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Development of Al-killed/Ti stabilized steels

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Abstract. Several Al-killed/Ti-stabilized low carbon steels were developed in a Mexican steel industry with the aim of obtaining an interstitial free steel for automotive applications. The steelmaking route involved the use of 100% sponge iron which was feed into an electric arc furnace, vacuum degassed, ladle treated and continuously casted. The resulting slabs were then hot rolled at 1100 °C and coiled at 650 °C. Then, the steel plates were cold rolled at room temperature and sheets annealed at 700 °C. As-cast microstructure showed the presence of α-ferrite with titanium nitrides in matrix and grain boundaries while in the as-hot rolled condition, elongated grains showed the presence of titanium nitrides, titanium sulfides and titanium carbosulfides. The annealed sheets showed, additionally to the other precipitates, the presence of titanium carbides. Microstructure, texture, the Lankford ratio and mechanical properties of fully recrystallized coils fulfilled the target properties established by the automobile industry.

1. Introduction

Al-killed/Ti-stabilized interstitial low carbon steel sheets have been developed for applications in the automotive industry because they fulfill the requirements for excellent drawability in order to produce panels with complex shapes [1]. High formability has been achieved as a result of lowering the interstitial content of carbon and nitrogen during the steelmaking practice and by the addition of stabilizing elements such as titanium, niobium and/or a combination of titanium plus niobium [2]. As a result, the ferrite matrix of heavily cold rolled interstitial low carbon and nitrogen sheet steels, recrystallized during annealing to a polycrystalline microstructure with a strong γ-fiber (<111>//ND) texture [3]. Attention has also been paid to the improvement of the final product by controlling hot rolling parameters [4]. For instance, finishing the hot rolling schedule in the ferrite region followed by annealing recrystallization resulted in stronger γ-fiber [5], and increasing the strain rate during ferrite rolling stage enhances the development of this texture [6]. Furthermore, lowering the rolling temperature from 850 to 600 °C also resulted in higher γ-fiber intensities [4] which have an impact on the drawability of annealed sheets. The recrystallization texture in metals has been discussed by means of the oriented nucleation [3] or the selective growth [7, 8] mechanisms; which for high drawability steels, implies that the first mechanism will be dominant [9, 10]. Additionally, it has been shown [11, 12] that γ-fiber texture is nucleated at the grain boundaries and proceeds to grow consuming the deformed neighboring grains. The present study shows the results of an industrial trial in order to obtain a low carbon Al-killed/Ti-stabilized steel which is intended to be used as an annealed sheet for deep drawing applications in the automotive industry.

2. Experimental procedure

The experimental steels were produced in a Mexican steel industry in order to fulfill a chemistry as that designated for interstitial free steels. The as-cast slab was thermomechanically treated, with sample dimensions of 0.03X0.1X0.2 m^3, at a temperature of 1100 °C and finishing at 840 °C, achieving 80% of accumulative hot reduction. The steel plate $5X10^{-3}$ m in thickness was air cooled in a run out table and coiled at 650 °C. Room temperature cold rolled plate resulted in a sheet with $3X10^{-4}$ m in thickness and with an accumulated reduction of 85%. Then, sheets were isothermally annealed under an argon atmosphere at 700 °C. Specimens were characterized by using a 440 Stereoscan scanning electron microscope and a 2100 Jeol scanning transmission electron microscope. The progression of recrystallization was followed by a point counting technique [13] while flat tensile room temperature test on fully recristallyzed samples were conducted on an Instron 1125 (10 t) test machine at a strain rate of 5×10^{-3} s^{-1}. From the tensile test experiments in the annealed condition, it was calculated the normal plastic anisotropy ratio value at 0°, 45° and 90° with respect to the rolling direction; from these values, the average plastic anisotropy ratio value (r) was obtained. Texture measurements on fully recristallyzed samples were carried out on a Siemens D5000 texture goniometer using cobalt radiation; the pole figures were measured up to a tilt angle χ = 80◦; the steps were $\Delta\chi$ = 2.5◦ in the tilt direction and $\Delta\varphi$ = 4◦ in the azimuth direction.

3. Results and Discussion

Table 1 shows the chemical composition of experimental steels slabs where the steel AM3 was chose for performing the thermomechanical, mechanical and annealing treatment because it was the steel which showed a C + N_2 content <25 ppm falling in the designation of interstitial free steels.

