acquisition of η fibers textures are closely related to the two types of orientation. In view of γ grains dominate nucleation and grain growth due to the orientation-dependent stored strain energy and grain boundary character[3,4], more researches focus on controlling the η and γ texture during recrystallization process[5-8]. In contrast, owing to its adverse nucleation and grain growth, the control of α texture in η texture development has received little attention . How to suppress γ fiber and α fiber without <001> along the rolling direction and strengthen η fiber is a critical problem for Fe-Ga alloy. Therefore, It requires understanding of the correlation among the three type textures.

The present study aims to explore an efficient and steady route to produce strong recrystallization η texture through sheet thickness in Fe$_{81}$Ga$_{19}$ alloy and to discuss the recrystallization evolution using X-ray diffraction analysis, which can provide important information for the optimization of recrystallization texture.

Experimental Procedure

Fe$_{81}$Ga$_{19}$ alloy ingot with 82g was prepared by arc melting high-purity Fe and Ga under argon atmosphere. The ingots homogenized at 1200℃ for 90 minutes and forged to 10mm, then hot rolled to 1.5mm with finishing temperature of 800℃. Afterwards, hot bands were cold rolled to 0.50mm at 200℃. Final annealing was carried at temperatures between 700℃ and 1200℃ for the same duration under flowing argon to achieve various recrystallization grain sizes.

Macro-texture evolution of rolled and annealed sheets were analyzed at two different thickness layers based on X-ray diffraction technique. Here, the thickness layer is defined as the parameter S=2l/d, where l represents the distance from the center layer of the sheet and d the whole sheet thickness. S=0 corresponds to the center and S=0.5 to the quarter thickness layer. Magnetostriction

was measured by the strain gauge, and gauge area of 2mm ×2 mm (base area of 6 mm×4 mm) was aligned along the rolling direction and attached to sample surface. The magnetostriction values ($(3/2)\lambda_S = \lambda_{//} - \lambda_{\perp}$) are calculated, where $\lambda_{//}$ and $\lambda_{\perp}$ represents the maximum magnetostriction when magnetic field parallels and perpendiculars to the RD.

Results and Discussion

Fig. 1 presents the texture and microstructure of $Fe_{81}Ga_{19}$ alloy cold-rolled sheet. The cold-rolling textures are typically composed of γ and α fibers at both quarter and center layers. It is noted that the γ fiber has no a much higher orientation density than the α fiber through thickness. This is different from conventional cold rolling texture of oriented electrical steel that γ fiber dominates the deformation texture through thickness[7,8]. The strong deformed γ texture ensures recrystallization η fiber development owing to the fact that η grain mainly nucleates at shear bands within the deformed γ grains. This is in contradiction with the fact that recrystallized γ grains mainly nucleate at grain boundary regions of deformed γ grains. Here, moderate rolling parameters were selected to balance the effects of cold-rolled texture and microstructure morphology on subsequent recrystallization texture. The as-rolled sheets show a outstanding microstructure such that shear bands widely appear in elongated deformed grains especially in the subsurface layers.
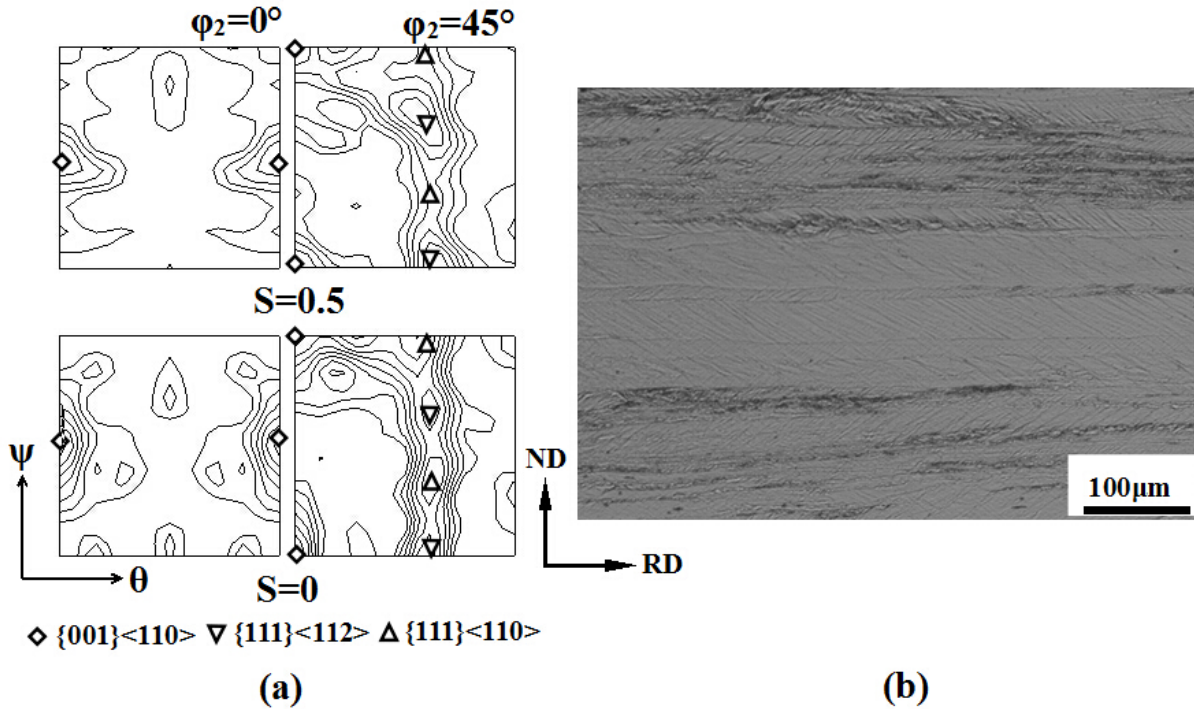