Table 1. Chemical composition of experimental steels (in wt. %).

Steel designation	C	Si	Mn	P	S	Al	Ti	N_2
AM1	0.0050	0.328	0.534	0.0423	0.0089	0.0797	0.0260	0.0015
AM2	0.0034	0.0015	0.0741	0.0055	0.0110	0.0312	0.0602	0.0027
AM3	0.0023	0.0006	0.1050	0.0057	0.0089	0.0428	0.0692	0.0016

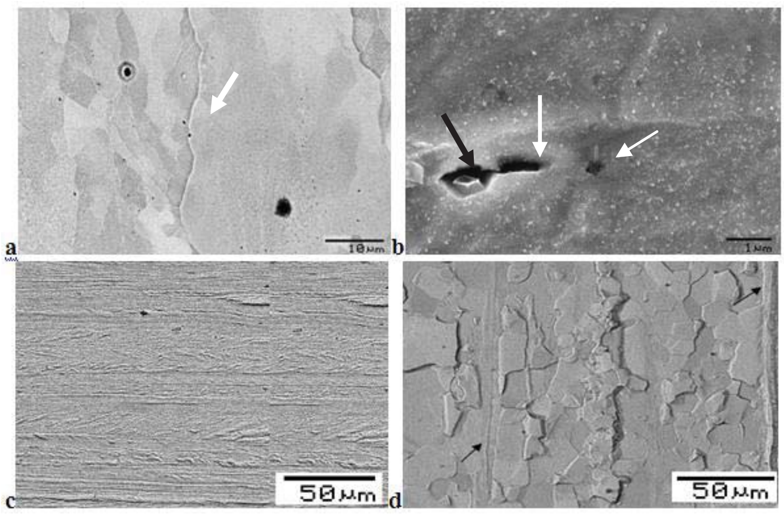

Fig. 1 Microstructure (a) As-cast, (b) hot rolled and coiled, (c) cold rolled, (d) annealed.

In Fig. 1 are shown the microstructure obtained in as-cast ingots, hot rolled, cold rolled and annealed samples, for instance, Fig. 1a shows α-Fe grains with the presence of rhombohedral precipitates, which were identified by SEM-microanalysis as TiN (white arrow). The microstructure obtained in hot rolled plates, from 1100 to 840°C is shown in Fig. 1b where it was observed a microstructure of α-Fe grains elongated in the rolling direction with the presence of TiN, TiS (white arrow) and TiC_4S_2 (black arrow) precipitates and with an grain size of 20±0.9μm. Fig. 1c shows the microstructure of as-cold rolled specimens. As may be observed, the ferrite grains are flattened, and inside the grains, some shear bands can be observed, which corresponded to the narrow regions of intense shear that carry large strains during deformation and appear to become the major deformation mode [14]. For instance, in some interstitial free-steels, it was observed that in-grain shear bands were inclined principally at angles of 30° to 35° to the rolling plane [15]. In the steel sheet under study, the shear bands were inclined ~32° with respect to the rolling plane and were relatively planar and parallel to each other within the individual grains. The grain boundary, after the cold rolling operation, remaining closely parallel to the sheet plane and when the steel sheet was annealed, recrystallization initiated preferentially in the region of the original grain boundary (pointed by a black arrow in Fig. 1d); spreading from there into the adjacent grains. It appears that the coiling temperature of 650 °C in combination with the 85% per cent of accumulative deformation was sufficient to induce recrystallization at 700 °C in 180s. Fig. 1d shows nonequiaxed grain shapes during recristallization of sheets..

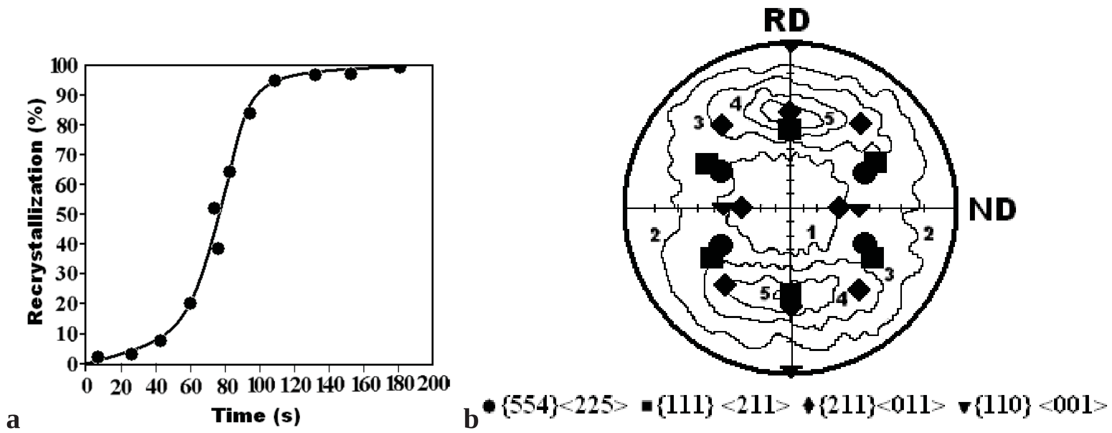

Fig. 2 Recrystallization curve and {100} pole figure for the steel under study in the annealed condition.

The recristallization rate of this IF-steel (Fig. 3a), is significantly lower than the rate of recrystallization of Al-killed steels (i.e. 100% of recrystallization in 20 s [2]). This delay in the recrystallization time is attributed to the contribution of Ti-precipitates, which retarded grain boundary migration by a pinning effect [16]. The ferrite grain size achieved in samples with 100% of recrystallization was 12±0.6 μm and the microstructure observed in this condition, consisted of a nonequiaxed grain shape. Fig. 3b presented a {100} pole figure for the steel under study in the annealed condition showing an appreciably strong texture than in the as cold rolled condition, from {554}<225> component near {111}<112> to {211}>011>. As reported in ref [6], during recrystallization, the pinning force ($3.7X10^5$ to $20X105N/m^2$) exerted by precipitates on the grain boundaries is one of the most important factors controlling the recrystallization texture. For instance, Barnett and Kestens [15] reported that for observations carried out in low carbon, ultra low carbon and interstitial free steels, regarding the presence of in-grain shear bands; the increasing density and severity of these in-grain shear bands lead to a bulk recrystallization texture dominated by {111}<112> near the normal direction–rolling direction (ND–RD), especially when titanium was added to the low carbon steel. On the other hand, industrial considerations in automotive technology are to improve safety and fuel efficiency by reducing vehicle weight and to shorten the manufacturing process of body panels. To achieve those goal s, interstitial free steels have been hot rolled in the austenite region. Reports show that when the finish discharge temperature was lower than the α/γ transformation temperature, the appearance of a coarse grain structure in hot bands and a decrease in the intensity of {111} texture in cold rolled and annealed sheets was observed, resulting in a deterioration of its drawability [16]. Further research [17] showed that hot rolling temperatures of interstitial free steels at 1050 ◦C resulted in similar values of the average plastic anisotropy ratio as compared to those IF steels hot rolled at 1200 °C. However, the resulting mechanical properties of annealed sheets may depend on the diversity of the steel composition, hot rolling process; finish discharge temperature, coiling, cold rolling process and annealing temperature. For instance, the most commonly produced steel corresponds to the interstitial free steel with carbon contents up to 50 ppm and nitrogen contents from 20 to 310 ppm, which have been stabilized with Ti and/or Nb additions. In spite of having similar compositions fulfilled target properties required in the automobile industry (see Table 3).

Table 2. Target and mechanical properties of interstitial free steel.

0.2 Y.S	T.S	El	r	n
138 to 173*	242 to 345*	46*	>2*	>0.21*
140	297	53.1	2.3	0.24

*Target properties

4. Conclusions

The low carbon Al-killed/Ti-stabilized steel shows outstanding behavior in terms of mechanical properties suggesting its use as an annealed sheet in the automobile industry. The automobile target properties were achieved in annealed sheets after employing low hot rolling temperatures, 1100 °C, instead of the typical 1250–1200 ˚C and annealing temperatures of 700°C, instead of the high recrystallization temperatures of 850 ◦C, normally needed in interstitial free steel processes.

The use of low rolling and annealing temperatures may represent industrial advantages from the point of view of reducing energy consumption of at least 40 MCal/t per 100°C. The use of titanium element to stabilize the low carbon steel was effective in retarding its recrystallization rate, enhancing formation of {111}<112> texture and Lankford values >2.

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