Fig. 1 (a) Constant φ2=0°and φ2=45°sections of ODFs at different thickness layers (levels: 1, 2, 3…) and (b) the microstructure of $Fe_{81}Ga_{19}$ cold rolled thin sheet

The final annealing temperatures at 700℃, 900℃ and 1200℃ were applied to make cold-rolled sheets obtain completely recrystallized and considerable grain growth. Grain size increases from 20μm to 300μm as raised temperature. Fig. 2 shows the annealed texture evolution at different temperatures. The recrystallization textures are mainly composed of η and α fibers through sheet thickness. It is noteworthy that η fiber with {011}<001> peak keeps the dominant component and α fiber tends to decrease with the grain growth, and meanwhile γ fiber is hardly observed during recrystallization process. This attractive phenomenon is in contrast with the normal observation in bcc steels that η fiber becomes weakened while γ fiber strengthened accompanied with grain growth[6].

Fig. 3 illustrates the orientation densities along η, γ and α fibers averaged over two layers for various annealing temperatures. After annealing at 700℃, the η fiber had a slightly higher
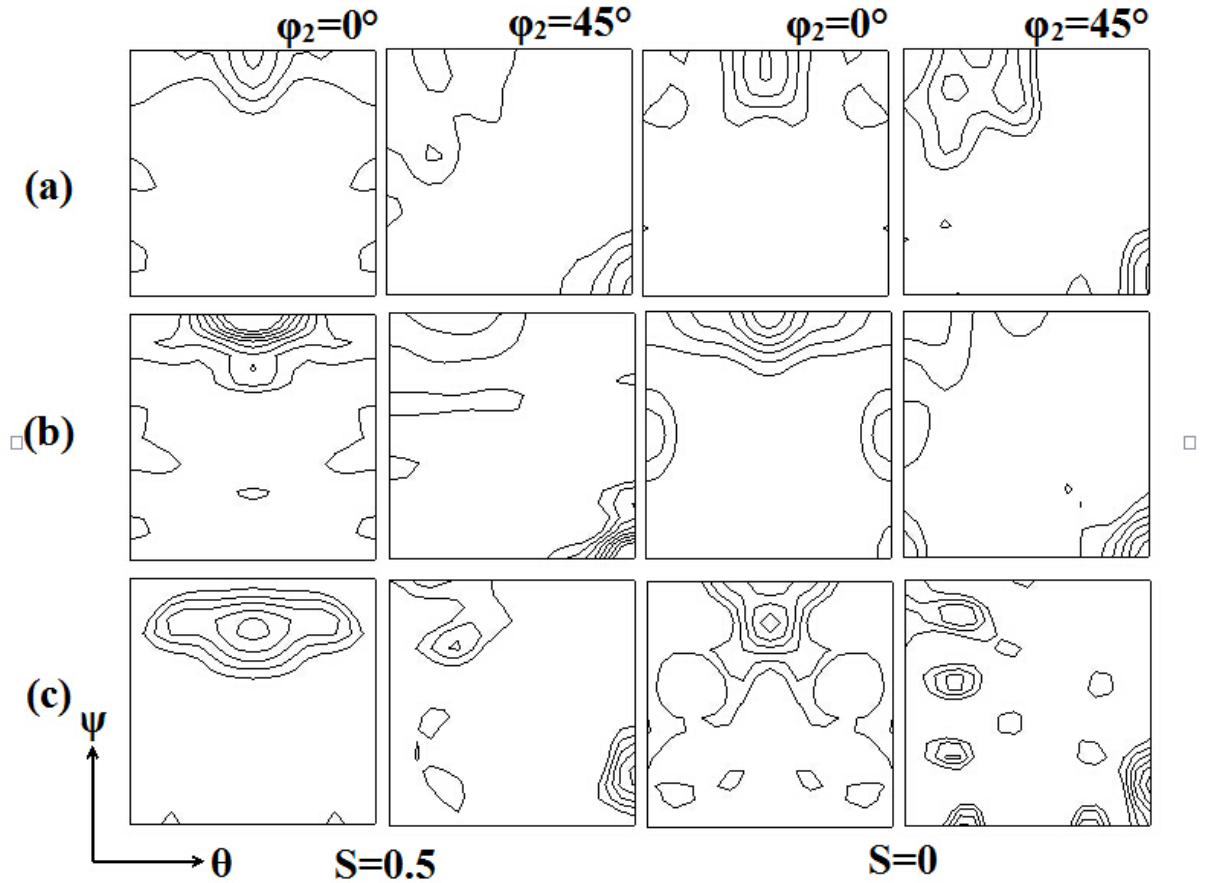
Fig. 2 Constant $\varphi_2=0°$ and $\varphi_2=45°$ sections of ODFs at different thickness layers of $Fe_{81}Ga_{19}$ cold rolled thin sheet annealed at (a)700℃, (b)900℃ and (c)1200℃ (levels: 1, 2, 3…)
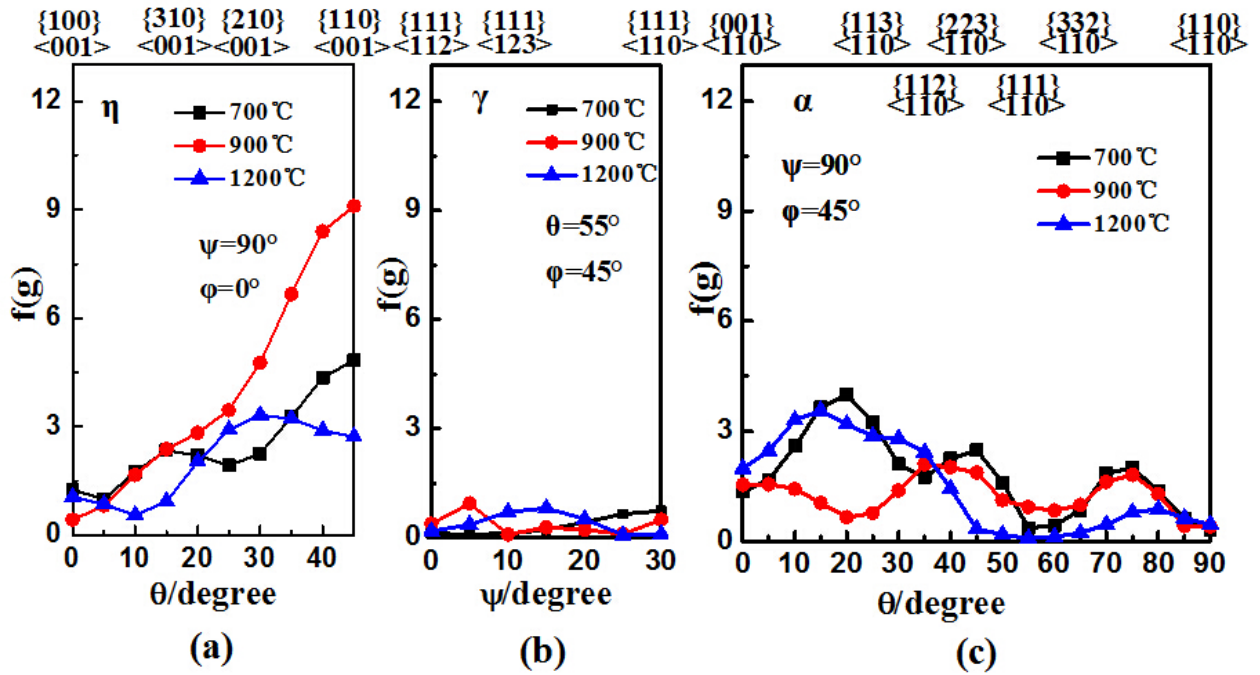

Fig. 3 Orientation densities along (a) η , (b) γ and (c) α fibers averaged over two layers of $Fe_{81}Ga_{19}$ alloy for various annealing temperature

orientation density than α fiber. When annealing at 900℃, a significant change took place in orientation density such that strong η fiber with {011}<001> peak was developed, while α fiber sharply reduced. For annealing at 1200℃, orientation density of η fiber and α fiber was same. It

should be noticed that, during recrystallization annealing, γ fiber keeps be in a minimums. The magnetostrictions ($(3/2)\lambda_S = \lambda_{//} - \lambda_{\perp}$) are shown in Figure 4. The value of magnetostriction obviously increases with the appropriate grain growth, which can be attributed to the enhancement of η fiber with largest saturation magnetostriction direction <001> along the rolling direction.
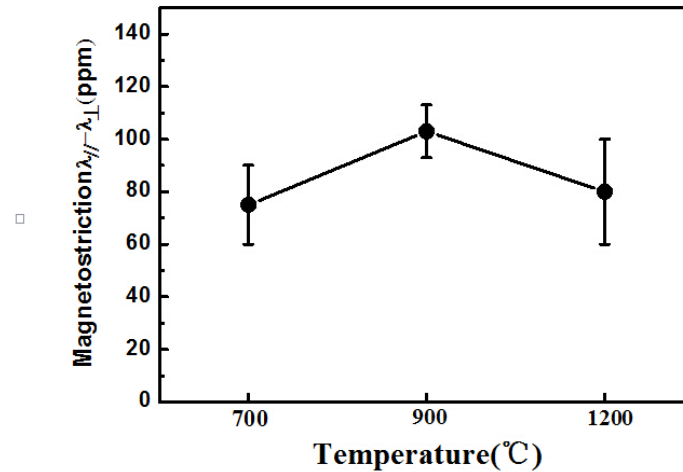

Fig. 4 Magnetostriction of $Fe_{81}Ga_{19}$ alloy sheets annealed at different temperature

Since shear bands within and grain boundary regions of deformed γ grains contribute main nucleation sites for η grains and γ grains during annealing process[5], there is a competition process between nucleation of η grains and γ grains. Therefore, how to acquire suitable deformed texture and microstructure is critical to benefit η fiber and limit γ fiber nucleation. In present work, appropriately intense deformed γ textures offer a necessary condition for extensively-distributed shear bands formation through cold rolled sheets. Favorable and abundant η fiber nucleation unavoidably restrain γ recrystallization nuclei. As a result, η fiber keeps the dominant component and γ fiber be in a minimums during recrystallization process (from 700℃ to 1200℃). Recent reports about various silicon steels have shown that the suitable intensity and density of shear band is pivotal for η fiber development to eliminate orientation pinning and inhibition for grain growth. However, recrystallization γ fiber still can easily be observed in their macro-texture dates due to the reason that the deformed γ fiber dominates the cold-rolled sheet[7,8]. Hence, moderate rolling parameters are indispensably applied to optimize the intensity of cold-rolled texture and characteristics of microstructure morphology.

In the low-carbon steels and IF steels[3,4], the strong γ deformed textures preferentially recrystallized during annealing and developed by consuming α fibers to constitute the dominant recrystallization textures owing to the orientation-dependent stored strain energy and grain boundary character. Supposing that γ fiber was restricted by means of special methods, α recrystallization texture has great hopeful to consist main recrystallization texture. Liu et al. obtained the weak γ fiber texture and strong λ fiber (<100>//ND) texture through Fe-Si cold rolled sheet, and λ fiber dominanted recrystallization texture[9,10]. The λ fibers and α fibers are similar in some respects. In present study, it is of particular interest to note the recrystallization texture mainly consists of η and α fibers during different annealing. After annealing at low temperature (700℃), the η fiber is slightly stronger than α fiber. Just as above analysis, nucleation of γ fibers are limited, and there are fewer opportunities that η grains mainly nucleated at shear bands within deformed γ grains consume α grains without experiencing any appreciable grain growth at low recrystallization temperature. The recrystallization of α fiber is not interfered. However, When annealing at high temperature (900℃), η Grains gained a grain number and size advantage from the earlier nucleation and longer time to grow than other grains owing to the special characteristics of shear bands[8], and α recrystallization texture sharply reducd after considerable grain growth. For annealing at too high temperature (1200℃), nucleation and grain growth occured in extreme time. η Grains inevitably rotate to deviate the ideal orientation, and α grain have enough driving force to grow.

Thus, suitable annealing parameters are essentially chosen to control grain growth.

In the future, more detailed works are needed to systematically clarify the correlations of the η , γ and α fiber texture with deformed microstructure, nucleation behavior and growth dynamic.

Conclusion

Cold rolled $Fe_{81}Ga_{19}$ thin sheet is characterized by strong γ fiber (<111>//ND), α fiber (<110>//RD) and widely distributed shear band. A predominant recrystallization η fiber with {011}<001> peak through thickness was successfully produced. Specially designed rolling and annealing process is pivotal for η fiber development. The present results provide an prospective way to optimize recrystallization texture of magnetostrictive Fe-Ga alloy sheets.

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